Hazardous Substances, Marine litter, Underwater noise, Non-indigenous species

Thematic assessment 2016–2021

Baltic Marine Environment Protection Commission

THIRD HELCOM HOLISTIC ASSESSMENT OF THE BALTIC SEA 2016–2021
HOLAS 3

Hazardous substances

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What is HELCOM?

Preface

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

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

Benefits of cooperation at the regional level:

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

HELCOM is...

Environmental policy maker

HELCOM develops common environmental objectives and actions

Environmental focal point

To help decision making in other international fora, HELCOM provides information about
- the state of and trends in the marine environment
- the efficiency of measures to protect it
- common initiatives and joint positions

Body for developing recommendations

HELCOM's own recommendations and those supplementary to measures imposed by other international organisations

Supervisory body

HELCOMS ensures that its environmental standards are fully implemented by all parties throughout the Baltic Sea and its catchment area

Coordinating body

HELCOM ascertains multilateral response in case of major maritime incidents

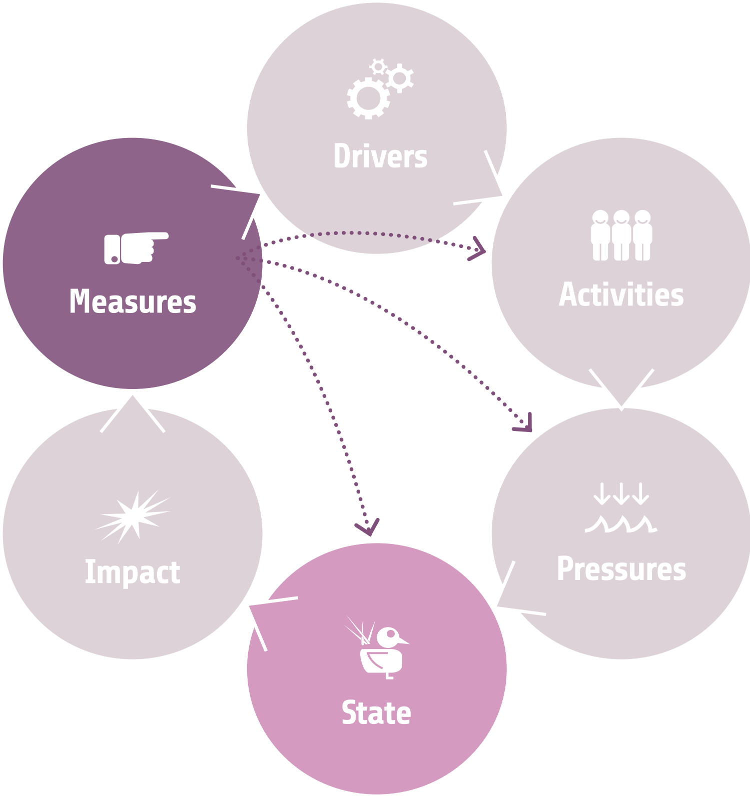


Figure P1. Conceptual overview of the management framework HELCOM works within.

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

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

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

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

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

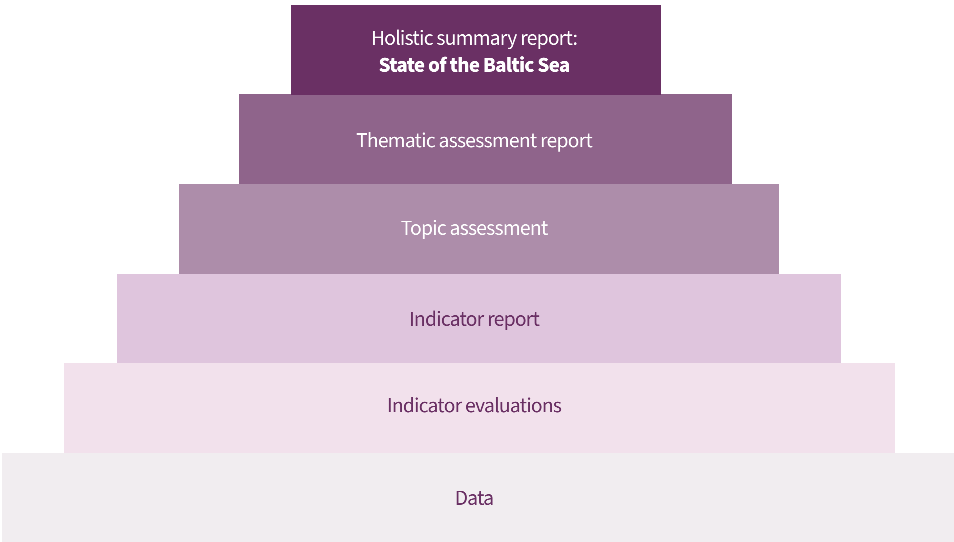


Figure P2. The structure and process of the HELCOM holistic assessment. Within the assessment structure, highly detailed results are progressively aggregated, allowing anyone to explore the results at whatever scale is most relevant to them and culminating in the overall summary report on the State of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

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

HOLAS

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

The holistic assessment also specifically enables tracking progress towards the implementation of the 2021 Baltic Sea Action Plan (HELCOM 2021) goals and objectives and functions as a regional contribution to the reporting under the Marine Strategy Framework Directive (MSFD) for those HELCOM Contracting Parties that are also EU Member States. The results of the assessment underpin HELCOM policy and the information from the assessment is incorporated in the ecosystem-based management of the Baltic Sea, as well as guiding measures nationally, regionally and globally.

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

Data

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

Indicators

HELCOM core indicators have been developed to assess the status of selected elements of biodiversity and human-induced pressures on the Baltic Sea and thus support measuring the progress towards regionally agreed targets and objectives. The core indicators are selected according to a set of principles including ecological and policy relevance, measurability with monitoring data and linkage to anthropogenic pressures (HELCOM 2020a). The observed status of HELCOM indicators is measured in relation to a regionally agreed threshold value specific to each indicator, and in many cases at the level of individual areas in the Baltic Sea. The majority of the indicators are evaluated using data from regionally coordinated monitoring under the auspice of HELCOM and reported by the Contracting Parties to the Convention. The status of an indicator is expressed as failing or achieving the threshold value. Hence, the results indicate whether status is good or not according to each of the core indicators. HELCOM core indicators make up the most detailed level of results, presented in the dedicated indicator reports (https://indicators.helcom.fi).

Thematic assessments

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

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

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

Summary report

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

Summary

Pollution, as addressed in this thematic assessment, includes pollution from hazardous substances (e.g., contaminant concentrations), marine litter, underwater noise and non-indigenous species (NIS). While these topics are somewhat disparate in nature, they have some key characteristics in common. Firstly, they are in the main all directly and primarily linked to human activities; secondly, they all exert (or have the potential to) significant pressures on the Baltic Sea marine environment; and lastly, in all cases the most effective measure to address them is likely directly linked to preventing or limiting their initial inputs. In all cases, once in the marine environment, the measures required to address (alleviate or remediate) such pressures are generally highly complex, difficult to successfully implement, and likely more costly than acting early within the relevant cycle. For example, hardly any successful approaches to address non-indigenous species (especially in aquatic systems) exist after their establishment, and once widely dispersed in the environment, the possibility (or at least practical application, success and cost to apply) to reverse or minimise the impacts of already established NIS is highly unlikely. While specific scales of impact from these pressures may differ, they are all proven to cause, or have direct potential to cause, significant negative effects on the ecosystem (habitats and species) and are thus highly pertinent to address to ensure the achievement of Good Environmental Status (GES) in the Baltic Sea.

Hazardous substances are in general shown to be at concentrations that prevent the achievement of GES across the region. The evaluation is based dominantly on the detailed evaluation of a number of priority substances, substances broadly identified due to their elevated concentration, persistence in the environment and toxic effects. When integrated together, the majority of assessment units – in particular the open sea subbasins (16 of 17 open sea sub-basins) – fail to achieve GES and broadly reside in the most distant category from GES. This sub-GES condition is dominantly driven by polybrominated diphenyl ethers (PBDEs), tributyltin (TBT), mercury (Hg) and copper (Cu), predominantly in the sampling matrix biota. It is also a general trend that those assessment units achieving better status also have lower confidence due to key parameters being missed. Despite the prevalence of sub-GES conditions being identified in the integrated assessment, there are certain signs of encouragement as well. A number of open sea sub-basins appear to have improved their status category since the previous assessment. Also, when looking at the stations, the number of downward trends (indicating improving conditions) markedly outweighs those where deteriorating trends were detected. However, only a small fraction of all potentially hazardous substances in the Baltic Sea are known and the true threat of hazardous substances to the Baltic Sea remains unknown. Work to address these issues has begun, in particular the work has started on Baltic Sea Action Plan (BSAP) action HL1 to 'Develop a regional strategic approach and, on the basis of that approach, an action plan for HELCOM work on hazardous substances by 2024'. Together with the results expected from that work, the pilot studies on biological effects of contaminants, and initial findings from the first Baltic Sea regional screening study that are presented in this report, provide important foundations for the future. Such future developments will likely support stronger and more directed action to minimize inputs, alleviate existing pressures and establish a structure to greatly improved the holistic management of hazardous substances towards the BSAP goal of a 'Baltic Sea unaffected by hazardous substances and litter'.

Marine litter is currently most strongly evaluated based on beach litter, a parameter that is used worldwide to monitor the input of marine litter to the ecosystem. Surveys of litter on the beach allow for a detailed evaluation of

litter in terms of amounts and composition. Its strength lies on the provision of information on potential harm to marine biota and ecosystems as well as social harm (aesthetic value, economic costs, hazard to human health) and, to some extent, on sources of litter and the potential effectiveness of management measures applied. The status evaluation of marine beach litter in the Baltic Sea for 2016-2021 shows that 11 out of 16 sub-basins are above the HELCOM threshold value of 20 litter items per 100 m beach. The most found category of litter is various plastic items and fragments above 2.5 cm. Several of the items on the top-ten list are related to single use plastics and other types of plastic used.

Litter that has accumulated on the seafloor is also relevant as the impacts can be significantly different depending on the habitat. For example, seafloor litter can cause anoxic conditions in the underlying sediments, which alters biogeochemistry and benthic community structure, may provide substrata for the attachment of sessile biota in sedimentary environments and alter faunal community composition. When litter density was measured in weight, litter related to the categories of "other", plastic, and fisheries increased significantly in the period from 2015 to 2021. When density was measured in numbers, only "other" and plastic litter increased significantly, thereby failing the preliminary threshold value of 'no significant increase' from 2015 to 2021 in both weight, numbers, and probability of catching litter. Fisheries related litter passed the threshold (trend not significantly >0) when measured in numbers per km^2 but not when measured in weight per km^2. The categories glass, metal, natural, rubber, and single use plastics (SUP) showed no significant increase in weight and numbers per km^2 and hence passed the preliminary threshold of no significant increase on the seafloor. Some evaluation work still remains to be carried out in the future, for example the evaluation of microlitter (in sediments and water), as well as the impact of litter on biota. The implementation of the 2021 HELCOM Regional Action Plan on Marine Litter is expected to enable the achievement of the marine litter ecological ("no harm to marine life from litter") and managerial objectives ("prevent generation of waste and its input to the sea, including microplastics" and "significantly reduce amounts of litter on shorelines and in the sea") of the 2021 Baltic Sea Action Plan to be achieved by 2030.

Underwater noise is categorised as either continuous or impulsive and can cause environmental impacts, in particular direct harm or disturbance to noise sensitive species. Continuous anthropogenic noise represents a significant pressure on the marine environment due to its constant presence and extensive spatial coverage over the entire water column in open sea areas. The noise from ships, when sailing at service speed, is caused primarily by their propulsion (engine noise and propeller cavitation), with secondary components being machinery and the movement of the hull through the water. Sound has the capacity to impact marine organisms in several ways; especially important effects are the masking of acoustic communication and reception of other biologically relevant sounds caused by low frequency continuous noise and the disturbance of behaviour that high levels of noise may lead to. This first-time quantitative assessment of continuous underwater noise shows substantial contributions of ship noise to the Baltic Sea environment, with considerable variations in space (shipping lanes much more affected than elsewhere) and in time (ship noise being more widespread in winter than summer). The recommendation from EU TG-Noise – the EU expert body working on establishing EU wide methodology and threshold values for the evaluation of underwater noise – is to use a spatial threshold of 20% or lower in the assessment. As there has not been an opportunity to discuss and agree on a regionally specific threshold value at this stage (i.e., a pre-core evaluation is carried out in this first iteration) for the Baltic Sea, the choice was made to use 20%, which is interpreted as the default value. Thus, this indicator evaluation was below the 20% spatial threshold for all assessment units for marine mammals but exceeded the 20% spatial threshold for 9 out of 17 assessment units for masking of fish communication, although not for fish behavioural disturbance, where it was below the threshold value. It is to be noted that the assessment itself comes with significant uncertainties, relating to the selection of input parameters (most notably the Levels of Onset of Biologically adverse Effects - LOBE levels) and the distribution of the indicator species.

The most intense man-made sources of loud impulsive noise are explosions, pile driving, seismic explorations and low frequency sonars. Sound waves propagate efficiently in water, which means that loud sources without noise mitigation measures may have far-reaching effects, up to tens of kilometres from the source. Thus, even though noise does not persist in the environment, it may harm marine species if no measures are taken to mitigate adverse effects. Effects of loud impulsive sound ranges from disturbance (stress, behavioural changes including lost opportunities, deterrence), impact on auditory systems (temporary and permanent hearing loss), to physiological injury and in extreme cases death. The indicator is based on the occurrences of impulsive noise-producing maritime activities reported by Contracting Parties to the regional HELCOM/OSPAR noise registry. Based on the available data, a broad range of impulsive sound events occurred in the Baltic Sea region during 2016-2021; however, no clear trends were observed for the prevalence of events related to any of the different types of source activity. Across the assessment period, the area exposed and disturbed with respect to displacement for harbour porpoise clearly remained below a fraction of 10% of the HELCOM area habitat per day.

Future work is needed to further develop the threshold values for both indicators and attain regional agreement on their application. Thus, further work is envisaged on, for instance, the Levels of Onset of Biologically adverse Effects (LOBE) for indicator species, the habitat sizes of indicator species and the following sizes of assessment subbasins. Bearing in mind, that the aim is to achieve a long-term reduction of anthropogenic noise in marine ecosystems, the implementation of international, regional, and national commitments is key. To list a few: the envisaged revised IMO Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life, the 2021 Baltic Sea Action Plan, and the HELCOM Regional Action Plan on Underwater Noise.

Non-indigenous and cryptogenic species have the potential to cause harm in the environments to which they enter. They can for example displace native species or alter food web structures and energy flows. Introductions (at least in their primary instances) are by definition a direct result of human activities, for example related to shipping. The trends in arrival of new NIS to the Baltic Sea increased sharply in the second half of the 20th Century and has not shown signs of decline in 2000s. In the current evaluation there is an apparent decrease in the number of new introductions compared to the previous assessment period, however, some uncertainties remain (due to reporting of new records for prior periods).

Once established, non-indigenous species are in general difficult to remove (likely impossible or at least impractical) – thus preventative measures are key. Future work on the topic includes improving the overall resolution of the evaluation – a task that requires more and more detailed monitoring, improving the understanding of natural spread and establishment of species, and determining the role or impact of such species in the environment. Such improvement would provide a stronger and more ecologically relevant understanding of non-indigenous species in the Baltic Sea ecosystem.

1. Introduction

This thematic assessment report addresses pollution, defined in this instance as all relevant pollution aspects with the exception of nutrients and eutrophication aspects that are handled separately. The four main topics addressed under this report relate to hazardous substances, marine litter, underwater noise, and non-indigenous species.

1.1. Pollution in the Baltic Sea

Pollution in the Baltic Sea is a very significant and impactful pressure that has the potential to significantly degrade the status of the marine environment. In this report the issue of pollution is addressed, covering the major topics of relevance, with the exception of nutrient inputs and their effects (addressed under the Thematic Assessment on Eutrophication). The major focus areas of this report are hazardous substances (i.e. elevated levels of man-made or natural substances due to anthropogenic activity and their effects), marine litter, underwater noise, and non-indigenous species (NIS); while other relevant or associated topics are also incorporated where additional information is available. These topics, although somewhat diverse in nature, are all characterised by the fact that the pressures in the Baltic Sea are, to a large extent, directly caused by human activities and can result in an impairment of ecosystem health. The inputs of hazardous substances, marine litter, underwater noise, and non-indigenous species occur through numerous diverse pathways, though they can all directly result in individual (e.g. on a specific animal) species level, population level, or habitat level impacts with the potential to harm ecosystem health and functionality.

The Baltic Sea is an enclosed brackish water sea surrounded by a large and heavily populated catchment area. It also represents one of the most active areas of marine traffic globally (HELCOM 2018a). The enclosed nature, connections to the North Sea area only via the Kattegat and narrow Belt Sea and The Sound channels, plus the strong freshwater inputs (particularly in the north) from rivers and catchment run-off, result in specific conditions. This, especially in the case of pollution from hazardous substances, means that the Baltic Sea can act as a sink where inputs readily accumulate and steadily magnify over time. Furthermore, the unique nature of the Baltic Sea with its strong latitudinal gradients (e.g., salinity, temperature, seasonality, etc.) results in relatively limited diversity and strongly demarked distribution gradients of biodiversity (see Thematic Assessment on Biodiversity), which further increase this ecosystem's susceptibility to pollution.

Pollution can manifest itself in numerous forms and can have diverse and diffuse impacts. Some of these impacts are clearly visible, such as the immediate and direct impacts, which are generally most significant at the individual or local level. These include for example an impulsive noise event, a pollution spill or a known hotspot area and may damage an area of habitat (https://helcom.fi/action-areas/industrial-municipal-releases/helcom-hot-spots/) or have direct toxic (i.e. even kill) or damaging (Siebert *et al.* 2022) effects on an individual animal (or several individuals). Other impacts, however, are often less clearly visible and may in fact be far more concerning and significant. Impacts that are prolonged or extensive can also play a major role in shaping species, population and ecosystem level aspects (e.g., health, distribution, feeding, breeding) and in such cases these effects may take many years or generations to be clearly seen (subsequent changes in abundance or ecosystem function are not immediately visible or detectable). For example, excessive noise levels could conceivably limit breeding or feeding in key areas for marine mammals and fish, an invasive species may feed on a native species and thereby alter the food web structure and function (Skabeikis *et al.* 2019), levels of hazardous substances may bioaccumulate and biomagnify in food webs lowering health and reproduction (Fenstad *et al.* 2017), or marine litter may have an impact on breeding success or rates of animal strandings/bycatch. Such factors potentially limit species and population level sustainability and impact on habitat health or ecosystem function in a broader, more long-term and more imperceptible manner and are vital to address to achieve sustainable and lasting environmental health.

Another aspect that is vital to consider is the cumulative, multiple, or mixed effects of such stressors. While a single event, occurrence or substance may commonly not be considered as a significant stressor or does not result in an immediate toxic or damaging effect (e.g., cause death or direct harm), the steady bioaccumulation of contaminants or the regular repeated contact with a stressor can also create an impact. Organisms that are systematically and regularly exposed to one or more substances or stressors may suffer from health effects or lowered reproductive success as well as transfer these contaminants further within the food web. In areas where noise levels persist above acceptable conditions, these habitat areas may become unsuitable for key sensitive species (e.g., certain fish or marine mammals) – a factor that can be especially important during vital life processes stages such as feeding (e.g., key feeding grounds) or breeding. Moreover, it's becoming

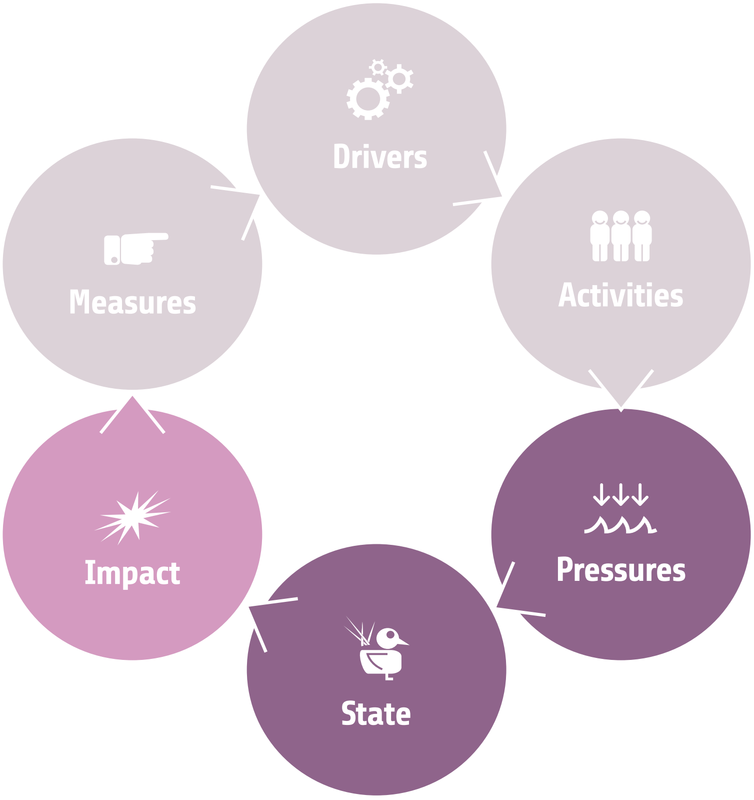


Figure 3. Schematic showing what sections of the DAPSIM cycle this assessment focuses on. DAPSIM reflects the conceptual management framework across Drivers (D), Activities (A), Pressures (P), State (S), Impacts (I) and Measures (M).

increasingly clear that pressures do not act alone (see Thematic Assessment on Spatial Pressures and Impacts), meaning that multiple or mixed effects are critical to address. Such issues can also be addressed by the evaluation of effect-based methodologies (biological effects of contaminants) that provide an understanding of the health of individuals or species in relation to the multiple and mixed effects of the pressures they endure.

While the evaluation of status with respect to pollution offers a clear and high confidence evaluation, it is important to acknowledge that this only directly addresses those issues/substances for which there is sufficient knowledge and data. Our understanding of the chemicalisation of the environment is growing and recent developments, such as in screening (target and non-target screening) and effects-based methods, identify a shift away from the doctrine that an overview of a few priority substances (usually of high concentration) provides an understanding of status. This highlights the fact that it is vital to fathom the broader picture where a vast array of substances at various concentrations (some often low, but compounded by the high cumulative number), often acting in parallel, ultimately determine the status. While this development does not detract from the need to maintain a solid evaluation of those key priority substances, it does reflect the need for vigilance (i.e., what may be emerging). In the future, additional improvements in the screening and/or assessment of multiple or mixed effects would be needed, to better support pre-emptive and risk-based management.

1.2. Pollution and its impact on ecosystem health

Pollution can have major detrimental ecosystem impacts that may range from direct toxicity and death of individual animals or plants (biota) to more persistent health and displacement effects. Classically these impacts are determined by the exceedance of threshold values, the threshold value being the level above which a specific substance or pressure will undermine ecosystem health in the short or longer-term. Although this approach achieves a general overview of ecosystem health, the specific pathways of pollution are often more complex, resulting in significant additional knowledge gaps by not taking into account all the relevant substances/pressures to which the ecosystem is exposed. The application of other supporting approaches is therefore also critical to provide a broader and more holistic overview of ecosystem health. This report focuses dominantly on aspects related to pressures, status and impacts as these are aspects for which there is currently readily available information, however all aspects of a conceptual management framework are relevant to the evaluation and management of pollution in the Baltic Sea (Figure 3).

A functional and healthy ecosystem (i.e. the Baltic Sea in Good Environmental Status) requires that pollution is not at levels that impact the species or habitats. This includes the individual pressures or substances and the multiple mixed and cumulative aspects generated by these pressures. In simple terms this entails: non-indigenous species not entering the ecosystems (in particular not via human activities) and their spread, establishment plus impacts on native species or habitats being minimised; underwater noise levels not causing habitat or species disturbance at levels that are detrimental to individuals, species or populations; marine litter being below levels that detrimentally impact biodiversity; and concentrations of hazardous substances that do not have acute or other detrimental effects on biota or habitats. Humans are also component within this ecosystem and an ecosystem unaffected by pollution is also highly relevant to human society (see Thematic Assessment on Biodiversity and Thematic Assessment on Economic and Social Analyses), this is in many ways most simply reflected for example by evaluations carried out against threshold values for human health (e.g., fish used as a food sources need to be at contaminant levels that are not harmful to human health).

The role and impacts of pollution in the Baltic Sea are often elusive or perceived as transient. This is in the main part due to the fact that pollution is generally not visible and perceivable to the naked eye or is at least infrequently encountered at such levels. Events that generate large oil spills or extensive fish die offs are potential exceptions to this general perception (though these often support the transient view), however, focusing only on such events would be deeply insufficient. It is vital that the broader and pervasive impacts such as the multiple mixed and cumulative effects are also reflected and communicated, in addition to the status at the individual substance/pressure level. Biodiversity (including humans) and ecosystem health are the result of a fine balance between individual biota (animals or plants), the species composition, the trophic interactions (e.g., food webs), and the habitats within which they reside. These aspects are all critically underpinned by factors such as abundance, distribution and the balance within and between individual components in the ecosystem (see Thematic Assessment on Biodiversity). Pollution can influence all of these critical ecosystem cornerstones as when pollution of certain types exceeds sustainable levels it undermines these in various ways. This may for example occur due to a non-indigenous species outcompeting a native species in its niche or preying on another native species; due to noise levels impairing communication in marine mammals and fish or disturbing normal behaviours (e.g., feeding or breeding); due to litter ingestion or entanglement reducing the survival and success of certain species; via acute pollution events oiling wildlife; as a result of hazardous substances accumulation via biomagnification in food webs; or due to multiple mixed effects of several substances or pressures resulting in reproductive failure. Each and every of these exclusively pollution focused examples has a detrimental impact on the ecosystem and its health as in practice the removal (death) or impairment of an individual or multiple individuals, impacts or selective impacts on a species, impacts or selective impacts on a population, or impacts on a habitat or area of habitat are interlinked and the resulting outcome in the short or longer-term can be the impairment of vital cornerstones that underpin the health and functionality of the Baltic Sea ecosystem. Minimising such impacts is therefore vital to achieve the sustainable use of the Baltic Sea marine environment so as to ensure that individually or cumulatively these pressures do not exceed levels that may selectively or diffusely impinge on ecosystem health.

1.3. Pollution and relevance of management in the Baltic Sea

The scope and complexity of the activities and pressures (as well as drivers and impacts) associated with pollution, and the often-imperceptible nature of pollution, make management response and policy implementation a significant challenge. There are however efforts under key policy initiatives to address pollution and further work is underway in HELCOM to fill a key gap regionally and bring forward a strategic approach and action plan on hazardous substances (see Information Box 1). For other topics such as marine litter and underwater noise there are recently approved action plans (see below).

Effective management of pollution to prevent detrimental impacts on the Baltic Sea ecosystem health is best achieved in a pre-emptive manner or alternatively described, at an early stage within approaches such as the DAPSIM conceptual management framework (i.e. at the Driver, Activity and potentially Pressure stages). Firstly, management can only really target (human) activities in a direct manner while drivers (and in some cases sources of pollution) are often highly complex and associated with large and convoluted or global processes that national or regional policy may not be able to fully address. Secondly, the further the targeted point in the DAPSIM cycle is, the more complex the required measure often needs to be (in simple terms removal of a pollutant once in the open sea is far more complex, potentially impossible, than prevention of release). Lastly, the more complex the measure requirement is then generally the more costly and more difficult it is to achieve effective results. In a simple example, finding measures to reduce pollutant generating activities or measures that lower/prevent inputs of pollutants from relevant activities at source (e.g., reduce new non-indigenous species introduction, minimise noise, reduce marine litter occurrence, or lower inputs of hazardous substances) is significantly more achievable than when these pollutants are already dispersed or released into the marine environment (both spatial and concentration-wise management is more achievable). In many cases, for example a widely distributed non-indigenous species or hazardous substance that persists in the environment, it may essentially be impossible (e.g., NIS eradication, Sambrook *et al.* 2014) or financially implausible to develop and apply suitable measures with any effect. To achieve such oversight and pre-emptive management it is thus vital to have a full, and as detailed as possible, overview of pollutants across their life cycles as well as across all relevant components of a conceptual management framework (such as DAPSIM).

Thousands of hazardous (or potentially hazardous) substances, noise of both an impulsive and continuous character, marine litter and non-indigenous species are all introduced to the Baltic Sea due to human activities. Strategies or action plans are relatively well developed for non-indigenous species, and more recently for marine litter and underwater noise (see below). In these cases, key activities have also been identified providing key linkages through which measures can be set and which evaluations of pressure and status can be made. For example, some of these linkages include the association between non-indigenous species and ballast water or shipping activities, or between certain construction activities or shipping and underwater noise. Similarly, for certain elements of the hazardous substances evaluation linkages have also been developed, such as between oil spills and shipping incidents/illegal discharges, or between the Cs-137 levels and the sources of radioactive substances. The remainder of the hazardous substances

Box 1

Plans towards a regional holistic framework and action plan on hazardous substances

HELCOM has recently reviewed its work on hazardous substances and is currently developing a strategic approach, leading to an action plan on hazardous substances, which is one of the key actions in the updated Baltic Sea Action Plan of 2021 (action HL1).

The target is to establish a new regional holistic framework for managing hazardous substances.

The current system is mainly based on adding new elements in a somewhat haphazard manner as each individual issue is identified. It focuses on a limited number of priority pollutants, their monitoring and assessment, and a list of measures to prevent their input to the marine environment compiled on an ad hoc basis.

By strengthening the management cycle and modernizing the tools involved, the new framework is expected to:

— facilitate identification of substances, sources, and pathways of the highest regional relevance, now and in the future.
— facilitate adoption of measures with clear added value on the top of – and in synergy with – the existing policy landscape (including current BSAP actions and HELCOM Recommendations). Explore measures which will be targeted, efficient, and effective in improving the state of Baltic Sea.
— promote utilization of all relevant information on hazardous substances and recognition of key information gaps. A different type of measures will target filling these information gaps (e.g., identifying need for projects or data/information collection).

For the 'identification' part, dealing effectively with the complex pool of multiple hazardous substances in current circulation will require assessment of the state of the environment using tools previously not applied, such as: target and non-target screening and monitoring of biological effects, evaluation of substance lists adopted in other policies in terms of their relevance for the Baltic Sea, pre-emptive / preventative management e.g. via assessing the use patterns of substances harmful for the marine environment, as well as consideration of combined effects.

The regional strategic approach and respective action plan is planned for adoption by 2024 and aims to form the foundations for future management of hazardous substances in the HELCOM region.

The project HAPhazard is co-financed by HELCOM, the NEFCO Baltic Sea Action Plan Fund, Germany and Sweden.

evaluated currently, however, are somewhat less straightforward. With the exception of diclofenac (a pharmaceutical compound addressed under a pre-core HELCOM indicator), the linkages – especially in any quantifiable from – between drivers, activities to pressure or status are not well developed. Furthermore, the evaluation focuses on, and provides a high confidence evaluation for a relatively limited number of substances or substance groups that are likely not a full representation of the actual pressure exerted by hazardous substances. Future in-depth evaluations of a broader scope of substances (e.g., via target and non-target screening), re-evaluation of priority substances, improved linkages within substance life-cycles, and improved incorporation of effects based approaches will likely support the needed paradigm shift in the management of hazardous substances (see Information Box 1).

To maintain a healthy and functional ecosystem it is vital that all forms of pollution are carefully managed and minimised. Understanding the current status, the trends over time, and subsequent changes in them is vital for effective management and thus the safeguarding of the Baltic Sea environment. There exists an extensive policy landscape aimed at achieving this.

1.4. Pollution and the Baltic Sea Action Plan

The Baltic Sea Action Plan (BSAP) represents the core tool by which HELCOM Contracting Parties aim to achieve a healthy and sustainably used Baltic Sea environment. The 2021 Baltic Sea Action Plan sets out a vision for 'a healthy Baltic Sea environment with diverse biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable economic and social activities'. The 2021 BSAP specifically addresses hazardous substances, non-indigenous species, underwater noise and marine litter under various segments and under a large number of designated goals and actions. Two key goals with relation to this report are under the hazardous substances segment, a 'Baltic Sea unaffected by hazardous substances and litter' and also the sea-based activities segment, 'Environmentally sustainable sea-based activities'. In addition, there is also importance of these topics for the Biodiversity goal of a 'Baltic Sea ecosystem [that] is healthy and resilient'.

To support the implementation of these goals the following mutually supportive and interlinked ecological objectives are important:

Hazardous substances
— Marine life is healthy;
— Concentrations of hazardous substances are close to natural levels;
— All sea food is safe to eat;
— Minimal risk to humans and the environment from radioactivity.

Marine litter
— No harm to marine life from litter.

Sea-based activities
— No or minimal disturbance to biodiversity and the ecosystem;
— Activities affecting seabed habitats do not threaten the viability of species' populations and communities;
— No or minimal harm to marine life from man-made noise.

Biodiversity (i.e., due to the pervasive nature of pollution)
— Viable populations of all native species;
— Natural distribution, occurrence and quality of habitats and associated communities;
— Functional, healthy, and resilient food webs.

These objectives have been chosen as a representation of the desired state of the environment. Pollution is a stressor that pervades the marine ecosystem and can have major impacts across the entire ecosystem. To support the achievement of the goals and objectives above there are also a number of relevant management objectives (as well as specific actions).

The following management objectives have been identified for hazardous substances and marine litter and sea-based activities segments:

Hazardous substances and marine litter
— Minimize input and impact of hazardous substances from human activities;
— Prevent generation of waste and its input to the sea, including microplastics;
— Significantly reduce amounts of litter on shorelines and in the sea.

Sea-based activities
— Minimize noise to levels that do not adversely affect marine life;
— No introductions of non-indigenous species;
— Minimize the input of nutrients, hazardous substances and litter from sea-based activities;
— Enforce international regulations; - no illegal discharges;
— Safe maritime traffic without accidental pollution;
— Effective emergency and response capabilities;
— Minimize harmful air emissions;
— Zero discharges from offshore platforms.

The 2021 BSAP also directly addresses these segments with 32 actions directed towards hazardous substances and litter, 6 actions directed towards non-indigenous species and 9 actions related directly towards underwater noise.

In addition to, or directly supporting, the Baltic Sea Action Plan HELCOM has a number of Recommendations or action plans that deal with marine litter, underwater noise, non-indigenous species or hazardous substances:

— Revised Regional Action Plan on Marine Litter;
— Regional Action Plan Underwater Noise;
— Regional Baltic Sea plan for harmonized ratification and implementation for the 2004 IMO Ballast Water Management Convention (BWMC);
— Implementing HELCOM's objective for hazardous substances (HELCOM RECOMMENDATION 31E/1).

1.5. Pollution and other key policy initiatives

In alignment with the vision, goals and objectives of the BSAP and also of major importance to addressing pollution are international and European Union (EU) level agreements such as the EU Marine Strategy Framework Directive (MSFD), EU Water Framework Directive (WFD) and the United Nations (UN) Sustainable Development Goals (SDGs).

The MSFD, in particular Commission Decision (EU) 2017/848 that sets out the detailed requirements for evaluating and towards achieving Good Environmental Status (GES), directly addresses the key pollution topics addressed under this thematic assessment. MSFD Descriptor 2 (D2) establishes the aim that 'Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystems', Descriptor 8 (D8) the aim that 'Concentrations of contaminants are at levels not giving rise to pollution effects', Descriptor 10 (D10) that the 'Properties and quantities of marine litter do not cause harm to the coastal and marine environment', and Descriptor 11 (D11) that the 'Introduction of energy, including underwater noise, is at levels that do[es] not adversely affect the marine environment'. The established Criteria to address these Descriptors include key issues relevant to providing an overview of each topic. For Descriptor 2 these include new introductions (D2C1), abundance and distribution of established (D2C2), and adverse effects of non-indigenous species (D2C3). For Descriptor 8 concentrations (D8C1), in particular of key contaminants for example those identified under the WFD), health effects (D8C2), extent and duration of significant pollution events (D8C3) and the adverse effects of acute events (D8C4) are relevant. Descriptor 10 considers the amount, type and spread of litter on the coastline (beaches), seafloor and in the water column (D10C1), the equivalents comprehension for micro-litter (D10C2), the ingestion of such litter types for biota (D10C3), and the number of individuals of a species adversely affected by litter (D10C4). Descriptor 11 specifically includes the distribution, level, temporal extent and effects of impulsive (D11C1) and continuous (D11C2) noise.

The UN SDGs focus on broader aspects than many of the MSFD Descriptors or Criteria or the specific BSAP actions. They are more akin to, especially the SDG targets, to the vision or goals of the BSAP. The most directly relevant is SDG 14 with the goal 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development' and the underlying target (14.1) of 'By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution'. Other relevant SDGs include SDG 6 with the goal 'Ensure availability and sustainable management of water and sanitation for all' and targets such as 'By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally' and 'By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate', SDG12 with the goal 'Ensure sustainable consumption and production patterns' and the targets (among others) such as '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' and 'By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse', and SDG 13 with the goal to 'Take urgent action to combat climate change and its impacts' and targets such as 'Integrate climate change measures into national policies, strategies and planning'. These goals and targets are also the focus of ongoing indicator development work within UN processes.

Beyond HOLAS 3 other key policy initiatives such as the European Green Deal and associated Zero Pollution Action Plan, and the Kunming-Montreal Global Biodiversity Framework will likely also become significant policy players.

1.6. Overview of the thematic assessment on pollution

This thematic assessment covers a broad array of topics and issues under the summary of pollution. The one pollution-related issue not addressed under this thematic assessment is the issue of nutrients (nitrogen and phosphorus), as this aspect and the resulting eutrophication impacts are covered in their own thematic assessment (see Thematic Assessment on Eutrophication). This thematic assessment addresses the following key topics: Hazardous substances, Marine Litter, Underwater noise, and Non-indigenous species.

The report addresses each of these topics separately, providing a sub-section for each topic under the relevant chapters within the report. In addition, where other information is known to be significant for the topic but currently not part of the developed and operational HELCOM assessment tool assortment, it is included to provide an overview of the current knowledge or potential for such approaches in the future. This is a relevant issue for all topics, but especially hazardous substances as the current assessments do not address all relevant policy requirements or cover all relevant ecological aspects (i.e., future work is still required at the scientific and holistic assessment level). Furthermore, it is vital to acknowledge for hazardous substances that while it is possible to make a strong evaluation based on the relatively few well-studied and well-monitored substances, there is a vast array of hazardous or potentially hazardous substances for which only a limited amount of information about their presence in the marine environment and/or their impacts is currently available.

Where relevant the report also provides more general overviews of the topics that are not directly covered by HELCOM core indicators, to provide a broad overview of pollution. However, no integration or quantifiable interlinkage between these separate topics (or with existing core evaluations) is applied in the process.

2. Overview of the pollution assessment approach

This thematic assessment represents the latest developments and current state of the art evaluation under HELCOM for the topics of hazardous substances, marine litter, underwater noise, and non-indigenous species (considered together as pollution). It reflects substantial progress towards indicator-based evaluations on all topics, building on foundations established in HOLAS II and corresponding work under aligned processes (e.g. EU level and MSFD relevant developments). In addition, other areas of development that are not complete or in the form of fully operational indicators are also included to provide a broader picture of the key issues relevant in the topic of pollution and the achievement of Good Environmental Status. There remains further scope for development at the indicator and integration level for all topics, however, this report aims to provide an overview of the current status and knowledge level while acknowledging the ongoing development work towards improved and more optimal assessments.

2.1. Introduction to the state of the art assessment

Each topic under the theme pollution is described separately as there is considerable variation in the underlying components and level of development for each topic.

2.1.1 Hazardous substances

Hazardous substances are known to be numerous, and it is acknowledged that management and scientific effort commonly addresses – in full or in sufficient detail – only a relatively small proportion of the substances or substance groups that have the potential to enter and be harmful to the ecosystem. There is however a significant weight of evidence and an extensive data set for those substances monitored and evaluated, often based on selection of key priority substances. Even though somewhat limited in the grander scale of hazardous substances, the evaluation of key priority substances identifies that there are serious impacts on the health and status of the Baltic Sea marine ecosystem. The main structure and foundations of the assessment presented in this report are the same as those applied in HOLAS II, however some improvements have been made), such as: 1) more abundant and longer time series are generally available (i.e. more stations and assessment units) as well as more stations with longer time series ('full' data series, data series of three or more years in length on which stronger analyses can be applied); 2) threshold values have been revised for some indicators based on improved scientific knowledge; 3) the application of a semi-quantitative and multi-component confidence evaluation per indicator at the assessment unit level (as opposed to a single confidence for an entire indicator evaluation as applied in HOLAS; 4) the addition of new indicators and conversion to core indicator level for others; and 5) improvement of the hazardous substances integration tool (CHASE), especially the confidence setting within it, and inclusion of more indicator evaluations within CHASE. The filling of data gaps identified in HOLAS II (e.g., in the Gulf of Riga) was a general focus area under EG HAZ and also in certain instances supported by work carried out in the Baltic Data Flows project. Further details are provided below on these main issues.

New indicators or indicators approved to become core indicators

The 'Tributyltin (TBT) and Imposex' HELCOM indicator was moved from a pre-core to a core indicator based on the agreement on a new threshold value. In addition, a new indicator to evaluate concentrations of copper in the marine environment, and relevant threshold value for this, was approved as a core indicator. Change from pre-core to core and the arrival of new core HELCOM indicators under the topic of hazardous substances is significant as the HELCOM Expert Group on Hazardous Substances has set this (the approval as core indicator) as the delineation line for indicators evaluating substance concentrations to be included in the integrated assessment (CHASE Hazardous substances integration tool). In HOLAS II the evaluation of hazardous substances was applied with nine core indicators (covering 12 substances or substance groups in the integrated assessment) and supported by two pre-core and one supplementary HELCOM indicator. For HOLAS 3 there are thirteen core indicators (covering 14 substances or substance groups in the integrated assessment), one pre-core and one supplementary indicator. The larger increase in the number of indicators yet the smaller increase in the number of substances or substance groups is due to the fact that the indicator addressing 'Metals' in HOLAS II was split into three separate indicators addressing each substance separately – Cadmium, Lead and Mercury.

New or revised threshold values

The new HELCOM 'Copper' indicator was approved as a core indicator to evaluate concentrations of copper against a regionally agreed threshold value in sediment, an Environmental Quality Standard (EQS of 30 mg/kg dry weight, 5% Organic Carbon (TOC, CORG, or loss on ignition conversion) normalised, in sediment). The new threshold value for TBT 1.3 µg/kg dry weight in sediment (5% organic carbon normalised) represents a slight lowering of the threshold value from what was applied in HOLASII (1.6 µg/kg) and the regional agreement on this new value resulted in the indicator being accepted as a core indicator. Despite the lowering of the threshold value to a more precautionary level it is not expected that the change would have a significant impact on status outcomes as, where measured, TBT is generally above the concentrations of either of these values (i.e., generally fails to achieve Good Environmental Status either way).

Other revised threshold values include the threshold values applied for cadmium and lead in the sampling matrix biota, and for fluoranthene in the sampling matrix sediment. For cadmium in biota the threshold value was revised based on studies carried out in Denmark to develop a suitable EQS value. The developed EQS value utilised newer and better data, including data from the marine environment, and replaced the previous Background Assessment Concentration (BAC) that had originally been developed for the OSPAR region (Greater North Sea). A similar process took place for the threshold value for lead in biota, however, in this instance, the OSPAR BAC for fish was also retained for samples collected using fish liver as the monitoring tissue (sampling matrix). This was due to there being no suitable conversion factors in place to correct between fish muscle and liver, making the assessment only against the new EQS value problematic (i.e., since many contaminants generally accumulate at higher levels in the liver tissue than in muscle or whole organism). For cadmium and lead there remains a need to improve the understanding and application of conversion factors between species and tissue types. The threshold value for fluoranthene in sediment was also revised to correct for an error identified in the original EQS dossier. The newly adopted threshold value of 3500 µg/kg (5% CORG) in sediment replaced the value of 2000 µg/kg (5% CORG) utilised in HOLAS II.

A threshold value change with a significant impact on the indicA threshold value change with a significant impact on the indicator evaluation outcome and the integrated assessment outcome is the change in the 'Radioactive substances: Caesium-137 in fish and surface seawater' HELCOM indicator. Utilising the guidance and prior work under the International Atomic Energy Agency (IAEA), dose rates from exposure scenarios to humans were developed and utilised to define new threshold values. This process was carried out to align the threshold values in the indicator with the requirements of the updated BSAP of 2021 under the ecological objective 'Minimal risk to humans and the environment from radioactivity'. The changes in the actual threshold values from 2.5 Bq kg-1 for herring, 2.9 Bq kg-1 for flounder and plaice and 15 Bq m-3 for seawater, as utilised in HOLAS II, to 20 Bq kg-1 in fish (wet weight for fish) and 40 Bq m-3 in seawater however represent a change from almost all areas assessed failing the threshold value in HOLAS II to all achieving the threshold value in HOLAS 3. Thus, Radioactive Substances no longer act as a major driver of failed status across the region within the integrated assessment. The earlier threshold values utilised in HOLAS II were based on levels that correspond to pre-Chernobyl activity concentration levels (i.e., levels before 1984), and it should be noted that these are in addition maintained in the indicator report as these represent 'natural conditions' and there are signs that these levels are also close to being achieved during the current assessment period.

Detailed information on the changes can be found under HOD 61-2021 document 5-1 Rev.1.

Semi-quantitative confidence evaluation

In HOLAS II each hazardous substances indicator was awarded a general confidence based on expert opinion (i.e., by the indicator leads or members of the regional HELCOM Expert Group on Hazardous Substances, EG HAZ). A single confidence per indicator (high, moderate or low) was applied to all evaluated assessment units for any given indicator. For HOLAS 3 work was carried out in the Baltic Data Flows project (co-financed by the Connecting Europe Facility of the European Union), which developed proposals on how a more detailed confidence setting approach could be applied. This followed an approach of developing a system more aligned to other HELCOM integrated assessment tools, such as the integrated assessment tool for biodiversity (BEAT), and the proposals were evaluated under EG HAZ. The final approach utilised applied a weighting between five separate confidence components (spatial, temporal, methodological, threshold value, and assessment) and provides a confidence outcome per evaluated assessment unit (and per indicator or substance/substance group). While there is further scope for a more detailed evaluation of this process beyond HOLAS 3, the current approach provides a comparative evaluation of confidence (i.e., a relative evaluation of the confidence ranging within a single indicator) and a higher resolution picture of the confidence and potential for it to vary per assessment unit.

Integrated assessment development (CHASE tool)

In HOLAS II twelve substances or substance groups were utilised in the integrated assessment whereas in HOLAS 3 that number is fourteen. The further development of the CHASE hazardous substances integrated assessment tool took place under the Baltic Data Flows project and focused on the following aspects of relevance to HOLAS 3: the inclusion of new indicators (or substances/substance groups), the incorporation of the new confidence evaluations per indicator (described above), and the improvement of confidence penalty setting. The resulting improvements and outcomes are presented in this report, including:

- the addition of the indicator evaluation results from the tributyltin concentrations component (i.e., imposex component not included) and the copper concentrations;
- the incorporation of the higher resolution confidence components per assessment unit (and per indicator) that provides a more nuanced reflection of the confidence at a scale closer to that at which monitoring effort is applied (i.e. not as the whole Baltic Sea scale, as applied in HOLAS II);
- a more appropriate application of confidence penalties where the required number of metals or organic substances evaluated must be the separate substance/substance group (i.e.,

lead, cadmium, copper, or mercury) and cannot be achieved by multiple occurrences of one substance but sampled in different sampling matrices (e.g., lead in biota and water).

2.1.2 Marine litter

For the first time, a dedicated quantitative section on marine litter is included as part of a Baltic Sea holistic thematic assessment. In HOLAS II in 2018, it was only possible to include a qualitative section on marine litter. However, advances on the topic since then have enabled the establishment of a threshold value for beach litter as well as an approach for the evaluation of seafloor litter, although the latter is a trend-based evaluation and can only be applied where data is currently available. The threshold value and approach applied for beach litter is built on a close alignment between HELCOM and EU work (e.g., within the EU Technical Group on Marine Litter), to ensure a strong harmonisation between the approaches applied for the BSAP and MSFD. No integrated assessment is applied currently, and these two components are evaluated separately as part of the overall topic.

2.1.3 Underwater noise

The topic of underwater noise was also only addressed qualitatively in HOLAS II. However, in this HOLAS 3 assessment, progress has been made on both the continuous and impulsive underwater noise indicators. Thus, for continuous noise the state of the marine environment has been evaluated based on sound pressure levels in the Baltic Sea in 2018, which, being the year when more monitoring data were available, is considered to be representative for the conditions in the whole 6-year assessment period (2016-2021). For impulsive noise, the occurrences of impulsive noise-producing maritime activities reported by Contracting Parties to the regional HELCOM/OSPAR noise registry hosted by ICES was evaluated. The distribution of sound was partially compared to the distribution of harbour porpoises in the Baltic Sea, providing a first appraisal of overlap of sound and the occurrence of this species. No integrated assessment is currently applied, and these two components are evaluated separately as part of the overall topic.

2.1.4 Non-indigenous species

The NIS indicator is currently not included in any integrated assessments within HELCOM work but is for the first time included in the thematic assessment report on pollution in the Baltic Sea as part of HOLAS 3. During HOLAS II, this topic was included in a section on "Pressures and their status", but not part of the overall pollution assessment. This inclusion of NIS under pollution reflects the similarities to other pollution topics in that their origin in general is directly linked to human activities. It also provides more attention to the topic and its importance for the ecosystem of the Baltic Sea, as well as providing the opportunity to highlight the further work required to expand the understanding and evaluation of the topic. The general threshold value is the same as in HOLAS II (no new introductions of NIS into the Baltic Sea). Data time series have been updated for the evaluation from HOLAS II (2011-2016) to HOLAS 3 (2016-2021).

2.2. Overview of data collection and monitoring

Each topic is addressed separately as there are significant differences in the structure and organisation between them. An overview of the major relevant processes and structures that underpin HELCOM monitoring is available via the HELCOM Monitoring and Assessment Strategy and relevant Monitoring Programmes under the Monitoring Manual (with selected relevant parts summarised in Table 1).

2.2.1 Hazardous substances

The general system for data collection and monitoring related to hazardous substances follows the standard procedure of each HELCOM indicator being supported by a regionally agreed monitoring and assessment and the annual reporting of all relevant nationally collected data to the HELCOM COMBINE database, hosted by ICES (International Council for the Exploration of the Sea). There are some exceptions to this rule and some instances where not all parts of the process are currently in place.

Utilising the agreed methodologies for sample collection, sample preparation and sample analysis as set out in relevant

Table 1. Overview of relevant monitoring programmes for the topics listed above.

Monitoring focus	Component	Monitoring programme
Contaminants (Hazardous substances)	Inputs	Contaminant inputs from the atmosphere
		Contaminant inputs from landbased sources
		Acute pollution
	Concentrations of contaminants	Contaminants in water
		Contaminants in sediment
		Contaminants in biota
	Biological effects of contaminants	Imposex
Marine Litter	Litter	Macrolitter characteristics and abundance-volume-beach litter
		Macrolitter characteristics and abundance-volume-litter on the seafloor
Energy, including underwater noise	Underwater noise	Continuous noise
		Impulsive noise
Non-indigenous species	Non-indigenous species	Non-indigenous species

guidelines, Contracting Parties carry out sample collection at selected national monitoring stations within their waters. Sampling occurs in one of three major sampling matrices, either water, biota or sediment and dependant in the sample collected and the substance(s) measured in it there may also be a need for specific supporting parameters to be recorded or analysed. Supporting parameters to be recorded may include aspects such as depth (e.g., for a sediment sample) and those supporting parameters requiring analysis may include factors such as lipid concentrations on biota samples or organic carbon concentrations in sediments samples, these latter supporting parameters being a vital component of the indicator evaluation calculation process (i.e. without which the indicator evaluation result cannot be attained). Analysed supporting parameters are in general critical for evaluating factors such as bioavailability or normalising the analysed substance concentration to a standard parameter (e.g., lipid concentration) that may otherwise result in significant differences between areas, species, or tissues. The required sup-

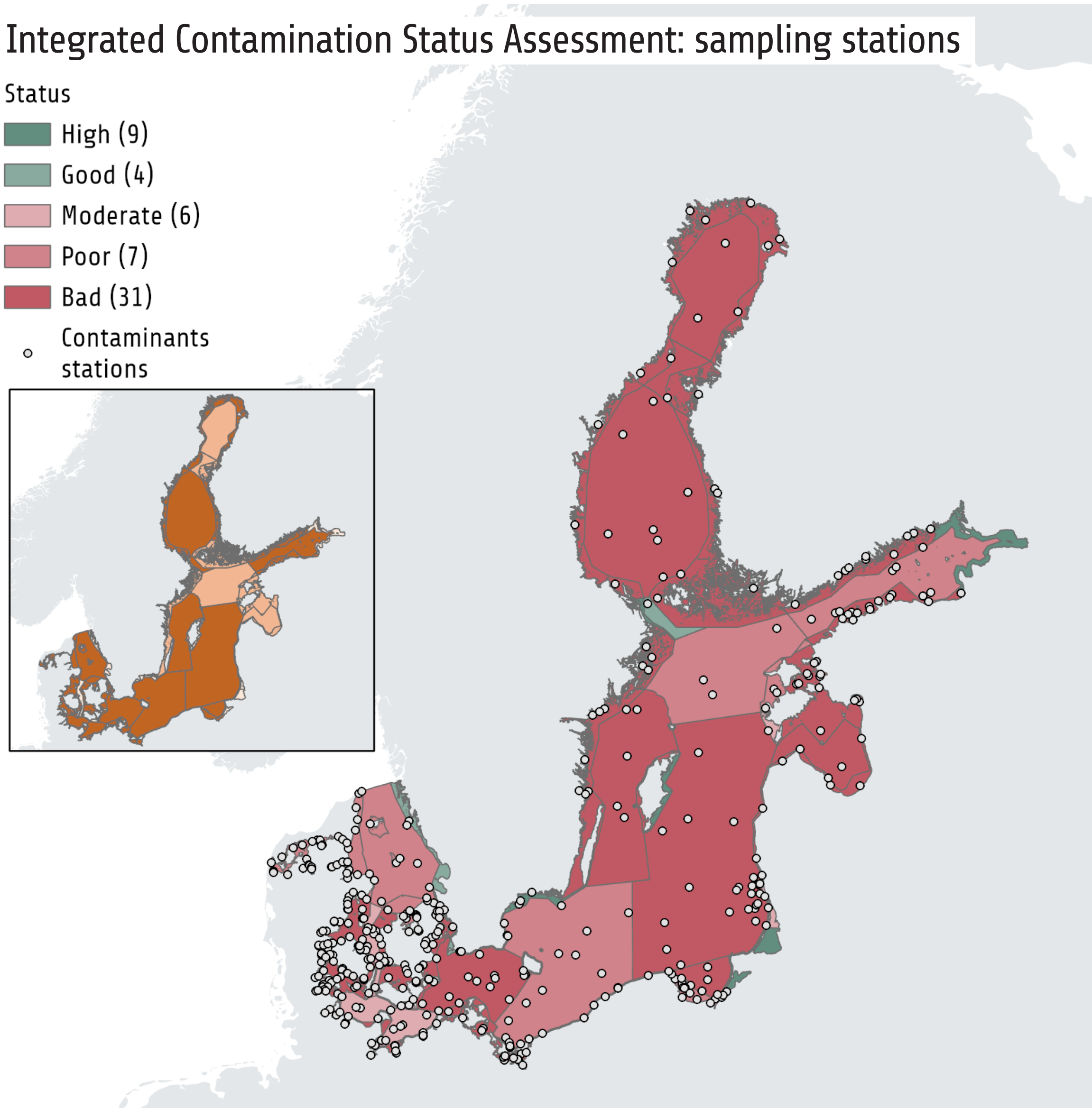


Figure 4. An overview of stations where data series for hazardous substances are evaluated and the outcomes of those evaluations enter the integrated assessment. It is important to note that this map shows the placement of the stations but between 1 and 14 of the substances or substance groups included in the integrated assessment may be analysed at any of the individual stations. Thus, in simple terms this simply depicts a spatial distribution of the sampling across those hazardous substances indicators utilised in the integrated assessment. It should also be noted that Denmark retains a study reservation on some of the threshold values applied within the indicators utilised in this integrated assessment.

porting parameters are documented in the EG HAZ 'extraction table', which is a living document curated by EG HAZ to identify the specific requirements for each indicator and provide the basis for the raw data extracted from the COMBINE database when an indicator evaluation or integrated assessment process is initiated. When an extraction from the COMBINE database is made (i.e., for HOLAS 3) all relevant data in the HELCOM region, that is available for all relevant indicators, is extracted and utilised at the root of all further analyses (though it is important to note that certain data such as duplicate data or data lacking the required supporting parameters may subsequently be excluded if it does not conform to the analytical process). An overview of the spatial spread of stations utilised in the integrated assessment is provided in Figure 4.

The bulk of hazardous substances indicators follow the process above and have established monitoring and assessment guidelines. Work remains under EG HAZ and the recently formed subteams, to improve these further and fill the gaps that remain.

One of the major exceptions to the above-described process is Diclofenac, that is currently not formerly monitored in a regional manner and the relevant national data is at the moment collected via ad-hoc HELCOM data calls. A similar process is also applied for the biological effects of contaminants supplementary HELCOM indicator, the 'Reproductive disorders: Malformed amphipod embryos'. In both cases, any data available within the COMBINE database is also utilised in addition to the data collected via ad-hoc data calls.

The 'White-tailed sea eagle productivity' HELCOM indicator currently has no formal monitoring and assessment guideline nor fixed data flows to support it. As there are general similarities and harmonised approaches regionally, the relevant data to support the evaluation is therefore also collected via ad-hoc HELCOM data calls.

Two other HELCOM indicators utilised to address hazardous substances – the 'Radioactive substances: Caesium -137 in fish and surface waters' and the 'Oil-spills affecting the marine environment' – do not utilise the COMBINE database, as they have established data reporting processes under the HELCOM Expert Groups that host them (the Expert Group on Aerial Surveillance (EG Surveillance) and the Expert Group on Monitoring of Radioactive Substances in the Baltic Sea (EG MORS), respectively). In both cases the data required for the indicator evaluations are part of regular annual reporting carried out under these Expert Groups.

2.2.2 Marine litter

Beach litter

Guidelines for monitoring beach litter (>2.5 cm) are in place (HELCOM 2018b). The HELCOM Revised Action Plan on Marine Litter from October 2021 (HELCOM 2021), recommends "improved coordinated monitoring programmes for the beach litter and seafloor litter indicators including data collection for regular assessment of the state of marine litter in the Baltic Sea area". Currently, however, HELCOM Contracting Parties still apply different methodologies and litter codes.

The OSPAR Guideline (2010) is followed in Denmark and Germany. Denmark uses the Joint List of Litter Categories for Marine Macrolitter Monitoring (Fleet *et al.* 2021) with a conversion to the OSPAR list. Germany uses a modified OSPAR list. Estonia, Finland, Latvia and Sweden use the MARLIN methodology (MARLIN, 2013) (based on the UNEP/IOC Guidelines, 2009) and associated litter items list. Poland established their own national slightly modified methodology also based on Guidance on Monitoring of Marine Litter in European Seas (JRC, 2013), using the Master list with G-codes for litter items. The Master list is also used by Lithuania.

The figure below (Figure 5) displays the location of the monitoring sites for the period 2016-2021, differentiating remote/natural, semi-urban and urban types of beaches.

Additional information can be found in the HELCOM Monitoring Programme on Beach litter (HELCOM, 2020).

Seafloor litter

There is a wide experience of collecting litter on the seafloor and fishing gear/lost fishing nets in the HELCOM area. Seafloor litter collection is integrated in bottom trawling for fish stocks assessment, so therefore the selection of the sampling stations as well as frequency is associated to the species of interest. It is to be noted that bottom trawling, however, is not conducted in the northernmost sea areas of the Baltic Sea, and thus information on seafloor litter is currently lacking from these areas. Additional information can be found in the HELCOM Monitoring Programme on Litter on the Seafloor (HELCOM, 2020).

2.2.3 Underwater noise

Continuous noise

Both monitoring guidelines as well as a monitoring programme for continuous noise (HELCOM, 2021, HELCOM 2019) are in place. Moreover, the HELCOM Regional Action Plan on Underwater Noise (HELCOM 2021), recommends "develop and operationalize common indicators and associated definition of Good Environmental Status (GES) related to underwater noise for application in the assessment of the state of the Baltic Sea marine environment, taking into consideration ongoing work at EU level for HELCOM countries who are EU Member States" as well as "continue and improve reporting of national monitoring data on continuous noise and impulsive noise events to the already established regional databases, to ensure availability of high-quality data for regular assessment of the state of underwater noise in the Baltic Sea area".

Impulsive noise

Monitoring of underwater noise is described on a general level in the HELCOM Monitoring Manual, in the monitoring topic 'Underwater noise' sub-programme 'Registry of impulsive sounds' (HELCOM, 2020).

The purpose of the indicator is to provide an overview of the potential effects of all loud impulsive low and mid-frequency sound sources, through the year and spatially across the region. This will enable HELCOM members to get an overview of the overall pressure from these sources. To achieve this target relevant sources are reported and registered in the HELCOM/OSPAR registry of impulsive noise events hosted by ICES (ICES, 2015).

2.2.4 Non-indigenous species

Non-indigenous species (NIS) and cryptogenic species (CS) have been detected both during regular environmental monitoring activities, as well as research surveys and citizens science observations. The data are generally verified by national experts and only new human-mediated introductions are considered. Thus, the

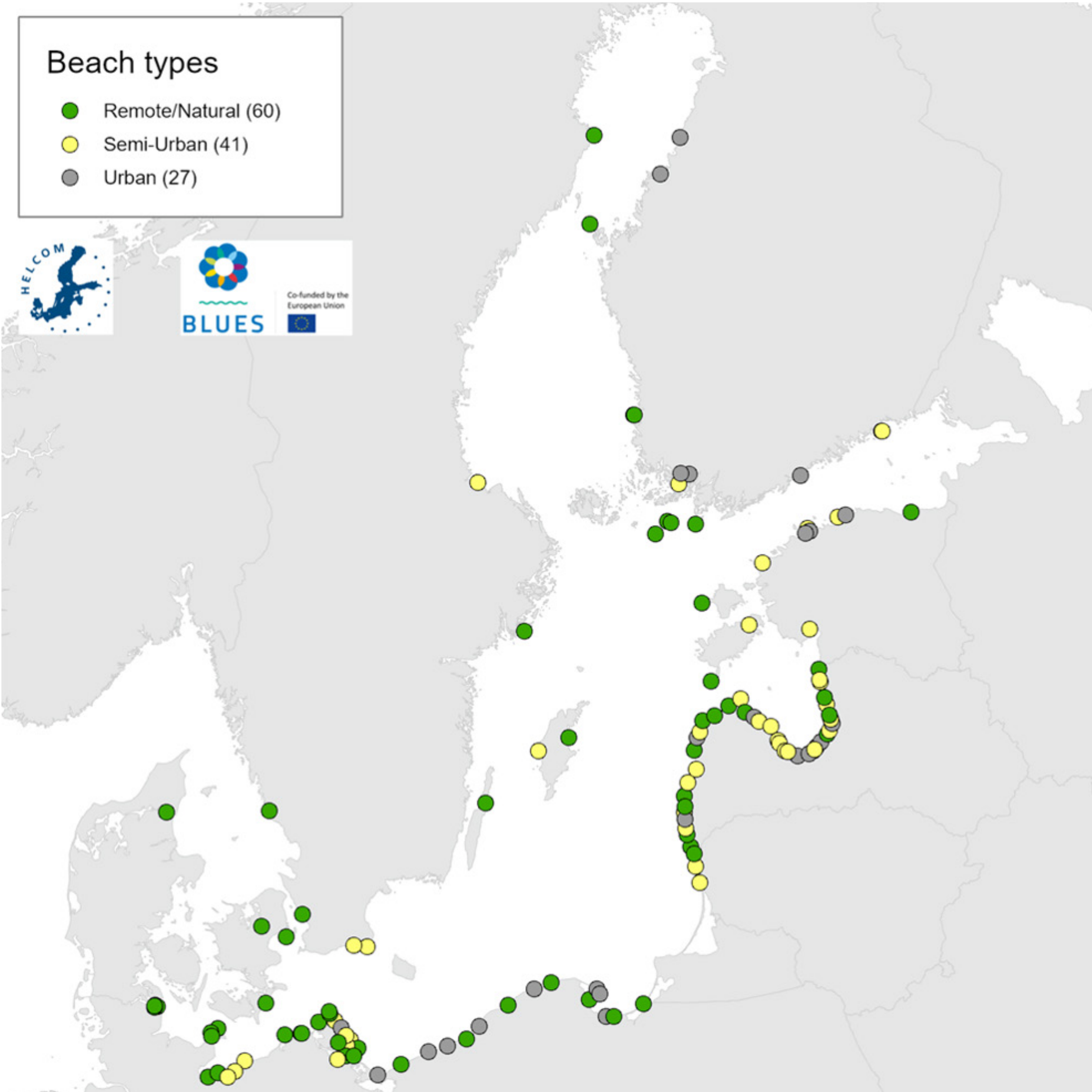


Figure 5. Map of beach types (Remote/Natural, Semi-Urban, and Urban) for the entire Baltic Sea for the period 2016–2021.

core indicator evaluates the success of management in preventing new introductions (Olenin *et al.* 2016). Accordingly, the secondary spread by natural means (migration, water currents etc.) within the Baltic Sea is not specifically part of this evaluation currently. The main human induced pathway associated with NIS/CS, in addition to spread by natural means, is maritime transport. NIS monitoring aims to address all biotic components as NIS may belong to any trophic level and be found in various man-made as well as natural habitats. Non-indigenous species are occasionally detected in regular biological monitoring programmes (e.g. as described in the Thematic Assessment of Biodiversity). Some national differences in the sampling strategies exist as well as different monitoring effort levels and spatial coverage, thus causing some discrepancy in the predicted detection rate of new NIS arrivals. Despite such differences, a homogenized strategy for NIS detection should be pursued also including port monitoring. Common HELCOM monitoring of relevance to the indicator is described in the HELCOM Monitoring Manual in the programme topic: Non-indigenous species. Gaps in monitoring exist in a sense, since routine monitoring does not cover all invasion hotspots, habitats, and taxonomic groups in many of the countries surrounding the Baltic Sea.

The current data provide a good overview of the new introductions regionally and are based on information collated in the AquaNIS database, with all the information in the database being verified by national or international experts. The indicator results could be significantly improved if dedicated monitoring program for NIS are launched in all countries. Current evaluations are biased towards better investigated groups (molluscs, crustaceans, fish), whereas almost no information on micro- and meio organisms and pathogens is available.

2.3. Assessment scales

The use of assessment scales (both temporal and spatial) is critical to ensure a harmonised evaluation across all assessed topics (i.e., providing a snapshot of status for a given period) and also to facilitate clear spatial comparisons. The latter is critical where ecological or hydrogeographical gradients are present (as is the case in the Baltic Sea) and also when carrying out integrated assessments between closely related indicators under a single topic or theme.

2.3.1 Temporal scales

Each HELCOM holistic assessment covers a timespan of six years, referred to as the assessment period. The current HOLAS3 assessment focuses on the time period 2016–2021. Hence, the HOLAS3 assessment period partially overlaps with that of HOLAS II, which covered 2011-2016 (HELCOM 2018b). The first HOLAS (HELCOM 2010) covered years 2003-2007.

In addition, where available, data showing longer term temporal development have been provided in order to understand long-term trends and evaluate the direction of ongoing changes.

2.3.2 Spatial scales

The HELCOM spatial assessment units are a key tool to perform regional assessments in a coherent way across a wide variety of topics and features, while still ensuring that each topic can be assessed at a scale that is ecologically relevant. The assessment units and scale of assessment are based on ecological and hydrogeographical gradients and are applied differently depending on the topic evaluated and in certain instances on the suitability of data to achieve the ecologically relevant assessment scale. For the purposes of indicator evaluations and integrated assessment, HELCOM applies a spatial division of the Baltic Sea (assessment units) on four different scales (Level 1-4):

— *Level 1:* HELCOM marine area. No division. The whole Baltic Sea encompasses the entire HELCOM area.
— *Level 2:* HELCOM sub-basins. Division of the Baltic Sea into 17 sub-basins.
— *Level 3:* HELCOM sub-basins with coastal and offshore division. Division of the Baltic Sea into 17 sub-basins and further division into coastal (per country) and open sea areas, i.e., additionally including 40 coastal areas.
— *Level 4:* HELCOM sub-basins with coastal WFD water types or water bodies. Division of the Baltic Sea into 17 sub-basins and further division into coastal and open sea areas and division of the coastal areas by Water Framework Directive (WFD) water types or water bodies, i.e., additionally including 240 coastal areas

To the extent possible the assessment units are nested, i.e. units with higher spatial resolution can be nested into units with lower spatial resolution, in order to allow for comparison across evaluations and assessments which are applied at different scales. The assessment units can also be further aggregated within one assessment scale, should for example ecological relevance require this (e.g., to reflect a species or population range). Maps showing the delineation of assessment units at each of these scales are presented in the HELCOM Monitoring and Assessment Strategy, as part of HELCOM Joint Coordinated Monitoring System and in detail in attachment 4 "HELCOM Subdivisions of the Baltic Sea".

The scale at which each assessment is done is dependent on the environmental issue that is being assessed, e.g. for eutrophication or contaminants higher resolution is possible whereas highly mobile marine mammals or birds, which move across large areas, require more coarse scale of the assessment to capture their true distribution.

In general, the hazardous substances indicators are applied at Level 4 HELCOM assessment units, with a few applied at Level 2. Other topics of Marine Litter, Underwater Noise and Non-indigenous species are generally applied at lower resolution, Levels 1 or 2. Table 2 below gives an overview of the spatial assessment scale and assessment period for the four topics and the sub-topics (indicators) within each topic.

The integrated assessment of hazardous substances is applied at Level 3, taking into account the different scales of assessment applied between those substances included in the integration process and to provide a clearer and higher confidence overview when summarising substance concentrations.

2.4. Overview of indicators included in the thematic assessment

Pollution is a broad term that in this thematic assessment addresses hazardous substances, marine litter, underwater noise, and non-indigenous species.

Man-made chemicals and heavy metals (hazardous substances) enter the Baltic Sea at elevated levels via numerous sources, including from wastewater treatment plants, leaching from household materials, leaching from waste deposits, and from industrial plant emissions. In addition, atmospheric deposition and sea-based sources (e.g., from shipping) also exist and may contribute significantly. Some sources and inputs are highly visible in the form of oil-spills, others, however, can remain unnoticed or are only apparent when detrimental impacts on the ecosystem or biota are observed. Many contaminants degrade slowly, and their impacts can magnify as they accumulate within aquatic food webs. The most harmful substances are persistent, toxic and accumulate in biota. Some substances are regularly monitored with a set of HELCOM indicators designed to evaluate the status (e.g., concentrations) of these substances in the Baltic Sea ecosystem. These indicators underpin this thematic assessment, are important evaluators of ecosystem health, and have direct relevance for the health of biodiversity and habitats as well as a clear influence on human wellbeing.

Marine litter is a significant aesthetic problem; but also results in -economic costs, threatens human health and safety, and has impacts on marine organisms. It is broadly documented that entanglement in, or ingestion of marine litter can have negative consequences on the physical condition of marine animals and even lead to death. Ingestion of artificial, polymer materials is also of concern, as it may provide a pathway for the transport of harmful chemicals into the food web. Additionally, marine litter is known to damage, alter or degrade habitats (e.g., by smothering). Floating plastic litter can also be a possible vector for the transfer of alien species, but the risk of this happening in the Baltic Sea is generally considered to be small.

Marine litter continues to have an impact on a wide range of marine fauna, with many new records of affected species reported every year, particularly attributed to the ingestion of and entanglement by various forms of plastic (UNEP, 2021). The total number of marine species known to be affected is also likely to be substantially underestimated. Negative effects on individuals are more obvious in cases of entanglement, where external injuries or death can often be observed. Determining the effect of ingesting marine litter on an individual can be more difficult, and the consequences of ingestion are still not fully understood. Sublethal effects of entanglement and ingestion that alter the biological and ecological performance of individuals have been documented. Marine and coastal species, that show a high incidence of litter ingestion or entanglement, may be susceptible to population-level effects. This could have negative consequences for species with small populations, particularly those that are considered endangered and/or exposed to multiple stressors. Identifying the impacts of marine litter at the ecosystem level is a critical area for attention and should include the evaluation of the loss of ecosystem services that can be attributed to this stressor. Marine litter (in the form of derelict fishing gear) can also affect terrestrial species (e.g., for those species spending part of their lifetime on beaches). Other forms of marine litter exist, such as floating litter items and also microliter, however, in the current assessment the available

Table 2. Overview of the assessment scales and assessment period for each of the four pollution topics addressed under this theme.

Topic	Sub-topic	Spatial assessment	Assessment period
Hazardous substances	Hexabromocyclododecane (HBCDD)	HELCOM Level 4 Assessment Units	2016-2021
	Perfluorooctane sulphonate (PFOS)	HELCOM Level 4 Assessment Units	2016-2021
	Polybrominated biphenyl ethers (PBDE)	HELCOM Level 4 Assessment Units	2016-2021
	Polyaromatic hydrocarbons (PAH) and their metabolites	HELCOM Level 4 Assessment Units	2016-2021
	Polychlorinated biphenyls (PCB) and dioxins and furans	HELCOM Level 4 Assessment Units	2016-2021
	Cadmium (Cd)	HELCOM Level 4 Assessment Units	2016-2021
	Lead (Pb)	HELCOM Level 4 Assessment Units	2016-2021
	Mercury (Hg)	HELCOM Level 4 Assessment Units	2016-2021
	Copper (Cu)	HELCOM Level 4 Assessment Units	2016-2021
	TBT and imposex	HELCOM Level 4 Assessment Units	2016-2021
	Diclofenac	HELCOM Level 4 Assessment Units	2016-2021
	White-tailed sea eagle productivity	HELCOM Level 3 Assessment Units (coastal areas only)	2016-2021
	Radioactive substances: Caesium -137 in fish and surface waters	HELCOM Level 2 Assessment Units	2016-2021
	Oil-spills affecting the marine environment	HELCOM Level 2 Assessment Units	2016-2021
	Reproductive disorders: Malformed amphipod embryos.	HELCOM Level 2 Assessment Units	2016-2021
	Integrated assessment of Hazardous substances (CHASE)	HELCOM Level 3 Assessment Units	2016-2021
Marine litter	Beach litter	HELCOM Level 2 Assessment Units	2016-2021
	Seafloor litter	HELCOM Level 1 Assessment Units[1]	2016-2021
Underwater noise	Continuous noise	HELCOM Level 2 Assessment Units	2016-2021
	Impulsive noise	HELCOM Level 1 Assessment Units	2016-2021
Non-indigenous species	Non-indigenous species	HELCOM Level 1 Assessment Units	2016-2021

1 With the caveat that it is based on ICES coordinated trawl surveys and that there is no sampling north of the Gotland basins, on rough grounds, in coastal areas or on grounds with dumped munition.

information focuses dominantly on indicators developed to date, that address beach litter and seafloor litter.

Properties of underwater sound are extremely diverse, and sound can be classified in many different ways. A commonly accepted division of underwater sound is into two categories, natural and anthropogenic, where the first encompasses all sounds that are produced by either animals or geophysical processes, while the second covers sounds produced by human activities. Examples of geophysical processes are rain, wind, waves, ice, thunder, and seismic activity. Biological sounds (animal vocalization and sound production) are produced by cetaceans, seals, fish, and invertebrates. Examples of anthropogenic sound sources are ships, pile driving, sonars (navy and commercial), seismic airguns and other geophysical survey equipment, underwater explosions, acoustic deterrence devices and infrastructure (bridges, platforms, offshore wind farms).

Continuous anthropogenic noise represents a significant pressure on the marine environment due to its constant presence and extensive spatial coverage throughout the entire water column in open sea areas. Low frequency ambient noise in the open oceans has increased by around 15 dB in the last half a century due to human activities (Andrew *et al.* 2002). The noise from ships, when sailing at service speed, is caused primarily by their propulsion (engine noise and propeller cavitation), with secondary components being machinery and the movement of the hull through the water (Breeding *et al.* 1996; Wales & Heitmayer, 2002; Wittekind, 2014).

The most intense man-made sources of loud impulsive noise are explosions, pile driving, seismic explorations and low frequency sonars. Although noise does not persist in the environment, it may harm marine species if no measures are taken to mitigate adverse effects.

Sound in water travels as a wave in which particles of the medium are alternately forced together and apart. The sound can be measured as a change in pressure within the medium, which acts in all directions, described as the sound pressure. Each sound wave has both a pressure component and a particle motion component, indicating the velocity and the acceleration of the moving molecules in the sound wave. Depending on their receptor mechanisms, marine life is sensitive to either pressure or particle motion, or both. Marine mammals are sensitive only to the pressure component, fish without swim bladders only to the particle acceleration component, whereas fish with swim bladders are sensitive to both components (Au and Hastings, 2008).

Elevated levels of underwater sound may affect aquatic animals, with impacts including masking of other sounds, behavioural disturbances, and physiological changes (stress, hearing loss, discomfort, injury to the auditory system). In extreme cases, where animals are close to very loud sources (in particular underwater explosions), the consequences can be tissue damage and death (CBD, 2012; Schack *et al.* 2016, DeBacker *et al.* 2017, Siebert *et al.* 2022). This assessment utilises recently developed indicator evaluations of both continuous and impulsive noise.

Non-indigenous species may spread in the Baltic Sea and cause harm to the marine environment. For example, the round goby (Neogobius melanostomus), a bottom-dwelling invasive fish originating in the Black Sea and Caspian Sea, was observed for the first time in the Baltic Sea in 1990. After a few years with low abundance, the species increased dramatically and it is now a dominant species in many areas of the Baltic Sea, with a capacity to change interactions in the benthic food web (Kotta *et al.* 2016). This pattern of establishment, and consecutive spread, is characteristic of invasive species. However, not all non-indigenous species are invasive, and may not spread widely nor become abundant. Established non-indigenous species may influence biodiversity and the ecosystem in different ways, and their effects are often difficult to foresee. Risk assessments are important to guide the management of non-indigenous species and help to implicate measures at an early stage (Katsanevakis *et al.* 2014). Currently a single HELCOM indicator addressing non-indigenous species exists and this only evaluates the number of new introductions and does not specifically evaluate issues such as spread, establishment or impact on the Baltic Sea ecosystem.

HELCOM uses indicators to evaluate the status of the Baltic Sea marine environment in a harmonised regional manner, providing an established threshold value (or occasionally a baseline) representative of acceptable condition. Scientists and researchers have come together to identify threshold values for each indicator, these being scientifically supported and politically approved at the regional level. These threshold values represent the boundary between good and poor status, and these have been agreed jointly by all the countries around the Baltic Sea. The approach allows evaluation to be carried out at regular intervals, resulting in a snapshot of the status for that period. In addition, regular evaluation in such a manner allows for longer-term trends to be established and comparisons made between earlier, current, and subsequent assessment periods. This provides the opportunity for change, or progress towards a threshold value (indicative of Good Environmental Status), to be examined.

This pollution assessment builds on many years of work in HELCOM to develop indicators for the four key topics (hazardous substances, marine litter, underwater noise, and NIS). The assessment of pollution utilises 20 HELCOM indicators and an integrated assessment of hazardous substances. Fifteen of these address hazardous substances, two address marine litter, two address underwater noise and one addresses non-indigenous species (see sections 2.4.1-2.4.4). The majority of the 20 indicators utilised are fully operational HELCOM core indicators with well-developed data flows, assessment methodologies and regionally approved threshold values, but some indicators utilised in the current assessment are also well-advanced pre-core indicators (indicators that may lack final approval on certain aspects or lack full data flows, but provide evaluations of value and are tested in this thematic assessment) or supplementary indicators (approved and applied by several but not all Contracting Parties). The long-term aim of HELCOM Contracting Parties is to develop the assessment further to appropriately cover all relevant aspects of pollution in future Baltic-wide assessments, and to strengthen existing indicators where needed.

2.4.1 Hazardous substances

The assessment of hazardous substances relies on 15 HELCOM indicators and is supported by a number of additional variables that provide a broader context but are generally not assessed against regionally agreed threshold values (Table 3). The integrated assessment of hazardous substances is carried out based on most of the indicators that address substance concentrations, representing a total of 14 substances or substance groups.

Table 3. Overview of hazardous substances indicators utilised in the assessment. An overview of other relevant supporting variables utilised in the report is also included. *represents those HELCOM core indicators that are utilised in the integrated assessment of hazardous substances (note that PAH metabolites and Imposex are not included in the integration process). EQS = Environmental Quality Standard, QS = Quality Standard, BAC = Background Assessment Concentration, EAC = Environmental Assessment Concentration.

Topic	Indicator/other variable	Threshold value	Assessment scale	Indicator report
Hazardous substance indicators	Hexabromocyclododecane (HBCDD)*	EQS in biota (human health) of 167 µg/kg wet weight (normalised to 5% lipid content)	Level 4	https://indicators.helcom.fi
		QS from EQS in sediment of 170 µg/kg dry weight (normalised to 5% organic carbon)		
	Perfluorooctane sulphonate (PFOS)*	EQS in biota (human health) of 9.1 µg/kg wet weight	Level 4	https://indicators.helcom.fi
		EQS in water (annual average) of 0.00013 µg/l		
	Polybrominated biphenyl ethers (PBDE)*	EQS in biota (human health) of 0.0085 µg/kg wet weight (normalised to 5% lipid content)	Level 4	https://indicators.helcom.fi
		QS from EQS in sediment (benthic community protective) of 310 µg/kg dry weight (normalised to 5% organic carbon)		
	Polyaromatic hydrocarbons (PAH) and their metabolites*	EQS in biota (human health) of 5 µg/kg wet weight benzo(a)pyrene.	Level 4	https://indicators.helcom.fi
		EQS in biota (human health) of 30 µg/kg wet weight fluoranthene		
		EQS in biota sediment of 3500 µg/kg dry weight (normalised to 5% organic carbon) fluoranthene		
		QS in sediment of 24 ug/kg anthracene dry weight		
		PAH metabolite 1-hydroxypyrene: EAC in biota of 483 ng/g fish bile		
	Polychlorinated biphenyls (PCB) and dioxins and furans*	dl-PCBs, dioxins and furans: EQS in biota (human health) of 0.0065 ng TEQ/kg wet weight (normalised to 5% lipid content)	Level 4	https://indicators.helcom.fi
		Non dl-PCBs (PCBs): sum of congeners (28, 52, 101, 138, 153, 180) in biota of 75 µg/kg wet weight (normalised to 5% lipid content)		
	Cadmium (Cd)*	EQS in water 0.2 µg/l	Level 4	https://indicators.helcom.fi
		EQS in biota (secondary poisoning) of 160 µg/kg wet weight mussels and fish (whole organism)		
		QS from EQS in sediment of 2.3 mg/kg dry weight		
	Lead (Pb)*	EQS in water of 1.3 µg/l	Level 4	https://indicators.helcom.fi
		EQS in biota (secondary poisoning) of 110 ug/kg wet weight mussel and fish muscle (whole organism)		
		OSPAR proxy BAC in biota of 26 µg/kg wet weight fish liver		
		QS from EQS in sediment of 120 mg/kg dry weight		
	Mercury(Hg)*	EQS in biota (secondary poisoning) of 20 µg/kg wet weight	Level 4	https://indicators.helcom.fi
	Copper (Cu)*	QS from EQS in sediment of 30 mg/kg dry weight (normalised to 5% organic carbon)	Level 4	https://indicators.helcom.fi
	TBT and imposex*	QS from EQS in sediment of 1.3 µg/kg dry weight (normalised to 5% organic carbon)	Level 4	https://indicators.helcom.fi
		EQS in water (annual average) of 0.2 ng/l.		
		EAC in Peringia ulvae: of 0.1 VDSI, Nucella lapillus of 2.0 VDSI, Neptunea antiqua of 2.0 VDSI, Hinia reticulata of 0.3 VDSI, Buccinum undatum of 0.3 VDSI, and Littorina littorea of <0.3 VDSI.		

Table 3. (Continued). Overview of hazardous substances indicators utilised in the assessment. An overview of other relevant supporting variables utilised in the report is also included. *represents those HELCOM core indicators that are utilised in the integrated assessment of hazardous substances (note that PAH metabolites and Imposex are not included in the integration process). EQS = Environmental Quality Standard, QS = Quality Standard, BAC = Background Assessment Concentration, EAC = Environmental Assessment Concentration.

Topic	Indicator/other variable	Threshold value	Assessment scale	Indicator report
	Diclofenac	EQS in water (annual average) of 0.040 µg/l (preliminary)	Level 4	https://indicators.helcom.fi
		EQS in biota (secondary poisoning) of 1.16 µg/kg wet weight (preliminary)		
	White-tailed sea eagle productivity	Reference periods for 'productivity' (combined the refence periods below) and the two supporting variables 'brood size' (from period 1858-1950) and 'breeding success' (from period 1915-1953)	Level 3 (coastal areas only)	https://indicators.helcom.fi
	Radioactive substances: Caesium -137 in fish and surface waters*	Dose-based in biota (human health) of 20 Bq/kg wet weight	Level 2	https://indicators.helcom.fi
		Dose-based in water (human health) 40 Bq/m-3		
	Oil-spills affecting the marine environment	Reference period - modern baseline of average per sub-basin during 2008-2013	Level 2	https://indicators.helcom.fi
	Reproductive disorders: Malformed amphipod embryos.	BAC and EAC derived from unpolluted reference sites to evaluate (1) the proportion of malformed embryos and (2) the proportion of females with more than one malformed embryo.	Level 2	https://indicators.helcom.fi
Hazardous substances supporting variables	Hazardous substances in sediment cores	NA	NA	Part of this report, Information Box 3.
	Biological effects of contaminants and integrated biological effects	NA	Level 2 (pilot studies)	Part of this report, section on Biological effects of contaminants, p.57
	Target and wide-scope screening of contaminants	NA	Level 1	Part of this report, section on Screening and other emerging substances or risk identification p. 66.

2.4.2 Marine litter

Two indicators are used in the assessment of marine litter, beach litter and litter on the seafloor (Table 4). In addition, additional qualitative information on microlitter, both in the water column and in sediments, is provided. The table below provides an overview of the indicators and their associated variables used for the assessment.

Table 4. Overview of marine litter indicators utilised in the assessment.

Topic	Indicator/other variable	Threshold value	Assessment scale	Indicator report
Marine litter	Beach litter	20 litter items per 100 m coastline (median without fragments < 2.5 cm and chemicals like paraffin, wax, oil and other pollutants)	Level 2 for all beach types	https://indicators.helcom.fi
	Amount and composition of litter on the seafloor	Trend not significantly >0 (preliminary)[1]	Level 1[2]	https://indicators.helcom.fi

1 The threshold was set as no significant increase over the observed time period in the monitored part of the Baltic Sea. The threshold is preliminary and for use only until further guidance is available

2 With the caveat that it is based on ICES coordinated trawl surveys and that there is no sampling in coastal areas, on rough grounds, grounds with dumped munition and north of the Gotland basins.

2.4.3 Underwater noise

Two indicators are used in the assessment of underwater noise, addressing the two major types of noise or relevance – continuous noise and impulsive noise. The table below provides an overview of the indicators and their associated variables used for the assessment (Table 5).

Table 5. Overview of underwater noise indicators utilised in the assessment.

Topic	Indicator/other variable	Threshold value	Assessment scale	Indicator report
Underwater noise	Continuous low frequency anthropogenic sound	20% spatial threshold for all months in 2018 (preliminary)	Level 2	https://indicators.helcom.fi
	Distribution in time and place of loud low- and mid-frequency anthropogenic impulsive sounds	Fraction of exposed area of 10% of the entire Baltic Sea within a year (preliminary)	Level 1	https://indicators.helcom.fi

2.4.4 Non-indigenous species

For the topic of non-indigenous species, a single core indicator is used in the evaluation. The table below provides an overview of key components of this indicator (Table 6).

Table 6. Overview of non-indigenous species indicator utilised in the assessment.

Topic	Indicator	Threshold value	Assessment scale	Indicator report
Non-indigenous species	Trends in arrival of new non-indigenous species	No new introductions of NIS during the 6 year assessment period	Level 1	https://indicators.helcom.fi

3. Results for the hazardous substance assessment

Assessment results in short

Overall, the assessment of hazardous substances does not achieve Good Environmental Status and there is a general picture that the Baltic Sea is in bad or poor status (the two categories furthest from achieving GES). There are however also positive signs that should not be overlooked, with decreasing trends in concentrations of several substances being observed at the station level. Due to the persistent, toxic and bioaccumulatory nature of many hazardous substances significant recovery lags can be anticipated from inputs that have already entered the Baltic Sea environment. While the main assessment provides an overview of the established priority substances, it is also vital to consider the potentially vast pool of other substances to which the Baltic Sea may be exposed to, utilising methods such as effect-based techniques and screening.

— The integrated assessment of hazardous substances indicates that the majority of the assessment units are not in Good Environmental Status (sub-GES) – circa 80% of assessment units (44 of 57).
— All but one of the open-sea assessment units are sub-GES and in general those assessment units (especially coastal assessment units) that achieve GES have low confidence (i.e., the underlying data quality or number of indicator substances/substance groups is insufficient, or a key substance driving status is missing (e.g., PBDEs in biota)).
— The overall integrated assessment is generally driven most strongly by concentrations of PBDEs (in biota), but also influenced markedly by TBT (in sediment), mercury (in biota) and copper (in sediment). Cadmium concentrations (in biota and sediment) and also lead concentrations (in biota) also contribute.
— Downward trends (i.e., decreasing concentrations and improving status) are detected at more monitored stations (209 of 663 'full' data stations) than stations where a worsening trend (25 of 663) is recorded. Improving trends are most commonly encountered in the biota monitoring matrix.
— An increase in data availability as well as longer time series is apparent in the current assessment, with an increase in the number of improving status trends at stations.
— The pilot assessment on the biological effects of contaminants indicated that biological effects or signatures of exposure to contaminants were commonly detected, and that such approaches offer complementary approaches to substance concentration evaluations. Some variation was found between the biological effect outcomes and the concentrations of contaminants (e.g., some areas with high concentrations did not express equally high exposure or effect values), though the initial pilot study shows promise and further work should be carried out to regionally develop these tools.
— The first regional screening (target and non-target) highlighted circa 130 substances that regularly occur across the region, some 40 of which showed exceedances of available environmental risk values. Substances detected commonly included pharmaceuticals, industrial chemicals, personal care products and tobacco/coffee related contaminants.

3.1. Introduction to hazardous substance

Hazardous substances represent a substantial pressure on the Baltic Sea marine ecosystem. They can have direct (e.g., death) or more inconspicuous (e.g., health and food web related) effects and rarely act alone as a substance specific pressure. Due to the large number and high variety of substances already detected in or potentially transferred to the marine environment, careful management actions are required. While highly visible and directly toxic events do occur – for example oil spills or accidental releases of chemicals that cause visible impacts on biota (Oil spill affecting the marine environment) – these are generally infrequent and well documented. However, the significantly larger proportion of continuous inputs of hazardous substances are almost imperceptible, with a variety of routes into the Baltic Sea including Wastewater Treatment (WWT), catchment runoff, diffuse atmospheric inputs, or point sources and activity related inputs. Hazardous substances are generated or utilised in an extensive number of human activities, including manufacturing (from clothes to construction material), energy production, maritime activities, waste disposal, and the medical industry. Thus, due to the vast complexity of the topic, any management of the topic needs to address not only status but also the input pathways and the complex life cycles of the myriad of hazardous substances.

A large number of hazardous substances (or potentially hazardous substances) are known to be used in or generated by human activities, while detailed information about them at the regional level is generally limited to only a few priority substances (HELCOM 2010). This is true in particular for the concentrations in the marine environment, where a strong focus has been on a relatively small – but important – list of priority substances (reflected by the HELCOM indicators). Even for these substances, some knowledge or data gaps in their life cycles might remain (e.g., related to uses, sources, pathways, or effective measures). Hazardous substances can have uses essential for our society (for example those associated with the medical industry such as pharmaceuticals) while in others they could be replaced by better and less environmentally harmful alternatives (Joerss *et al.* 2019). Achieving a sustainable balance between societal value (i.e., the clearly defined benefits) and the potential risk to the ecosystem, is therefore the role of management. This ideally requires an understanding of the numerous components within the chain, which include the role and benefits of a substance within a process or product, the toxicity and impacts of the given substance, the release of the substance and pathways to the marine environment, and the appropriate disposal or treatment of the substance or products containing it, amongst others. By comprehending such factors, better management decision can be made about necessary actions. When some cases would warrant a substitution with a more suitable and less environmentally harmful option, other cases may end up with improved development or targeting of measures, facilitate setting of sustainable use and release levels (e.g., via threshold values or input targets), or – in critical circumstances – result in bans. Inevitably, while such processes should also take into account societal needs, we are a member of the ecosystem – therefore, such tools should mainly be used to provide an understanding of the benefits and potentially taken into account during the prioritisation of measures.

Since it is far from straightforward, potentially even impossible, to address every hazardous or potentially hazardous substance of relevance to the Baltic Sea ecosystem, appropriate monitoring

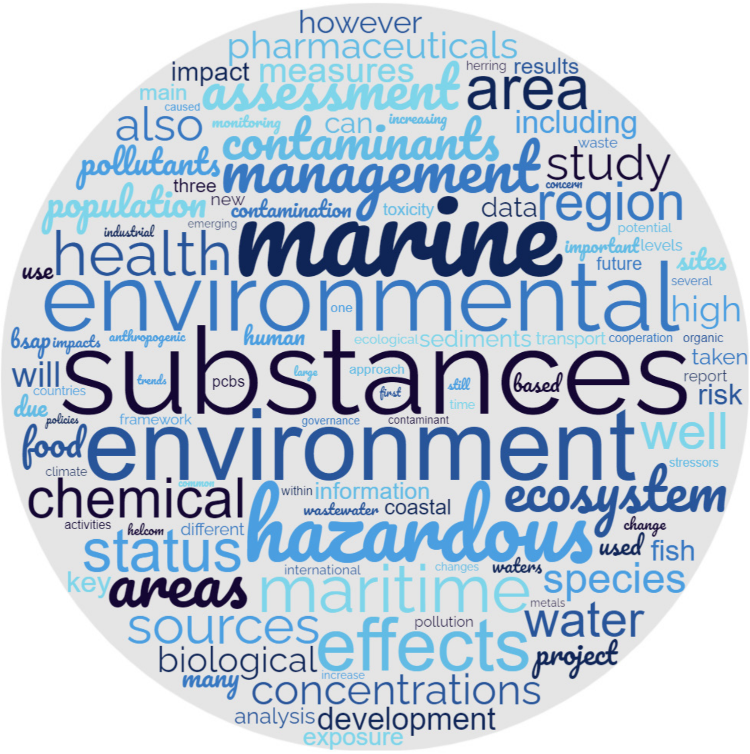


Figure 6. Words used in publications about hazardous substances in the Baltic Sea. The word cloud is based on the full abstracts of the first 50 publications to occur in a Google Scholar search, carried out on 13 December 2022, using the terms 'Baltic Sea Hazardous Substances' and with the year of publication range (custom range) set as 2016–2021. The image contains all words occurring 10 or more times, except for the words Baltic and Sea, scaled so that more commonly occurring words appear in larger font size. The initial word cloud was prepared using www.wordclouds.com. Several of the changes reflected in the scientific output since HOLAS II (e.g., differences between this word cloud an the one carried out in HOLAS II) are also reflected in new initiatives within HELCOM work, indicative of a good coupling between the regional expert community and the policy implementation process.

and 'overview approaches', or likely some combination of the two, are vital (e.g., classical monitoring of single substances and other broader evaluations such as effect-based approaches or screening). In addition, a way to prioritise and establish the appropriate approach and level of monitoring relevant for each substance or substance group (for example dependent on its toxicity or concentration) is also needed. Such issues are the focus of the regional holistic framework and action plan on hazardous substances (See Information Box 1). Initial developments related to effect-based approaches and screening for hazardous substances are provided in this report and support the main integrated assessment and indicator-based assessment carried out. The further and ongoing development of such tools, in particular with the aim of supporting effective management, appears well aligned with the apparent changes in the field of hazardous substances (Figure 6). Based on a simple comparison of commonly occurring words in the abstracts of publications from the HOLAS II and HOLAS 3 periods terms such as health, pharmaceuticals, measures, climate, exposure, stressors, emerging, effects, impacts, and risk appear to be new or more common. This shift in the expert level focus is also well aligned with the discussions and focus on the policy implementation level (i.e., in HELCOM processes).

This report focuses on the available HELCOM indicators addressing the topic of hazardous substances (see Table 3), but in addition utilises pilot studies and other relevant resources to provide a broader picture of the topic. The HELCOM indicators addressing substance concentrations (those that are core indicators, i.e., are fully operational) form a major basis of the assessment as they are utilised in the integrated assessment of hazardous substances (CHASE). This integrated assessment is composed of 14 substances or substance groups and provides a regional understanding of the status of those priority substances that are regularly and intensively monitored (as also presented in detail within the respective indicator reports, see Table 3). In addition, a core indicator addressing the effects of hazardous substances on a top-predator, the 'White-tailed sea eagle productivity', a supplementary indicator addressing impacts on sediment dwelling organisms, 'Reproductive disorders: malformed embryos of amphipods', and a pilot study exploring test cases for an integrated biological effects of contaminants (I-BEC) are provided. The core indicator on 'Oil-spills affecting the marine environment' and the pre-core indicator addressing the pharmaceutical 'Diclofenac' also provide relevant evaluations.

This report summarises the current knowledge on the status of hazardous substances in the Baltic Sea, based on information gathered through regionally agreed monitoring and the HELCOM core indicators. Furthermore, it details the methodology and results of the integrated assessment of selected hazardous substances to support the third HELCOM holistic assessment of ecosystem health in the Baltic Sea. The key results from the integrated assessment are presented, and these are also given in the 'State of the Baltic Sea' summary report.

3.2. Details on the assessment results for hazardous substance

This section of the report addresses the integrated assessment of hazardous substances, the hazardous substances indicators and other relevant topics that support the overarching assessment.

3.2.1 Integrated assessment of hazardous substances

The integrated assessment of hazardous substances uses the HELCOM core indicators that evaluate substance or substance group concentrations (see Table 3) as its base. These consist of 11 core indicators that address 14 substances or substance groups. In general, Good Environmental Status is not achieved across the region (Fig-

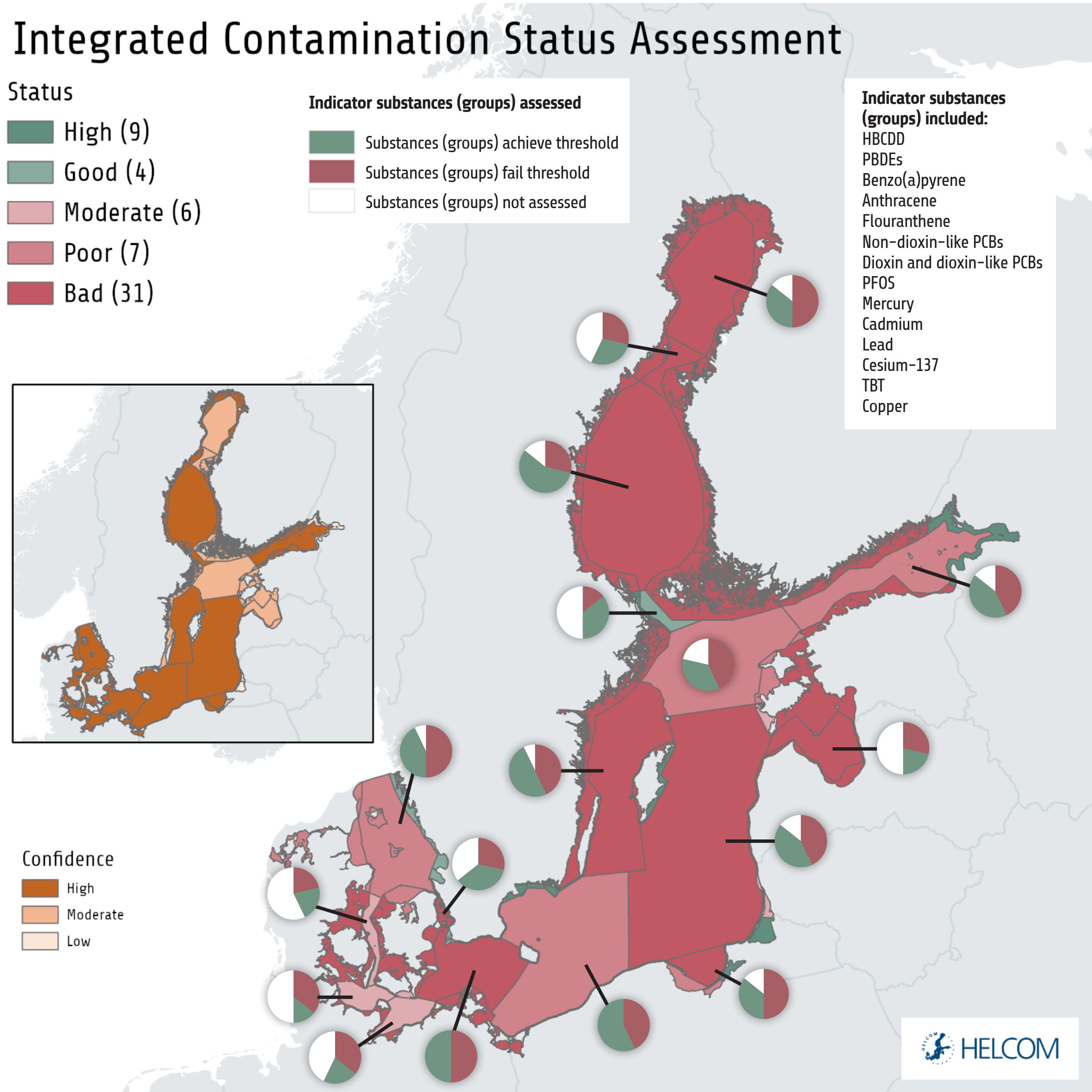


Figure 7a. The integrated assessment of hazardous substances status in the Baltic Sea, assessed using the CHASE integrated assessment tool. The assessment shows that hazardous substances give cause for concern (sub-GES) in almost all assessed units and those showing good status (GES) are generally lacking a full and suitable assessment. The integrated assessment is based on 11 core indicators integrating concentrations-to-threshold derived values (Contamination ratios) for fourteen individual hazardous substances (or substance groups). The pie charts indicate how many out of the fourteen substances were assessed, defining those that achieved (green) or failed (red) their respective threshold value in each of the open sea assessment units. The overall assessment is moderated by a parallel assessment of confidence (see inset map to left, emlarged in figure 7b) and can be considered as an appraisal of the data coverage and assessment quality in any given assessment unit.

ure 7a). Of the 57 assessment units assessed (HELCOM Level 3 units) 44 were sub-GES (Moderate, 6, Poor, 7 and Bad, 31) and 13 achieved GES (Good, 4 and High, 9) – circa 80% sub-GES and 20% in GES, respectively. Moreover, a large proportion, approximately 55%, of all open sea and coastal assessment units were in the worst category (bad). With the exception of the Åland Sea open sea assessment unit (SEA-014), which achieved GES and had a high confidence in the assessment, all other assessment units that achieved GES were coastal areas and in all cases the GES evaluation is also paired with low confidence (i.e., indicative of poor input data or missing indicator substances/substance groups). Since GES is generally only achieved in smaller coastal areas the spatial majority (or area) of the Baltic Sea is sub-GES. Overall, the failure to achieve GES is mainly driven by concentrations of PBDEs (in biota), TBT (in sediment), mercury (in biota) and copper (in sediment). Thus, pressure on the marine ecosystem remains high from hazardous substances.

Confidence in the integrated assessment

The integrated assessment incorporates a large amount of information and presents it at an aggregated level (Figure 7b). This aggregated level is important to provide key messages and support management and the public outreach, but it is also critical to understand any underlying uncertainty that may not be immediately recognised at such a summarised result level. The accompanying

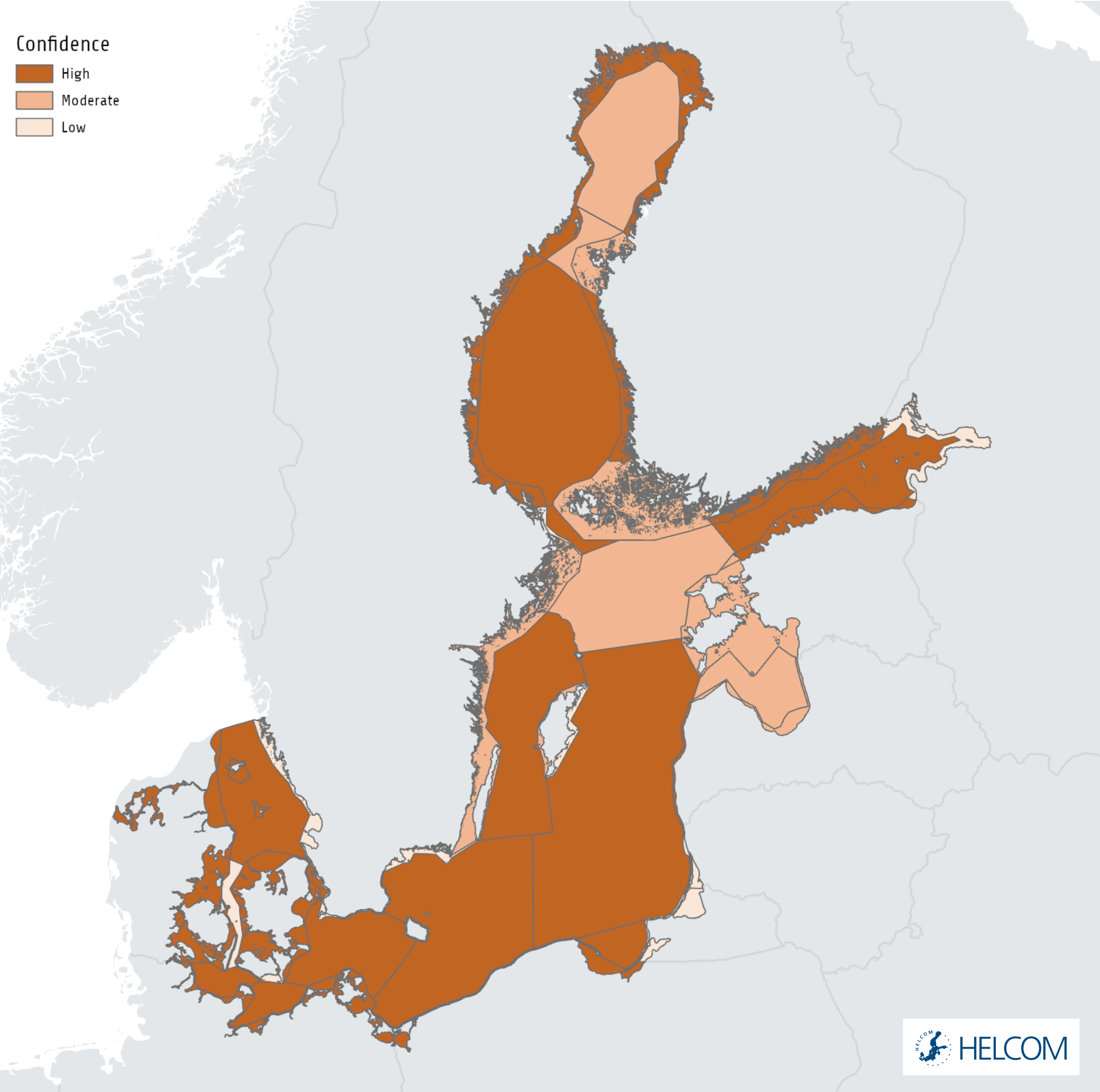


Figure 7b. Confidence evaluation of the integrated assessment of hazardous substances status in the Baltic Sea. Map to be replaced will proper map including legend (dark to light = high to low confidence).

confidence in the integrated assessment is therefore vital. Each indicator or substance/substance group is provided with a confidence at the assessment unit level (and per sampled matrix; i.e., biota, water or sediment). The overall confidence for each of these assessment unit items is composed of an evaluation of the spatial, temporal, threshold value, methodological and analytical confidence. In HOLAS 3 these confidence components are applied as relative aspects within any given indicator and address the number of stations per area of assessment unit, the number of 'full' and 'initial' monitoring stations, an expert-based categorisation, an expert evaluation, and application of Standard Error values form the analysis as the parameters to fulfil the five components, respectively. The integrated assessment makes use of these 'assessment unit'-'sampling matrix' confidence values and also carries out an integration of these to provide a confidence evaluation equivalent to the integrated assessment result. In addition, since many hazardous substances exceed threshold values and are thus in sub-GES condition it could be possible to achieve GES outcomes as an artifact of simply having few substances evaluated. To counterbalance this, penalties are applied to the confidence evaluation where to few substances are included in the integration process. The relevance of this can be clearly seen in the current assessment where coastal assessment units achieving GES are all concurrently identified as of low confidence due to the quality and quantity of data (or substances) included in the assessment (Figure 7). Overall, large areas of the integrated assessment of hazardous substances in the Baltic Sea achieve a high confidence class, suggesting that the underlying data quality and array of substances or substance groups is adequate.

Major factors determining the results of the integrated assessment

The integrated assessment of hazardous substances reflects the integrated contamination status of a selected number of priority substances in the Baltic Sea region, where substantial monitoring effort is in place and full evaluations can be achieved in regional indicators. These priority substances are often key substances from the regional perspective as well as from a current or historical perspective (e.g., legacy contaminants). In general, the worst contamination scores (derived from the contamination ratios) are encountered in biota, thus failure to achieve threshold values of individual substances in biota is a major contributor to the overall failed GES outcome. In addition, certain substances contribute more strongly to the overall failure to achieve GES. These are polybrominated diphenyl ethers (PBDEs), tributyltin (TBT), mercury (Hg), and copper (Cu) respectively (Figure 8).

Ten of the substance or substance groups in the integrated assessment generally achieve their respective threshold values (i.e., the mean values do), while four generally fail their respective threshold values (Figure 8) and are thus the major drivers of the overall sub-GES condition derived from the integrated assessment (Figure 6). This in itself does not suggest that in certain assessment units or at certain stations a particular substance will always achieve or fail to achieve GES, but it provides a generalised overview of the major contributors to the poor status of the Baltic Sea marine environment from hazardous substances. A similar overview is also presented in Table 7, showing the contamination scores that most strongly influence (i.e., have values >1) the integrated assessment per open sea assessment unit (note only open sea sub-basins). The substance and sampling matrix in which the evaluation is made is also provided. The same four substances outlined above obviously play a significant role, however lead (Pb) in biota and cadmium (Cd) in sediment and biota are often regular contributors, falling within the substance-matrices combinations that markedly influence the overall failure of GES in the integrated assessment (i.e., Table 7, red and yellow shades). Although the concentrations of polybrominated diphenyl ethers (PBDEs) in biota are regularly the largest contributor in all open sea assessment units where they are evaluated, there are potentially spatial differences across the other substances when examined on large sub-basin scales. For example, in more northerly areas such as the Gulf of Finland and above (SEA-013 to SEA-017), tributyltin appears less significant, whereas copper and in particular cadmium (in biota) appear more

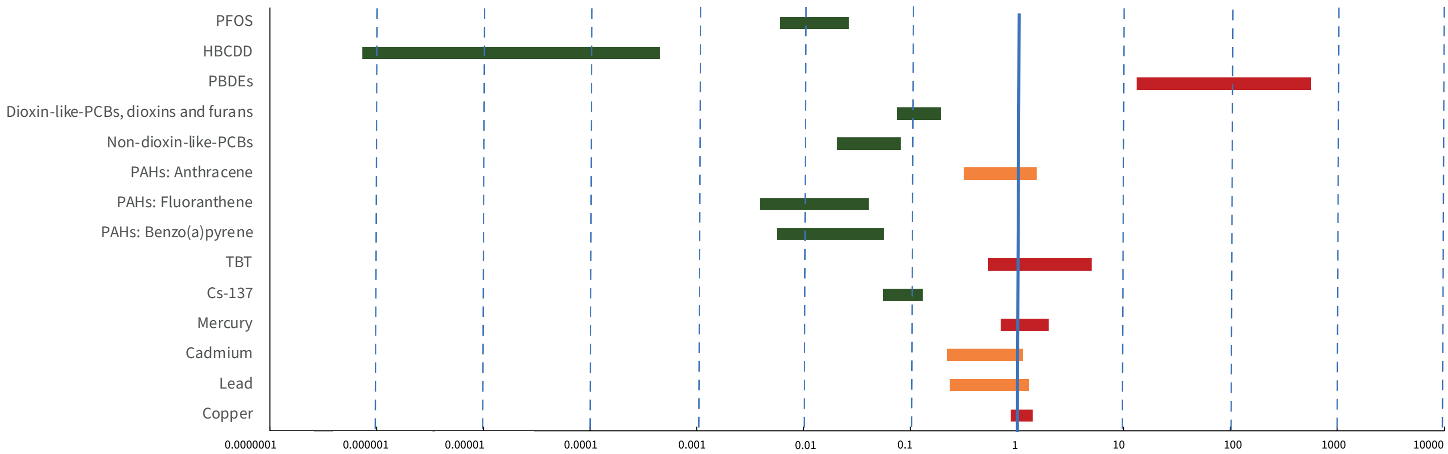


Figure 8. Range of contamination ratios of the evaluated hazardous substances. The contaminant ratios are the observed concentration value divided by the threshold value, based on the mean concentrations for the assessment period 2016–2021. The horizontal bars show the range of contamination ratios from percentile 20 to 75 for each substance on a log-transformed scale. Red bars indicate that the median value fails the threshold value, as identified by the solid blue line (at 1). Orange bars represent a situation where the median value achieves the threshold value but some stations (in the 75th percentile) fail to achieve GES.The figure is based on the coastal and open sea data used in the integrated assessment. Figure to be replaced with improved quality.

Table 7. Overview of the main substances that influence the outcome of the integrated assessment of hazardous substances. The values presented are rounded Contamination Scores (ratio of the observed value (monitored value) to the specific threshold value), where values <1 represent GES. The indicator substance or substance group and the monitoring matrix in which it is analysed are presented. NM = Not Monitored (or at least no result currently available for HOLAS 3). Colours are used to highlight similarly categorised values: = very high (CS values >10), = high (CS values of 5-10), = moderate (CS values of 2-5), = low (CS values of 1-2), and = good (in GES, CS values <1)*.

	PBDEs in biota	TBT in sediment	Hg in biota	Cu in sediment	Cd in biota	Cd in sediment	Pb in biota
SEA-001 Kattegat	22.80	0.78	2.09	1.06	1.06	0.04	0.53
SEA-002 Great Belt	NM	NM	0.55	NM	0.89	NM	1.53
SEA-003 The Sound	28.75	NM	3.62	NM	1.48	NM	3.86
SEA-004 Kiel Bay	NM	4.77	3.20	NM	1.12	0.16	2.22
SEA-005 Bay of Mecklenburg	NM	6.09	0.44	NM	1.36	0.20	1.45
SEA-006 Arkona Basin	42.02	3.64	1.10	1.36	1.22	0.20	0.76
SEA-007 Bornholm Basin	24.62	3.75	0.81	1.69	2.18	0.60	0.99
SEA-008 Gdansk Basin	29.76	6.35	2.55	1.24	0.84	1.28	3.12
SEA-009 Eastern Gotland Basin	40.54	6.54	1.33	1.20	0.26	3.44	1.01
SEA-010 Western Gotland Basin	35.80	3.51	1.08	1.21	3.13	2.48	0.64
SEA-011 Gulf of Riga	22.32	NM	1.10	NM	0.69	NM	2.41
SEA-012 Northern Baltic Proper	13.10	4.36	0.89	1.02	3.26	3.60	0.46
SEA-013 Gulf of Finland	14.77	0.37	1.36	0.88	2.14	0.95	1.97
SEA-014 Åland Sea	NM	<1	NM	1.50	NM	0.12	NM
SEA-015 Bothnian Sea	32.96	<1	0.61	1.78	4.27	0.10	0.37
SEA-016 The Quark	23.91	NM	1.00	NM	4.13	NM	0.77
SEA-017 Bothnian Bay	162.83	<1	0.97	1.58	1.79	0.56	0.27

*Note that this table should not be used as an indicative guide of status (see Table 9 for indicator evaluation outcomes in full per sub-basin) as there can be small discrepancies between the results in this table and the full indicator results. This discrepancy arises from the fact that the CHASE integrated assessment utilises the mean value for generating the Contamination Scores (contamination ratios) that are then applied in the integration process (as shown in Table 7) to determine the general main drivers of overall status whereas the indicator evaluations present the mean values and the confidence limit on the mean value, where the threshold value is failed if that confidence limit exceeds the threshold value not the mean value alone (see indicator reports for detailed figures on this issue).

important contributors (Table 7, shaded cells). It should however be noted that not all substances are currently monitored (or data not available) in all assessment units (see cells marked NM), and for certain substances it may be needed to spatially or temporally expand monitoring to give a more solid reflection of status. Still, while there are gaps in the current data, the overview of the substances or substance groups that have the most significant influence on the integrated assessment, can be informative.

An overview of the outputs from the integrated assessment of hazardous substances for all assessment units is provided in Annex 3. Similarly, in Annex 3 an overview map of the integrated hazardous substances status and respective confidence is provided at HELCOM assessment units Level 4 (i.e., more and smaller assessment units at which each independent indicator is commonly evaluated). The most striking change from the scale of assessment presented above is the fact that GES appears to be achieved more commonly, yet the accompanying confidence in the evaluation is also markedly reduced. In addition, areas achieving GES are often outlined by areas of sub-GES status, in particular outer coastal areas that are commonly only then evaluated by a single indicator. The evaluation presented above at Level 3 thus appears most appropriate.

Polybrominated diphenyl ethers (PBDEs)

Polybrominated diphenyl ethers (PBDEs) have mainly been used as flame retardants in certain fabrics, plastic materials and polyurethane foams, but also to an extent in the automotive and electronics industries. Studies examining sources, emissions and pathways specific to the Baltic Sea are relatively scarce (scarce even at the European level), however there is evidence of volatilisation to air via usage and from landfills and destruction of PBDE-containing products, as well as contributions to land (landfills and destruction) and water (via Waste Water Treatment Plants, WWTPs). Materials related to the construction industry are considered to be a significant standing potential source of PBDEs (i.e., releases from them when in use and in particular when disposed of). All of these sources act as potential points of contamination for the Baltic Sea as pathways may be direct (e.g., effluents from coastal WWTPs) or indirect via run off or atmospheric deposition (including long-range transport). An overview and extensive reference material, including information about specific PBDE congeners, is provided in Polybrominated diphenyl ethers (PBDEs) in the Baltic Sea (Undeman and Johansson, 2020).

The use of polybrominated diphenyl ethers as flame retardant has been banned in most products in Europe since 2004, thus ecosystem recovery and achievement of GES in the future can be anticipated. PBDEs have been shown to decline in the Baltic Sea, for certain congeners and in certain areas (e.g., monitoring stations, PBDE indicator report) and the threshold value for sediment – where assessed, – achieves the threshold value. In biota though, the threshold value is exceeded, indicating sub-GES conditions. It should however be noted that the threshold value is under review via the appropriate evaluating committees (e.g., review and derivation of Environmental Quality Standards), as the threshold value currently applied for biota has been identified as potentially incompatible with other threshold values for the same substance (e.g., in other sampling matrices).

Tributyltin (TBT)

Tributyltin (TBT) in the Baltic Sea is mainly derived from anti-fouling paints applied to large ships but was also potentially common even on leisure boats. The use of TBT-based antifouling paints was regulated in most European countries (Champ, 2000) as early as in 1989 (Jokšas *et al.* 2019). In 1989 regulations banned the use of TBT-containing antifouling paints on vessels up to 25 m long (Council Directive 89/677/EEC). The Helsinki Convention, published in 1992, also introduced such a ban in the Baltic Sea region (Radke *et al.* 2008). Subsequently, the use of TBT in new antifouling system has been restricted in 2003 with the Regulation 782/2003/EEC (EU, 2003), followed by international ban on using harmful organotins in antifouling paints in 2008 by the International Maritime Organization (IMO 2001). After the ban on TBT in antifouling paints, few uses of organotins as pesticides (mainly phenyltins) are still legal. The major source is now its release from impacted sediments in harbour areas and shipping routes (dredging) and other historic uses of TBT-containing antifouling paints such as that associated with some leisure boats (Eklund *et al.* 2018, Lagerström *et al.* 2019).

TBT generally associates rapidly with sediments on entering the marine environment. The specific manner and rates of association are often linked with sediment properties. However, once bound to sediments TBT is persistent and poses a distinct risk to biota (e.g., the imposex effects included in the indicator but not integrated in the concentrations assessment). Studies show that TBT can persist in sediment for extensive periods, ranging from circa 1-9 years for oxic surface sediments (De Mora and Pelletier, 1997; Omae 2003) and even as long as circa 90 years in deeper anoxic sediments (Viglino *et al.* 2004). The high concentration sediments or port soils can in the future become the new sources of TBT, as the adsorbed organotins can be released from sediments into water column by resuspension or diffusion into the water column (Fent, 2006; Filipkowska *et al.* 2014). A detailed overview and summary of reference material related to TBT sources, persistence, and time lags for the recovery of GES is provided in (HELCOM ACTION 2021). The HELCOM indicator detects a limited number of improving trends in the assessment of biota (Imposex) but no clear trends, either improving or worsening, in concentrations of TBT at water or sediment monitoring stations (TBT indicator report).

Mercury (Hg)

Mercury has no specific biological functions and even relatively low levels can be toxic, with bioaccumulation also commonly occurring. Mercury (Hg) in the Baltic Sea has generally been heavily regulated in the Baltic Sea region (and globally) meaning that a significant contribution of the negative effects from mercury are due to historic inputs and the lingering effects of these. Mercury is currently legally used in some applications such as low-energy light sources, but its common use in several previous industries, including electrodes in paper bleaching and thermometers, has already been phased out with some phasing out actions currently ongoing (amalgams in dentistry). However, it is also important to acknowledge that there still remain inputs (or possible re-releases) from local and particularly global processes that have an impact on the Baltic Sea. Major current sources of mercury input are coal-fired energy generation, fossil fuels and waste combustion, all of which lead to atmospheric load and subsequent deposition to the Baltic Sea. The main pathways for mercury (as well as cadmium and lead) to enter the Baltic Sea are from highly industrialized and densely populated areas via atmospheric deposition and riverine input, as the mercury deposited on land can be washed off and transferred to the sea (Schneider *et al.* 2000; Knuuttila, 2009; Zaborska, 2014; Bełdowska *et al.* 2015; Senze *et al.* 2015; Jędruch *et al.* 2017; RemeikaitėNikienėa *et al.* 2018). In the most recent evaluation stations showing downward trends (i.e., decreasing concentrations, 13 in number) were near equally balanced by those showing worsening conditions (increasing trends, 8 in total) (Hg indicator report).

Copper (Cu)

Copper inputs to the Baltic Sea can be of natural origin (e.g. leaching from forest and other land areas) or from anthropogenic sources (e.g. antifouling paint and industries). Load estimations of Cu to the Baltic Sea from natural sources and human activities have been compiled by Ytreberg *et al.* (2022). The compilation included the following activities/sources: atmospheric deposition, riverine inputs, point sources (i.e. coastal industries and wastewater treatment plants), shipping, and leisure boating. Riverine inputs reflect the largest load contributor to the Baltic Sea, followed by the second major contributor that is shipping and leisure boats. There are thus significant inputs both to the coastal zone (river flow) and also in open sea areas of the Baltic Sea (Cu indicator report). Copper is an essential element for organisms but is toxic to marine species when concentrations exceed levels that are physiologically required (Campbell, 1995). Copper is accumulated by plants and animals. At high concentrations, copper becomes toxic, as it affects the metabolic processes of marine organisms. In addition to acute effects (e.g. mortality), chronic exposure to copper can lead to adverse effects on survival, growth and reproduction of individual organisms. This may in turn transform into changes at species and population level, impacting biodiversity and ecosystem health. In the current HELCOM indicator assessment, the first iteration of the indicator, only one station with a long data timeseries shows a distinct trend – a worsening in condition (Cu indicator report).

3.3. Changes over time for hazardous substances

Identifying and suitably classifying changes in the status for hazardous substances is complex. Some generalised trends are possible to identify and describe but more statistical or advanced approaches may be relevant for the future as a larger number of indicator evaluation and assessment outcomes become available over time. Additional complexity in exploring changes and trends in the assessment of hazardous substances comes from issues such as the potential for re-dispersal/transfer (e.g., from disturbed material) or when extrapolating point samples across large sediment areas or waterbodies. The existence of potentially long recovery time lags, and in certain instances monitored concentrations close to the GES threshold values also represent issues where careful interpretation is required. There are however some interesting trends to be explored and some encouraging signs within these, that measures have been effective towards the BSAP goals on the priority substances targeted.

3.3.1 Change in integrated assessment status between assessment periods

The changes in the results of the integrated assessment (CHASE) between the HOLAS II assessment period (2011-2016) and HOLAS 3 assessment period (2016-2021) can only be compared at a qualitative level, as no formal or statistical approach has been developed to compare these outcomes currently. The integrated assessment outcomes place each assessed unit into one of five categories dependant on the outcome contamination score as follows: High (0 to 0.5 contamination score values), Good (0.5 to 1), Moderate (1 to 5), Poor (5 to 10) and Bad (>10). The level between Good Environmental Status (GES) is drawn between Good and Moderate, thus only the categories High and Good reflect GES conditions. A direct comparison can therefore be made between the outcome categories to determine if there has been a change in category between the two assessment periods (Table 8).

Evaluating actual trends or changes in status is more complex than this overview alone provides, however, some interesting factors can be elaborated. Firstly, there are six open sea assessment units (sub-basins) where the status category has apparently improved between the two assessment periods. This trend may warrant further exploration towards future assessments, to understand if those sub-basins are also highly represented for stations that also show improving trends. Secondly, three sub-basins appear to show a worsening trend, however, this is quite likely due to the inclusion of new indicators or data making the likelihood of failing to achieve GES conditions stronger. This for example is clearly the case for the Gulf of Riga, where in HOLAS II the assessment was based on a single indicator (Cs-137) whereas in HOLAS 3 seven indicators (or substances/substance groups) are included in the integration process, four of which are responsible for driving the sub-GES condition. Lastly, confidence in the assessment is critical to consider in such comparisons. In all three instances where a deterioration in status category is apparent the current assessment period has a higher confidence value than the former period, reflecting the stronger availability of data, indicators, and key components for the integrated assessment. On the other hand, there's also an increase in the confidence level in some sub-basins, where an improvement in category is detected, which may support the suggested positive change. It should be noted though that there were changes made to the confidence calculation between the two assessment periods, while in general the new approach is unlikely to have elevated confidence assessments compared to HOLAS II. Regardless, the apparent trends of change in status shown in Table 8 should be treated with caution as not all underlying information is represented there (e.g., the constellation of specific indicator components and changes in those) that needs to be taken into account before making broad statements on the overall outcome.

3.3.2 Overview of indicator status

As described in section 3.1, the integrated assessment of hazardous substances generally indicates bad or poor (sub-GES) conditions. This sub-GES conditions are also in general driven by a few key members of the monitored priority substances: Polybrominated diphenyl ethers (PBDEs), tributyltin (TBT), mercury (Hg), and copper (Cu). This is particularly so in the 17 open sea assessment units. There is however another layer of status information that underlines this high-level integrated status evaluation. Table 9 provides an overview of each HELCOM core indicator utilised in the integrated assessment of hazardous substances (concentrations) by indicator, substance, or substance group and by sampling matrix (i.e., biota, sediment and water).

In general, the pattern observed in the current integrated assessment, as well as in the HOLAS II (2011-2016 assessment period) indicator overview, is also observed in HOLAS 3 (2016-2021 assessment period). There are also more indicators developed and utilised in the HOLAS 3 assessment and also available for being applied in more of the open sea assessment units (a slight increase in general) as compared to HOLAS II. The status assessment at the assessment unit level (open sea sub-basins) clearly shows the same pattern as identified in the integrated assessment, with PBDEs, TBT, Hg and Cu broadly being sub-GES in the vast majority of the open sea assessment units for one or several of the evaluated monitoring matrices (Table 9). These same substances (except for Cu that was not included in HOLAS II) were also major drivers of sub-GES conditions and the integrated assessment outcome in HOLAS II. One substances, however, for which there is a distinct change between HOLAS II and HOLAS 3, is Caesium -137 (Cs-137, the Radioactive substances HELCOM core indicator), which contributed significantly to the overall sub-GES outcomes of the integrated assessment for the 2011-2016 period (HOLAS II). In HOLAS 3 GES is achieved in all assessed sub-basins and in both the water and biota sampling matrices (Cs-137 indicator report), whereas in HOLAS II only a few sub-basins recorded GES conditions (only for biota) in more south-westerly areas of the Baltic Sea (e.g., the Kattegat or Kiel Bay). This change in status means that the radioactive isotope Cs-137 no longer acts as a major driver in the integrated assessment outcomes (for HOLAS 3). Despite many assessment units now also showing values close to pre-Chernobyl levels, due to the natural half-life of the isotope, the actual overall change in status across all assessment units is most strongly influenced by the development of new threshold values. The pre-Chernobyl levels threshold value, as applied in HOLAS II, is additionally presented within the indicator report, but the new threshold values were developed to align the indicator with the updated BSAP ecological objective of 'Minimal risk to humans and the environment from radioactivity' and resulted in new threshold values that represent a dose-based approach and consider the protection of the ecosystem and human health (described in detail within: Cs-137 indicator report).

With the exception of the significant change related to radioactive substances, as described above, smaller changes in assessment unit statuses do occur between HOLAS II and HOLAS 3 (for example the Kattegat is GES for anthracene in sediments in HOLAS II but sub-GES in HOLAS 3 or the Bornholm Basin was sub-GES in cadmium previously and is now GES in HOLAS 3). These, however, are not discussed further in detail as there is no solid or quantitative method in place to evaluate the meaningful nature of such changes, especially as the changes may also be influenced by changes in data availability. Some changes in status might also result from measurements being close to the threshold values across both periods, as even small fluctuations can appear to have a major status influence. Furthermore, at the sub-basin level, the status is also generally derived from multiple monitoring stations and those monitoring stations, in particular those with long data series ('full' data), offer a better understanding of the direction of trends.

Table 8. Overview and comparison of status outcome category from the integrated assessment of hazardous substances in the HOLAS II and HOLAS 3 assessment periods. The categories follow the order: High-Good-Moderate-Poor-Bad. Confidence is provided in brackets, where H = High, M = Moderate and L = Low. Change in category between the assessment periods is shown with arrows, where ↑ = improvement, → = no change in category, and ↓ = deterioration (lower category since previous assessment).

	HOLAS II (confidence)	HOLAS 3 (confidence)	Change
SEA-001 Kattegat	Bad (M)	Poor (H)	↑
SEA-002 Great Belt	NA (NA)	Moderate (L)	NA*
SEA-003 The Sound	Moderate (M)	Bad (H)	↓**
SEA-004 Kiel Bay	Bad (M)	Moderate (H)	↑
SEA-005 Bay of Mecklenburg	Moderate (M)	Moderate (H)	→
SEA-006 Arkona Basin	Bad (M)	Bad (H)	→
SEA-007 Bornholm Basin	Bad (M)	Poor (H)	↑
SEA-008 Gdansk Basin	Bad (M)	Bad (H)	→
SEA-009 Eastern Gotland Basin	Bad (M)	Bad (H)	→
SEA-010 Western Gotland Basin	Bad (M)	Bad (H)	→
SEA-011 Gulf of Riga	Moderate (L)	Bad (M)	↓**
SEA-012 Northern Baltic Proper	Bad (M)	Poor (M)	↑
SEA-013 Gulf of Finland	Bad (M)	Poor (M)	↑
SEA-014 Åland Sea	Moderate (M)	Good (H)	↑
SEA-015 Bothnian Sea	Bad (M)	Bad (H)	→
SEA-016 The Quark	Poor (L)	Bad (M)	↓**
SEA-017 Bothnian Bay	Bad (M)	Bad (H)	→

* No assessment applied in HOLAS II, thus no comparison possible.
** Apparent deterioration also likely reflects the inclusion of new data/indicators missing in the previous assessment.

Table 9. Detailed results for the hazardous substances assessment in the open sea assessment units, by core indicator, substances or substance group and monitoring matrix (biota, water or sediment). Red denotes that the substance fails the threshold value, and green denotes that threshold value is achieved. White circles are shown for units not assessed due to a lack of data. Abbreviations used for matrices: B=biota; S=Sediment, W=Water, for substances (or groups). NOTE: Table to be given a publication level re-make similar to HOLAS II version.

Substance or substance group	Matrix	Kattegat	Great Belt	The Sound	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Gdansk Basin	Eastern Gotland Basin	Western Gotland Basin	Gulf of Riga	Northern Baltic Proper	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Hexabromocyclododecane (HBCDD)	B	green					green	green	green	green	green	green	green	green		green		green
	S	green					green	green		green	green		green	green	green	green		green
Polybrominated diphenyl ethers (PBDEs)	B	red		red			red	red	red	red	red	red	red	red		red	red	red
	S	green					green	green		green	green		green		green	green		green
Polychlorinated biphenyls (PCBs): Non-dioxin-like-PCBs	B	green		green			green	green	green	green	green	green	green	green		green	green	green
Polychlorinated biphenyls (PCBs): Dioxin-like-PCBs, dioxins and furans	B	green					green	green			green		green	green		green	green	red
Polyaromatic hydrocarbons (PAHs): Benzo(a)pyrene	B		green	green		green	green	green										
Polyaromatic hydrocarbons (PAHs): Fluoranthene	B		green	green		green	green	green										
	S	green			green	green	green	green	green	green	green		green	green	green	green		green
Polyaromatic hydrocarbons (PAHs): Anthracene	S	red			red	red	red	green	red	green	green							
Polyaromatic hydrocarbons (PAHs) metabolites: 1-hydroxypyrene	B				red	red	red	green	red	red			green	green	green	green		green
Perfluorooctane sulphonate (PFOS)	B	green		green			green	green	green	green	green	green	green	green		green	green	green
	W									red								

Table 9. (Continued). Detailed results for the hazardous substances assessment in the open sea assessment units, by core indicator, substances or substance group and monitoring matrix (biota, water or sediment). Red denotes that the substance fails the threshold value, and green denotes that threshold value is achieved. White circles are shown for units not assessed due to a lack of data. Abbreviations used for matrices: B=biota; S=Sediment, W=Water, for substances (or groups). NOTE: Table to be given a publication level re-make similar to HOLAS II version.

Substance or substance group	Matrix	Kattegat	Great Belt	The Sound	Kiel Bay	Bay of Mecklenburg	Arkona Basin	Bornholm Basin	Gdansk Basin	Eastern Gotland Basin	Western Gotland Basin	Gulf of Riga	Northern Baltic Proper	Gulf of Finland	Åland Sea	Bothnian Sea	The Quark	Bothnian Bay
Mercury	B	red	red	red	red	red	red	red	red	red	red	red	red	red		red	red	red
Cadmium	B	red	red	red	red	red	red	red	red	green	red	red	red	red		red	red	red
	S	green			green	green	green	green	red	red	red		red	red	green	green		green
	W				green	green	green	green		green								
Lead	B	red	red	red	red	red	red	red	red	red	red	red	red	red		green	red	red
	S	green			green	red	red	green	red	green	green		green	green	green	green		green
	W				green	green	green	green		green								
Copper	S	red					red	red	red	red	red		red	red	red	red		red
Tributyltin (TBT) and imposex	B	red	red	red														
	S	red			red	red	red	red	red	red	red		red	red	red	green		red
	W					red	red	red		red								
Radioactive substances (Cs-137)	B	green			green		green	green	green	green	green			green	green	green	green	green
	W	green	green	green	green	green	green	green	green	green	green			green		green		green

3.3.3 Trends within indicators addressing hazardous substances

A large array of monitoring stations with a wide spatial spread across the Baltic Sea region are utilised in the assessment of hazardous substances (Figure 4, section 2.2.1 and also presented individually within each indicator report). These monitoring stations are the foundations of the indicator evaluations and subsequent integrated assessment outcomes, and can be categorised as either 'full' data (longer time series for which distinct trends can be examined) or 'initial' data (data of less < 2 years or not possible to assign trend evaluation to due for example to limits of quantification or less than values, see HOLAS II Hazardous substances Supplementary report, section 3.5). An overview of the station data can also be found in association with the HELCOM COMBINE database, as part of the ICES DOME view under the HELCOM Hazardous Assessment Tool.

In the current assessment 2,436 (2,298 when Cs-137 is excluded) monitoring stations were included, 663 (542 when Cs-137 is excluded) of which were 'full' data series. In HOLAS II the equivalent numbers were 2,517 monitoring stations (2,226 when Cs-137 is excluded) of which 559 (355 when Cs-137 is excluded) were 'full' data series (see Figure 9 and Annex 4). There has thus been a marked increase in monitoring stations with 'full' data series, thus offering a strengthening of the assessment as these stations provide the possibility to carry out stronger evaluations and define distinct trends within the analysis. In the equivalent HOLAS II summary, all stations with information for the radioactive isotope Cs-137 indicator data set were included, whereas in HOLAS 3 only those in the specific assessment period and thus utilised in the current assessment have been included. A similar approach utilising expert evaluation to determine trends for Cs-137 was used in both assessment periods. Thus, when comparing between HOLAS II and HOLAS 3 there has been a small increase in overall monitoring stations included in the assessment (2,226 to 2,298) but a relatively strong increase in stations achieving 'full' data series requirements (355 to 542). This generally represents an increase in monitoring but appears most strongly to reflect a significant increase in data reporting and availability for the current 6-year assessment period, including the benefits of longer time series due to the data reported in the 6 years post-HOLAS II.

The number of 'full' and 'initial' data series per indicator (substance or substance group) differs widely and in particular for monitoring in the sediment matrix. This is mainly due to the accepted regularity of sediment monitoring (i.e., commonly occurring once in a 6-year assessment cycle and thus not technically meeting the definition of a 'full' data series). Where 'full' data series exist and distinct trends could be identified, there are encouraging signs as 209 stations (119 when Cs-137 is excluded) show downward trends (i.e., decreasing concentrations of contaminants), 429 stations show no detectable (or stable) trends (398 when Cs-137 is excluded), while only 25 stations show signs of a deteriorating condition (increasing concentrations of contaminants). Focusing only on the 'full' stations then around 60% of them achieve GES (51% of all stations) and, when excluding Cs-137, around 21% exhibit improving conditions as compared to only circa 5% showed deteriorating trends. These trends also reflect progress since the HOLAS II assessment period (2011-2016), both in data availability/quality and potentially in status as 119 stations, as compared to 84 (Cs-137 is excluded) in HOLAS II, show trends towards improving status. Similarly, there is an increase in the number of stations showing a deteriorating trend between the two assessment periods (12 to 25), however these stations showing deterioration still only represent a relatively small number overall (<5% of overall 'full' data series).

The bulk of decreasing trends (i.e., improving status) were recorded in biota (112 stations, when excluding Cs-137), as compared to 3 in sediment and 4 in water (n of 'full' stations = 499, 26 and 17, respectively, see Annex 4). This is a positive sign, suggesting that bioaccumulation levels in certain places and for certain substances are decreasing which should also reflect an overall reduction of pressure (both effects and bioaccumulation potential) in biota, while it is also directly influenced by the total number 'full' data stations increasing. For most of the evaluated substances or

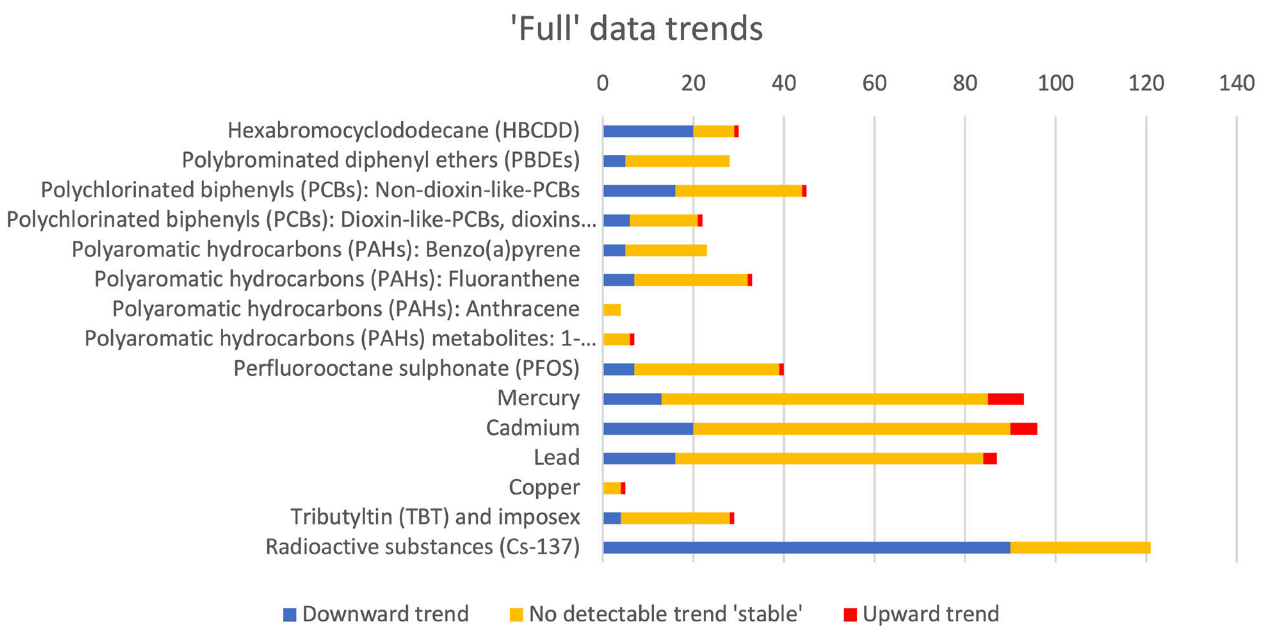


Figure 9. Trends in indicator substances or substance groups shown as counts of data series based on the type of assessment methodology applied. NOTE: Figure to be adapted at publication.

substance groups there are stations showing improving trends (downward trends in concentrations). However, for copper and anthracene, both monitored in sediments, no downwards trends are currently observed, a factor likely compounded by the nature of monitoring frequency. The increasing concentration trends (i.e., upward trends) are generally spread across all substances or substance groups, while a large number of the upwards trends are related to heavy metals (mercury, cadmium, lead), which could warrant some further study (Figure 9).

3.3.4 HELCOM indicators and relevant evaluations on hazardous substances

The following section briefly outlines the key indicator evaluations that make up the integrated assessment (e.g., HELCOM core indicators) and addresses other relevant topics (e.g., pre-core or supplementary HELCOM indicators), aspects under development (e.g., biological effects or sediment core evaluations), or aspects relevant in providing a broader overview of hazardous substances in the Baltic Sea (e.g., screening). Many of the sub-topics addressed below are also covered in HELCOM indicator reports, that can be found on the HELCOM indicator web page and offer further details to support the summaries provided below.

Perfluorooctane sulphonate (PFOS)

Perfluorooctane sulphonate (PFOS) is considered a global environmental contaminant. It is a persistent, mobile, bioaccumulating and toxic compound which besides strong developmental effects can also cause possible harm on the reproductive, and immune systems in organisms, as well as on their lipid metabolism. The substance has been produced since the 1950s and was used in the production of fluoropolymers, and as a surfactant to provide grease, oil, and water resistance to materials such as textiles, carpets, paper and coatings. PFOS has also been widely used in firefighting foams. Concentrations of perfluorooctane sulphonate are below the threshold value in biota in all the monitored areas. However, concentrations in water exceed the threshold value (EQS for water) where measured, which is reflected in the red area in the one-out-all-out (OOAO) summary map (Figure 10, see also PFOS indicator report). Where trends are possible to explore (e.g., where long and high frequency data series are available), most distinct trends identified are decreasing trends (e.g., lower concentrations) in biota, though one instance of an increasing trend is also detected. No general trends are detected across the entire region and most stations show no distinct trend currently. Decreasing trends appear most commonly in the southern and south-western sub-basins which provides a positive indication that exposure to the monitored PFOS substances is decreasing (PFOS indicator report).

Perfluorooctane sulphonate has been banned in the EU since 2008 for most of its used categories, but it has been replaced with other similar substances (per- and polyfluoroalkyl substances; PFAS), which still have widespread use. Most PFAS are highly persistent and bio-accumulating, and other PFAS (in addition to limited number of PFOS congeners currently addressed) are also a cause for concern. Since large volumes of such substances are also already included in the standing stock of certain products (e.g., fabrics, construction material, etc.) then future trends may also be determined by disposal/recycling and handling in substance/material lifecycles. Some per- and polyfluoroalkyl substances (PFAS) are listed on the EU candidate list on 'Substances of very high concern' under the REACH regulation (ECHA 2017). Inclusion of additional PFAS as core indicators should be considered in the future to keep track of their use and occurrence in the Baltic Sea region and this is one topic that the recently initiated EMPREST project will address.

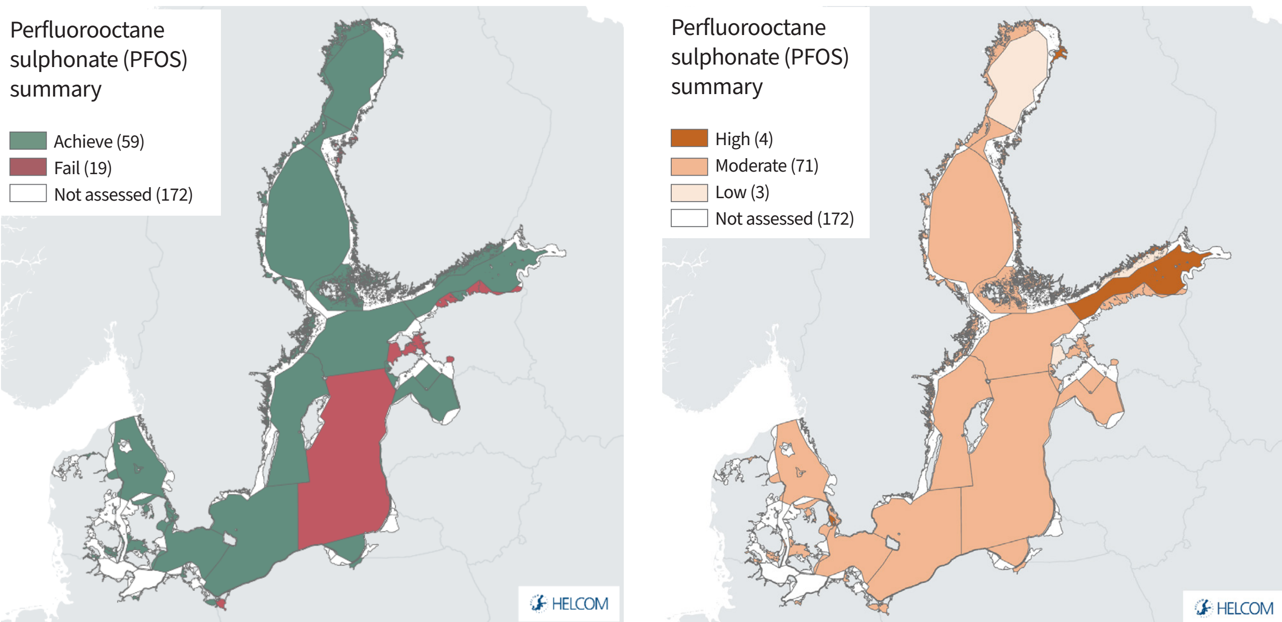


Figure 10. One-out-all-out (OOAO) Perfluorooctane sulphonate (PFOS) status evaluation (left) and confidence in the evaluation (right) based on monitoring in biota and water. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4). In general biota evaluations are almost all in GES while the vast majority of water evaluations are sub-GES (see indicator report).

Hexabromocyclododecane (HBCDD)

Hexabromocyclododecane (HBCDD) is a persistent, bioaccumulating and toxic substance with possible developmental and reproductive impacts. It is a globally used substance and has been detected in biota across the globe, including in remote areas such as the Arctic. HBCDD is a brominated flame retardant, which is used in insulation material for the construction industry and as textile coating to improve the fire resistance of materials. HBCDD has been on the Stockholm Convention list of chemicals since 2013, aimed to be eliminated from both production and use, while currently some uses for which specific exemption permits are required, are allowed. In biota, the levels of HBCDD are below the threshold value, which is set to protect the marine ecosystem and humans consuming fish from adverse effects (HBCDD indicator report). HBCDD concentrations are also below the QS threshold value for sediments, indicating that overall this substance achieves the GES (One-out-all-out combination of all matrix-threshold values per assessment unit, see Figure 11). Where stations with longer time series are available (mainly in biota) there is a fairly widespread trend showing decreasing concentrations across the region (see HBCDD indicator report), which is consistent with studies from Sweden that show increasing HBCDD concentrations from the 1970s and 1980s to the 2000s with subsequent improvements after that (Soerensen and Faxneld, 2022). Several other man-made brominated substances are also used in a wide range of products, often as flame retardants (e.g., decabromodiphenyl (DBDE)), and some have also been found in the environment (Swedish Chemicals Agency, 2023). In certain cases, little is known about the environmental (or human health) impact of these individual substances and an evaluation of the broader group of substances (e.g., brominated flame retardants) in any future review of priority substances may be relevant.

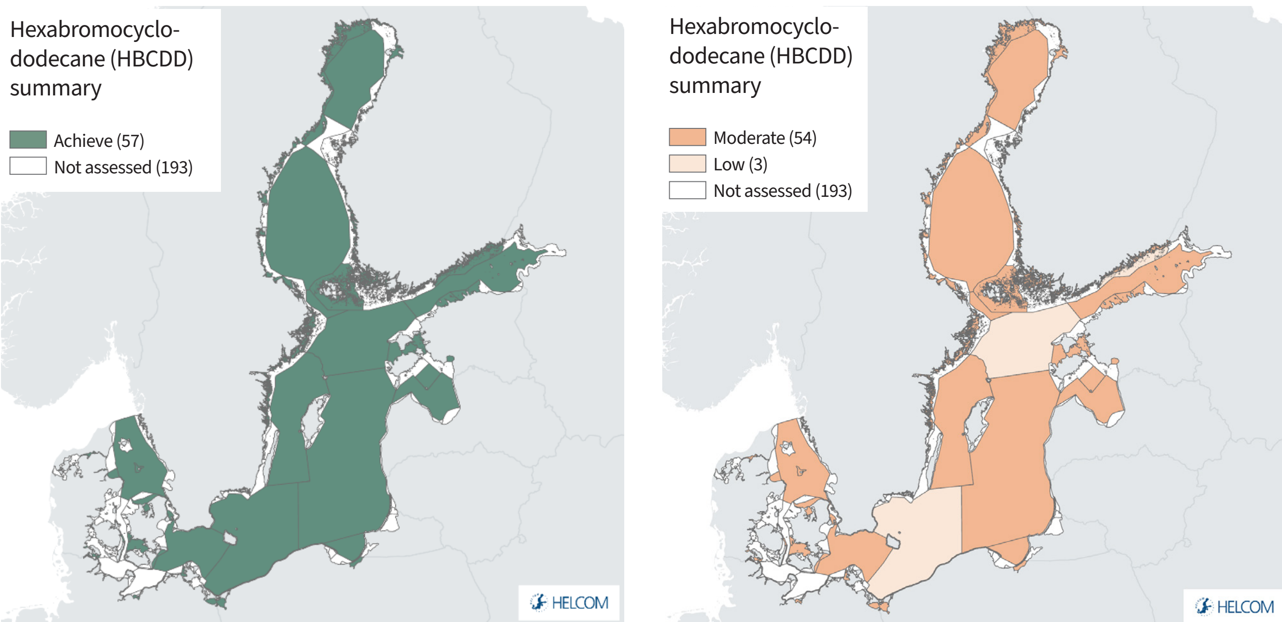


Figure 11. One-out-all-out (OOAO) Hexabromocyclododecane (HBCDD) status evaluation (left) and confidence in the evaluation (right) based on monitoring in biota and sediment. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Polybrominated diphenyl ethers (PBDEs)

Polybrominated diphenyl ethers (PBDEs) are persistent toxic substances, which bioaccumulate in the marine food web. In the current assessment, the sum of six PBDE congeners are compared to the threshold value. The threshold value for biota is an environmental quality standard set to protect both the marine ecosystem, and humans consuming fish from adverse effects. The threshold value in biota has been identified as being over-precautionary and is due for scientific re-assessment. Polybrominated diphenyl ethers fail the threshold value for biota in all areas where they are monitored, while in evaluated sediments the threshold value is achieved. This difference between the two sampling matrices results in the Good Environmental Status (GES, green) evaluation in the Åland Sea open sea sub-basin, as the area is lacking data from biota and the evaluation is based on sediments only (Figure 12). Concentrations of several PBDEs in the marine environment are declining (Soerensen and Faxneld 2022) and in the current evaluation downward trends (i.e., decreasing concentrations) are detected in a small number of monitoring stations for biota (where long and high frequency data are available for the assessment period). Such trends are generally only found in open sea areas, whereas the bulk of stations, especially in coastal areas, generally show no distinct trends (PBDE indicator report). Other man-made brominated substances are also used in a wide range of products, often as flame retardants, and some have also been found in the environment (Swedish Chemicals Agency, 2023). In certain cases, little is known about the environmental (or human health) impact of these individual substances and an evaluation of the broader group of substances (e.g., brominated flame retardants) in any future review of priority substances may be relevant.

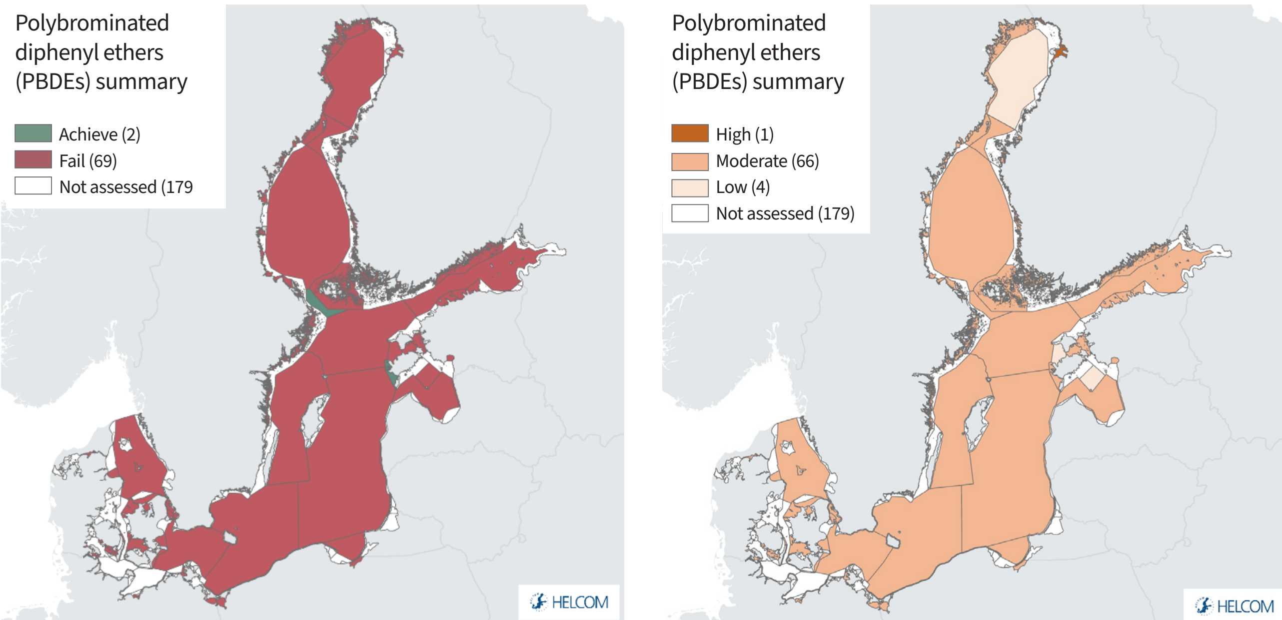


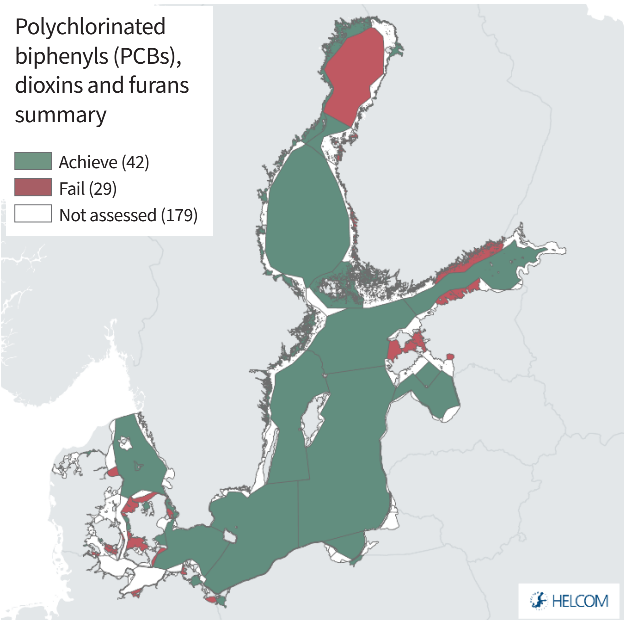
Figure 12. One-out-all-out (OOAO) Polybrominated diphenyl ethers (PBDEs) status evaluation (left) and confidence in the evaluation (right) based on monitoring in biota and sediment. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4). Evaluations in biota are exclusively sub-GES while those evaluations in water are in GES, thus where biota is not evaluated (e.g., the Åland Sea open sea sub-basin) GES is achieved.

Polychlorinated biphenyls (PCBs), dioxins and furans

Polychlorinated biphenyls (PCBs) are persistent toxic substances and bioaccumulate in the marine food web. The substances have been used in a wide variety of applications and manufacturing processes, especially as plasticizers, insulators, and flame-retardants. Polychlorinated biphenyls enter the marine environment mainly due to inappropriate handling of waste material or via leakages from transformers, condensers, and hydraulic systems. Dioxins (PCDD/Fs) are an unwanted by-product, often formed in industrial combustion processes, which is also found in several chlorinated chemicals (e.g., PCBs, chlorophenols, hexachlorophene, etc.).

HELCOM has recommended bans and restrictions on transport, trade, handling, use and disposal of polychlorinated biphenyls. The HELCOM Ministerial Declaration of 1998, and the 1995 'Declaration of the Fourth international conference of the protection of the North Sea' called for measures against persistent, bioaccumulating toxic substances like PCBs by the year 2020. PCBs have been on the Stockholm Convention list of chemicals since 2001, and measures are in place to eliminate their production and use in the industry, and to make sure they are not produced unintentionally as a by-product.

Non-dioxin-like PCBs were assessed in relation to a threshold value that is based on food safety, showing values above the threshold value in some coastal assessment units. In general, a similar pattern was recorded for dioxins, furans, and dioxin-like PCBs, when assessed against an EQS based on levels in foodstuffs (WHO TEQ). The bulk of monitoring stations with longer term or higher frequency data series showed no distinct trends, however a good number of stations also showed decreasing trends (decreasing concentrations) with only two showing a deterioration (Figure 13, PCB indicator report).



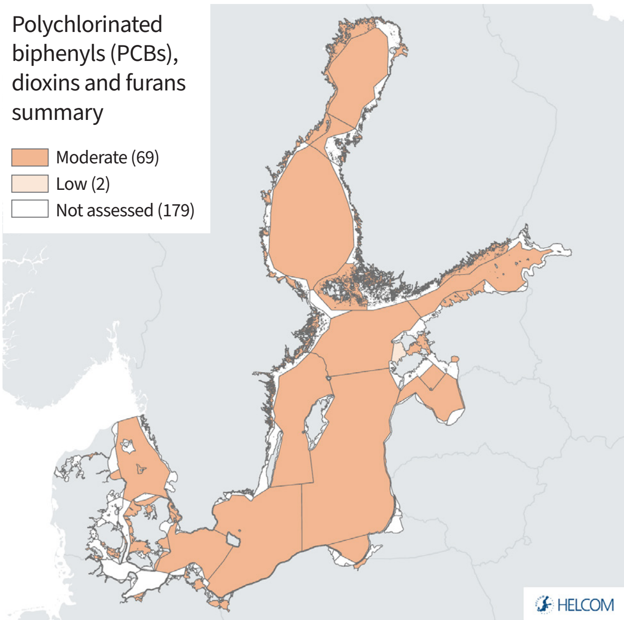
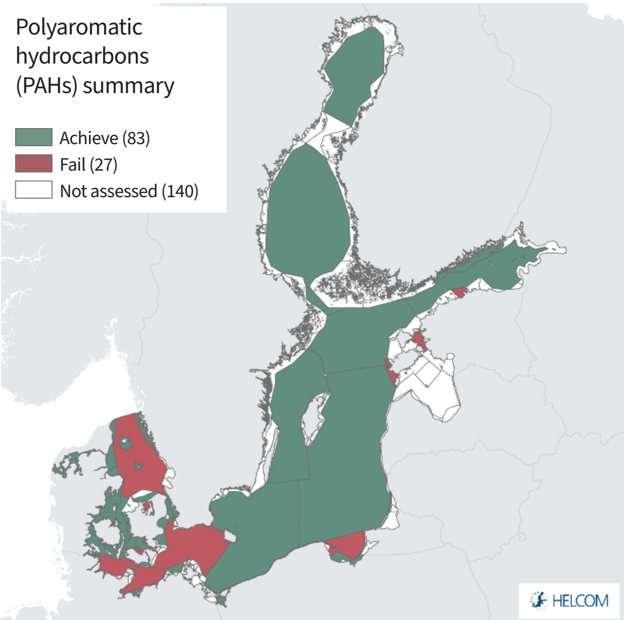


Figure 13. One-out-all-out (OOAO) Polychlorinated biphenyls (PCBs) status evaluation (left) and confidence in the evaluation (right) based on monitoring in biota and sediment. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Polyaromatic hydrocarbons (PAHs) and their metabolites

Polyaromatic hydrocarbons (PAHs) with low-molecular-weight, such as anthracene, are acutely toxic to many marine organisms. High-molecular-weight PAHs, such as benzo(a)pyrene, are less toxic but have greater carcinogenic potential. PAHs enter the marine environment via the release of crude oil products and can be emitted during the incomplete combustion of all types of fossil fuels – coal, oil, and gas or even during wood or waste incineration. Benzo(a)pyrene and fluoranthene in biota are generally monitored in more south-westerly areas and in both cases the majority of assessment units achieve Good Environmental Status (GES). Most of the longer time series stations have no distinct trend, while a number of stations for both substances showing downward trends (i.e., decreasing concentrations) are also recorded. In sediment monitoring fluoranthene generally achieves GES, though some stations in coastal areas record sub-GES condition, whereas a number of both coastal and open sea assessment units in the southwestern region are sub-GES for anthracene. No obvious trends are detected in the sediment monitoring, partly due to the nature and frequency of monitoring occurring in sediments (PAH indicator report). When summarised by applying the one-out-all-out (OOAO) approach, a few open sea areas (mainly in the southwestern region) as well as some coastal assessment units are sub-GES (Figure 14). PAH metabolites are addressed below in association with the sub-topic on biological effects.



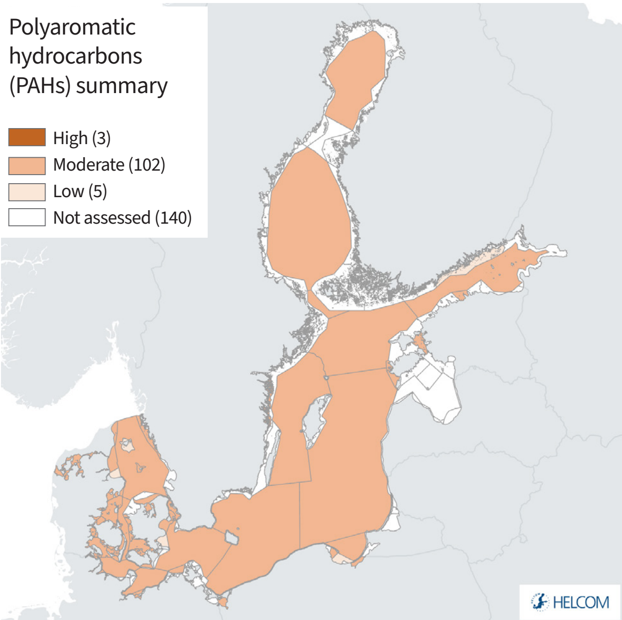


Figure 14. One-out-all-out (OOAO) Polyaromatic hydrocarbons (PAHs) status evaluation (left) and confidence in the evaluation (right) based on monitoring in biota and sediment. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Tributyltin (TBT) and imposex

Tributyltin (TBT) is one of the organotin compounds that has been shown to be very toxic to marine life, resulting in changes in oyster shells and interference with the marine gastropods female reproductive organ. This effect is known as imposex, causing sterility in some sensitive species. TBT is bioaccumulated in marine organisms and causes harmful effects that mainly depend on the level of its final concentration in the tissues. High levels of TBT can also accumulate in top predators in the environment (Strand et al, 2005; Law et al, 2012). TBT and triphenyltin (TPT) were introduced in antifouling paints in the 1960s, but soon after the detrimental effects on marine organisms were discovered. This led to a ban on the use of these paints on pleasure boats and was eventually followed up with a total ban on TBT in antifouling paints (782/2003/EC (EC, 2003)) effective from 2008 (OSPAR, 2014). TBT in water is predominantly monitored in more coastal areas in the southern and southeaster areas of the Baltic Sea, where assessment units almost exclusively fail to achieve Good Environmental Status (sub-GES). Evaluation in sediments is more targeted towards open sea assessment units, however, in the majority of the assessment units evaluated the condition is found to also be sub-GES (Figure 15). Only limited distinct trends are identified, these mainly occurring in biota (imposex, to be addressed separately under the sub-topic biological effects), though these few trends do appear to show signs of improving conditions (TBT indicator report). TBT is highly persistent and hard to degrade, thus the levels of TBT in sediments can persist and cause effects on species such as on marine gastropods, indicating that historic pollution is still impacting the Baltic Sea. Other uses of organotins than directly from antifouling paints and the re-release from previously contaminated sediments (e.g., due to dredging or runoff from harbour/port areas) may need careful surveillance to maintain any downward trends in concentrations within the Baltic Sea.

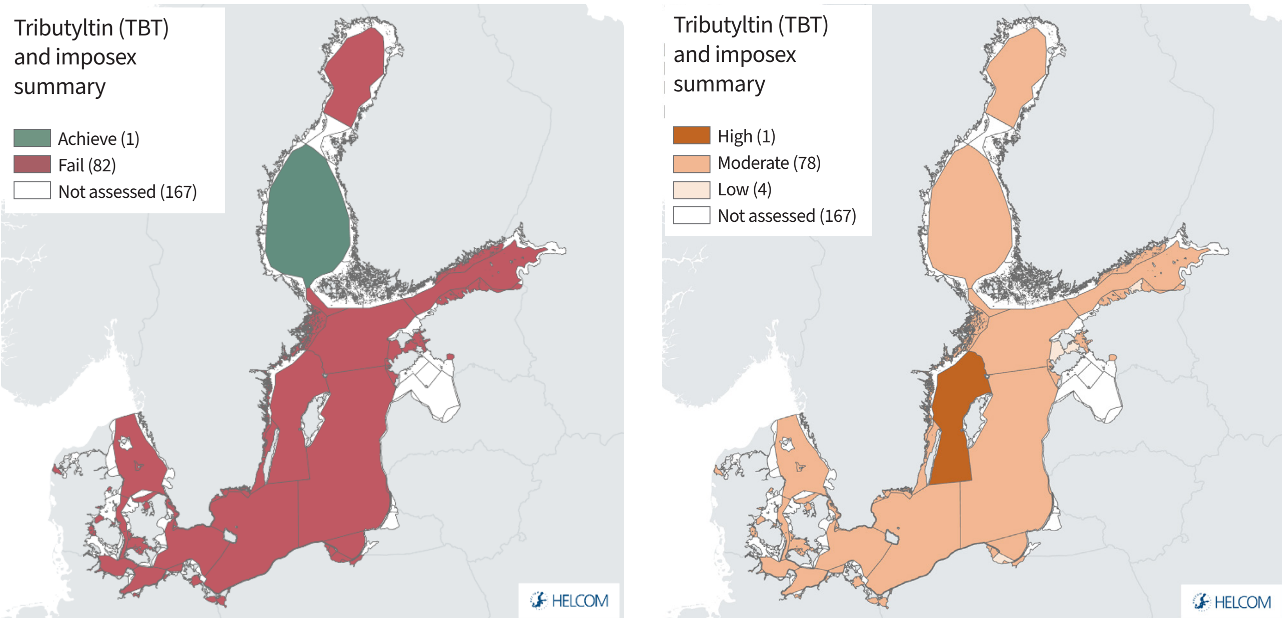
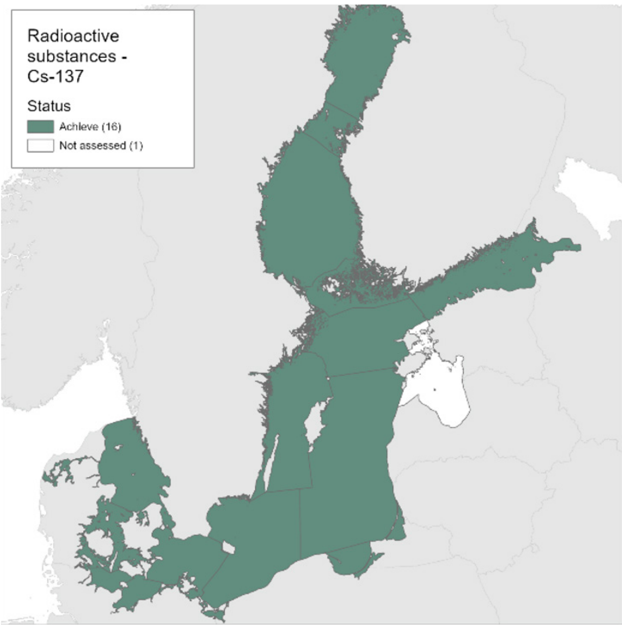


Figure 15. One-out-all-out (OOAO) Tributyltin (TBT) status evaluation (left) and confidence in the evaluation (right) based on monitoring in biota and sediment. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Radioactive substances (Cs-137)

Caesium-137 (Cs-137) is the greatest contributor of artificial radionuclides to the Baltic Sea. The radionuclides were deposited in the Baltic Sea after the Chernobyl nuclear power plant accident in 1986. Since the accidental release, it has bio-accumulated in marine flora and fauna and has been deposited in marine sediments. Cs-137 emits ionizing radiation, which can have effects at the cellular level and lead to internal damage of organisms. The concentrations in biota (fish) and water have decreased from the high values in the 1990s in all sub-basins due to the natural half-life of Cs-137. In HOLAS II (the 2011-2016 assessment period), the concentrations of radionuclides measured in fish from a few open sea sub-basins in more south-westerly areas were below the threshold value, while the trends in both water and biota was towards achieving the established threshold values (a threshold value established to represent pre-Chernobyl levels, HELCOM 2018c). In this assessment period (HOLAS 3) all evaluations of all assessment units and in all matrices achieved the threshold values applied (Figure 16). This is in the main part due to a change in the threshold values applied during HOLAS 3, as new threshold values utilising a dose-based approach with relevance to environmental and human health were developed to better address the ecological objective of the updated Baltic Sea Action Plan of 2021 'Minimal risk to humans and the environment from radioactivity'. This should not however detract from the fact that due to the steady half-life of radioactive decay, the concentrations have fallen further, and in several assessment units (for biota and water) evaluations occur below the previously applied 'pre-Chernobyl levels' threshold values (Cs-137 indicator report).



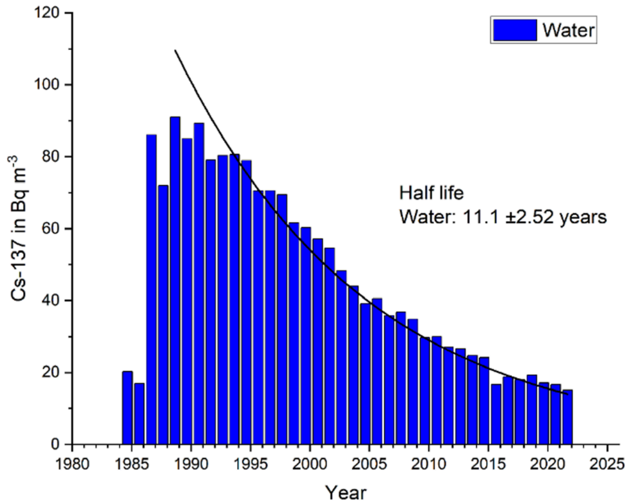


Figure 16. One-out-all-out (OOAO) Radioactive substances (Caesium, Cs-137) status evaluation (left) based on monitoring in biota and water, and decreasing trend due to half-life in water (right). The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Mercury (Hg)

Heavy metals, such as mercury (Hg), are naturally occurring substances, though at elevated concentrations they can cause harm to the environment. Although inputs to the Baltic Sea have been reduced as bans or strict regulations are applied, mercury (Hg) persists. The main remaining inputs come predominantly from waste or fossil fuels combustion and end up spread out in the environment via long range atmospheric deposition. Mercury is toxic to wildlife and humans even at relatively low levels. The severity of the effect mainly depends on the concentration at which exposure occurs and how much of it accumulates in the tissues. When heavy metals bioaccumulate in tissues, they can cause different biological effects on the individual organism, which transform into changes at the population, then species level, and finally affect biodiversity and ecosystem functioning.

Mercury (Hg) is one of the most toxic metals (UNEP 2013, 2019) and it has no known essential biological function. Even low levels of Hg in the body can lead to disruptions of important biochemical processes, and irreversible disorders of the nervous system and brain functions (Axelrad *et al.* 2007). Mercury has hepatotoxic, embryotoxic and mutagenic properties and may lead to cardiovascular disorders (Roman *et al.* 2011). Mercury is a stable and mobile element that accumulates in living organisms and biomagnifies in the food web, thus the toxic effect of exposure to Hg may be enhanced at higher levels in the food chain (Kwasigorch *et al.* 2020). The toxicity of Hg depends on the form in which the element occurs. Its labile forms can be more easily transformed and absorbed by organisms, whereas stable forms are not bioavailable (Kwasigorch *et al.* 2020). The most toxic form of this metal is highly bioavailable methylmercury (MeHg), which is formed by a bacterial process called methylation (Boeing 2000; Kwasigorch *et al.* 2020). Methylmercury has high affinity for protein and is stored in protein rich tissues like muscle tissue.

The current indicator evaluation is based on monitoring in biota (fish and mussels), and a failure of Good Environmental Status (sub-GES) is determined in almost all assessment units where data is available (Figure 17). The majority of monitoring stations where long time series are available currently show no distinct directional trend, while the few stations with directional trends show more decreasing (improving conditions) than increasing trends (worsening conditions or increasing concentrations, Hg indicator report).

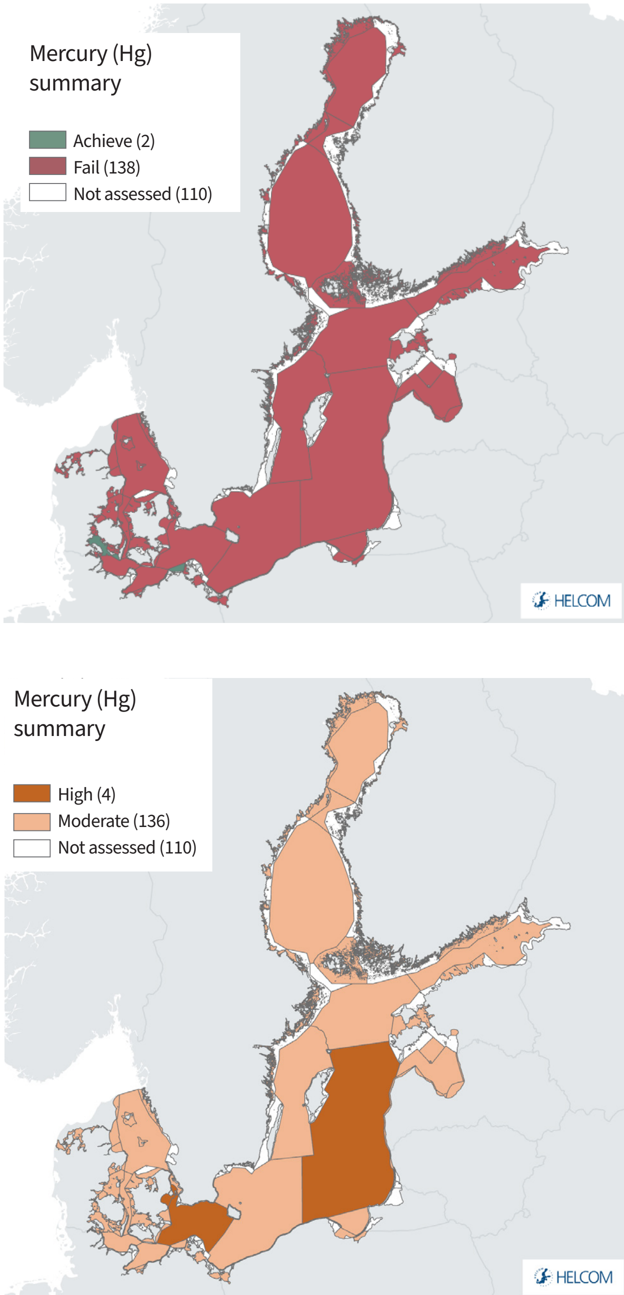


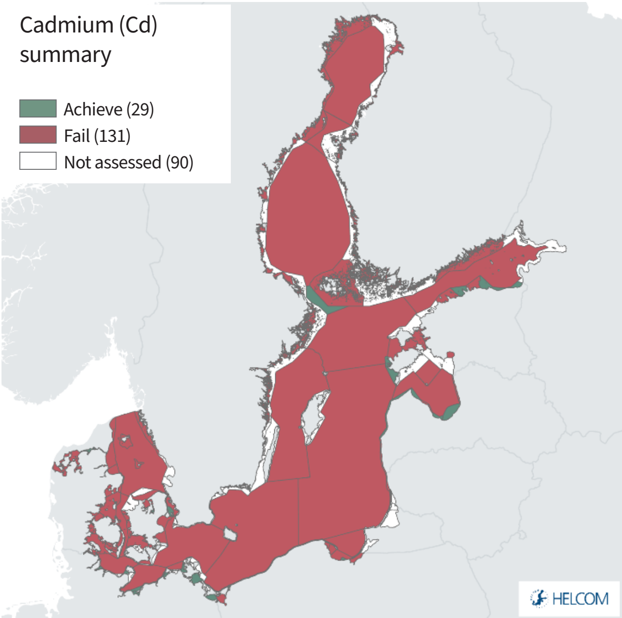
Figure 17. Mercury(Hg) status evaluation (top) and confidence in the evaluation (bottom) based on monitoring in biota. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Cadmium (Cd)

Cadmium (Cd) is a heavy metal toxic to wildlife and humans and can cause harm to marine organisms even at low levels. Although regulations to reduce the releases of cadmium to the environment are in place, emissions still occur from combustion activities (e.g., fuel), batteries, fertilizers, fireworks, and certain paints. In the marine environment the severity of the effects mainly depends on the concentration level at which exposure occurs. cadmium is known to biomagnify, i.e., the concentrations increase upwards through the food web, and this reflects a transfer through multiple species. When heavy metals bioaccumulate in tissues, they can also cause different biological effects, which can transform into changes at the population, then species level, and finally affect biodiversity and ecosystem functioning.

Cadmium as a chemical element is relatively sparse in the earth's crust, but significant amounts of it have been introduced into the environment as a result of human activities. It is relatively widely used in industry for the production of dyes, stabilizers of plastics, electroplating protective coatings, solders and alloys, and cadmium rods. It is also used in the production of nickel-Cadmium alkaline batteries, fireworks, and fluorescent paints. Chemical fertilizers (e.g. superphosphates) are a significant source of cadmium in the environment, as cadmium is a common element (often as a contaminant) in many phosphate-rich minerals fertilisers are produced from. Fuel combustion processes are also a very important source of cadmium. Once introduced into the environment, cadmium remains in constant circulation. It causes the greatest damage to organs in which it bioaccumulates easily in, for example fish liver. Cadmium can also damage DNA and is therefore considered carcinogenic.

Where monitored in water, the cadmium concentrations are commonly below the threshold value (i.e., suggest Good Environmental Status, GES), particularly so in the open sea assessment units. However, monitoring in water is generally limited to a small number of assessment units and monitoring in sediment and biota is more broadly distributed across the Baltic Sea. Threshold values in sediment and especially in biota are generally not achieved (i.e., sub-GES) and thus the overall one-out-all-out (OOAO) evaluation when all of these monitoring matrices is combined is generally sub-GES across the region (Figure 18). While many stations with longer or higher frequency time series show no distinct trends, there are also some stations that show downward trends (i.e., decreasing concentrations). These trends are most common in biota, but can also be detected in a few stations where water is monitored, offering some indication of improving conditions (Cd indicator report) in the region.



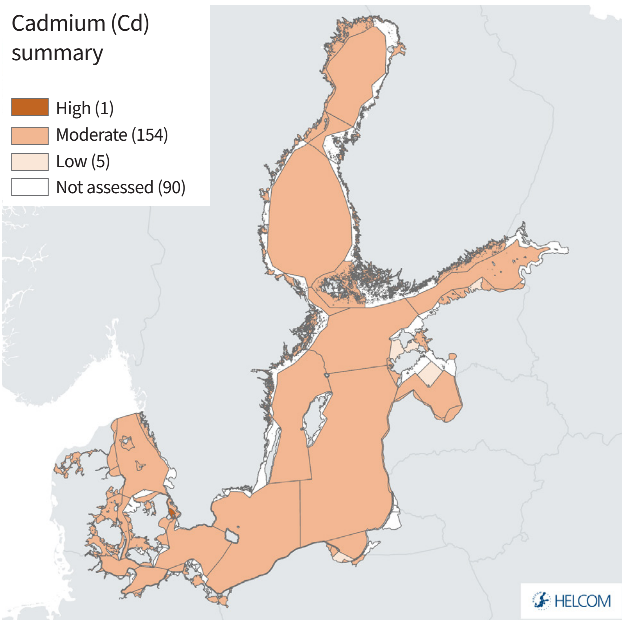
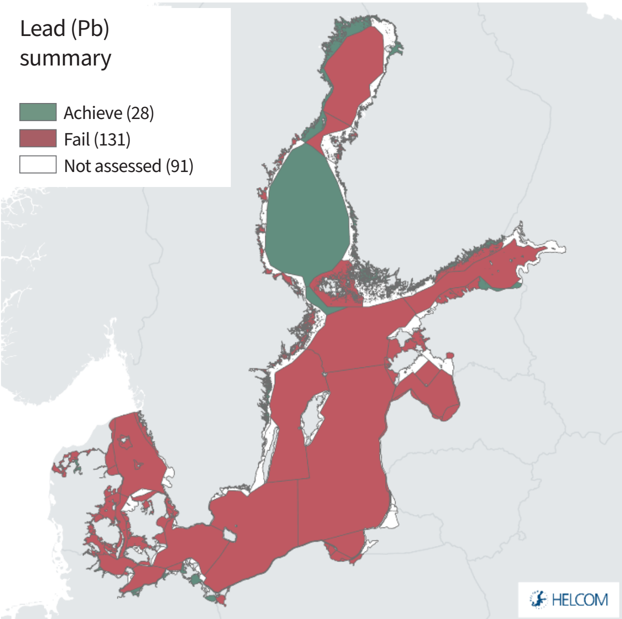


Figure 18. One-out-all-out (OOAO) Cadmium (Cd) status evaluation (top) and confidence in the evaluation (bottom) based on monitoring in biota, water and sediment. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Lead (Pb)

Lead (Pb) is a heavy metal toxic to wildlife and humans and can be harmful to organisms even at low levels. The severity of the effect mainly depends on the concentrations organisms are exposed to and the amount that accumulates in tissues. When heavy metals bioaccumulate in tissues, they can cause different biological effects in the individual organism, which transform into changes at the population, then species level, and finally affect biodiversity and ecosystem functioning. Lead can cause increased blood pressure and cardiovascular problems in humans. Long-term exposure to high levels of lead can affect the neurological system. Lead is a metal that is not essential for life processes and at high concentrations proves acutely toxic to most organisms. Compared to other metals lead is rather immobile in the environment but still, its biogeochemical cycling is greatly perturbed by human activities. Regulations have been implemented, and releases of lead have greatly decreased in the last decades. However, some releases of lead, for example from combustion activities, remain a relevant source of contamination for the marine environment.

Lead is monitored in water, biota and sediment, and in all cases, there is a mixture of assessment units failing and achieving the threshold value (i.e., in Good environmental Status (GES) and sub-GES). Monitoring in the water matrix is applied more often in the coastal areas in the southern and south-eastern regions, with biota and sediments commonly being evaluated more broadly across the region. When all matrices are combined using a one-out-all-out (OOAO) approach, the general pattern is sub-GES (Figure 19). There is however variation across the region between and within the sampling matrices status evaluations, and also between stations making up the assessment unit level status evaluation. Overall, there is a large number of stations with longer term time series data that show no detectable trends, while a good number of stations also show downward trends (i.e. decreasing concentrations), especially in biota. There are relatively few trends indicating a worsening status for lead (Pb indicator report).



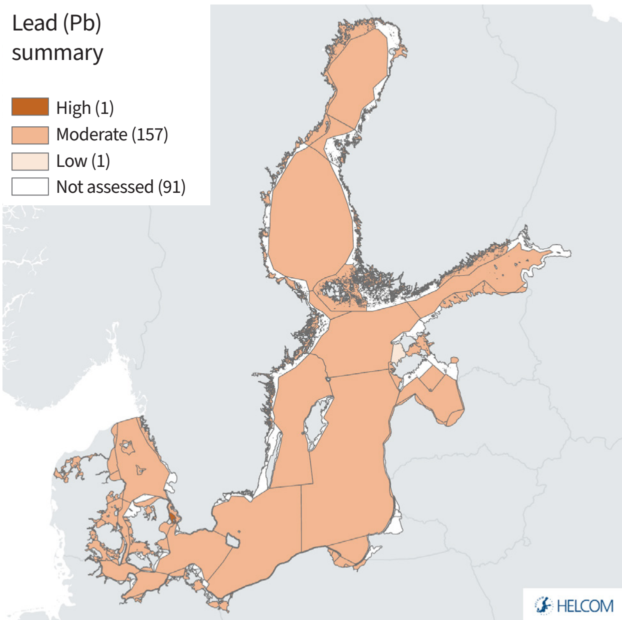


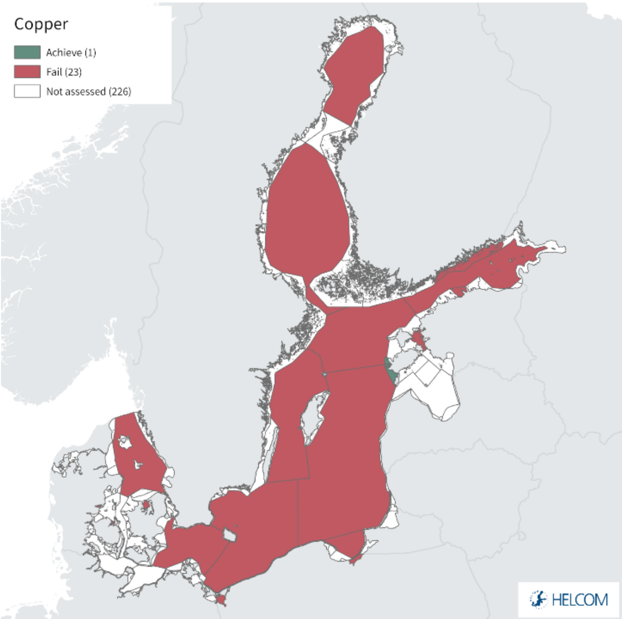
Figure 19. One-out-all-out (OOAO) Lead (Pb) status evaluation (top) and confidence in the evaluation (bottom) based on monitoring in biota, water and sediment. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Copper (Cu)

Copper is an essential element for organisms but can be toxic to certain marine species when concentrations exceed levels that are physiologically required (Campbell, 1995). Copper is bioaccumulated by plants and animals and can affect metabolic processes of marine organisms at high concentrations. In addition to acute effects (e.g. mortality), chronic exposure to copper can lead to adverse effects on survival, growth and reproduction of individual organisms. This may in turn transform into changes at species and population level, impacting biodiversity and ecosystem health.

Copper in the Baltic Sea comes from a number of sources, with the two largest inputs being riverine loads and maritime activities (ships and leisure boats, Ytreberg *et al.* 2022). Riverine load originates from natural and anthropogenic sources, though apportioning this to one or the other is complex and poorly understood. Initial (and sub-regional) studies suggest that leaching from forest lands, urban stormwater, and agriculture represent significant contributors (Ejhed *et al.* 2010). Copper (as cuprous oxide) is the dominating biocide in antifouling paints used on ships and leisure boats (Amara *et al.* 2018), but the release rate from the coating to the ambient water can vary greatly (Jalkanen *et al.* 2021). Copper from these antifouling paints is generally directly released to the marine environment and has been shown to be widely in bioavailable form (Sandberg *et al.* 2007), thus it reflects a major potential source capable of causing impacts.

The evaluation of copper concentrations (reflecting also organic carbon effect on bioavailability) in the Baltic Sea marine environment is new for this assessment period (HOLAS 3, 2016-2021) and available data provides a broad spatial overview, with the majority of monitoring stations falling in open sea sub-basins. In general, long period and high frequency monitoring stations are limited (in part due to the standard sampling frequencies applied for sediments) and there is a widespread failure to achieve Good Environmental Status (sub-GES) across the region (Figure 20). In certain areas the natural background levels are also critical to comprehend as the applied threshold value and natural concentrations may be closely aligned, requiring additional analyses or studies (Cu indicator report).



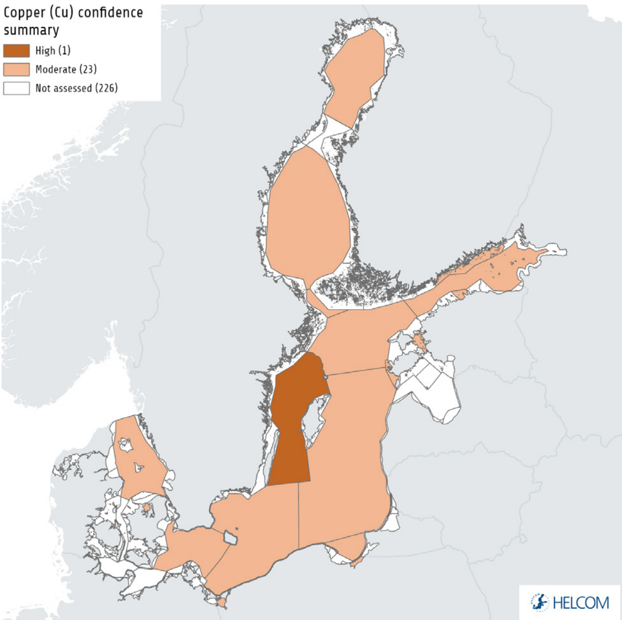


Figure 20. Copper (Cu) status evaluation (top) and confidence in the evaluation (bottom) based on monitoring in sediment. The assessment is carried out using Level 4 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4).

Pharmaceuticals (focusing on Diclofenac)

Pharmaceuticals are a large group of substances that are increasingly important both from a human health and an environmental perspective. Pharmaceuticals and other emerging organic micropollutants are more frequently being detected in wastewater treatment processes (e.g., Wastewater Treatment Plant (WWTP) influents, effluents, and sludges) and even in the marine environment, raising concern about the potential for such new and emerging substances to accumulate at harmful levels. Pharmaceuticals are a somewhat exclusive group of substances due to their role in society, often providing vital medical requirements for humans or animals. As with other hazardous or potentially hazardous substances, the pharmaceuticals may be possibly replaced with other more environmentally friendly options, however their key role in human health services is often also a vital consideration. Pharmaceuticals usually find their way to the Baltic Sea via diffuse sources such as the urine and faeces of humans and animals, as well as the inappropriate disposal of unused medical products into sewers. Municipal wastewater treatment plants are considered a major pathway for their introduction to the aquatic environment, with an estimated release of about 1,800 tons of pharmaceuticals per year to the Baltic Sea. Furthermore, current wastewater treatment processes are effective at removing only a few of the detected pharmaceuticals (UNESCO and HELCOM 2017).

A more recent overview of pharmaceuticals (and other micropollutants) in WWTP processes identified antimicrobial and antiparasitic substances, anti-inflammatory and analgesic substances, and hormones and hormone antagonists (of 11 commonly occurring groups) as among the groups of substances most commonly occurring in influent, effluent and/or sludges (supported by the Interreg CWPharma project, HELCOM 2022). Of the antimicrobial and antiparasitic substances group, 24 substances were detected in in at least one sample, and this included, amongst other substances, four antibiotics that occurred at regular frequencies (i.e., were recorded in many of the samples for which they were analysed) and were also on the EU Water Framework Directive (WFD) Watch list (Commission Implementing Decision (EU) 2018/840). In the recent review several of these substances also exceeded the preliminary threshold values (Environmental Quality Standards) set for them, indicating potential cause for concern (HELCOM 2022). A similar pattern is observed across all 11 commonly occurring groups, where certain substances occur at relatively high concentrations regularly in large numbers of the samples taken, and in several cases these substances are recorded at elevated concentrations in WWTP influent and effluent waters and in sludges. These include for example, furosemide or metoprolol from the cardiovascular agents category. Such findings can be highly informative not just in identifying concentrations and evaluating the risk of environmental conditions being impacted (e.g., sludge disposal or use may act as a new source or substances not degraded and passing through WWTPs may enter the Baltic Sea) but can also inform us on required legislative changes or the need for improvements, such as investments into new or improved WWTP technologies, to prevent their release into the environment (HELCOM 2022).

Within the anti-inflammatory and analgesic substances category, a number of widely used substances, such as Diclofenac, Ibuprofen, Ketoprofen, or Naproxen, were regularly recorded at elevated concentrations throughout the WWTP process. (HELCOM 2022). In order to carry out any specific actions or come up with measures though, there needs to be enough data and scientific knowledge proving the environmental risks associated with the substances, which is still missing for many organic micropollutants. Diclofenac is one such substance where sufficient data and knowledge does exist to establish threshold values indicative of Good Environmental Status (GES), thus determining concentrations or levels below which harm to the marine ecosystem does not occur. For diclofenac, the concentrations commonly recorded in WWTP effluents exceeded such threshold values, suggesting that inputs of this substance are a risk for the marine environment (HELCOM 2022). Diclofenac mainly enters the Baltic Sea via municipal WWTPs, with excretion of ingested (and not transformed) products being the major contributor, however topical creams may also be significant contributor. Other potential sources include incorrect disposal (i.e., disposal to the sewer system rather than medicine take back systems, where they are available), and municipal waste (Undeman, 2020).

Diclofenac concentrations in EU surface waters have previously been identified to exceed the predicted no effect concentration (e.g., Loos *et al.* 2018). This is in alignment with the UNESCO and HELCOM (2017) and Graumnitz and Jungman (2021) reports that identify diclofenac as one of the active pharmaceutical ingredients (APIs) detected most commonly within surface waters in the Baltic Sea region. Moreover, according to the UBA database on pharmaceuticals in the environment (UBA 2021), diclofenac is the API with the highest number of both database entries and positive detections in surface waters reported from the Baltic Sea coastal countries. Diclofenac is one of the most used and most widely sold anti-inflammatory and analgesics in the Baltic Sea region and it has been utilised for an extended period of time, where sales trends and prescriptions products are often high and changes in one are often counterbalanced by the other (Undeman, 2020).

The HELCOM pre-core indicator on diclofenac targets the development of a status evaluation of the occurrence and concentrations of diclofenac in the Baltic Sea marine environment. The evaluation is applied against the latest threshold value proposals (currently pending review and approval under the Environmental Quality Standards setting procedure, European Commission (EC) 2021 Draft EQS Datasheet: Diclofenac). Good Environmental Status (GES) was achieved in terms of diclofenac concentrations in marine waters in seven of the 39 evaluated assessment units and failed in 15 (sub-GES). Unfortunately, as the limit of detection was higher than the EQS value in some cases, the status was considered uncertain 11 for 17 assessment units (Figure 21). Concentrations in biota achieved GES in 13 of the 23 evaluated assessment units and were uncertain in 10. However, information on concentrations in biota is very scarce, and the dataset did not contain a single positive detection. While further monitoring (and also analytical improvements) is clearly needed to evaluate this topic more strongly, there are signs that diclofenac concentrations exceed acceptable levels in the marine environment and more information is needed, in particular to evaluate trends, to understand if this substance is likely to develop to concentrations that may cause harm to the environment (Diclofenac indicator report).

Future work is needed to gather a better overview of pharmaceuticals, including diclofenac, in the marine environment, and understand their impacts or risk. Such work will need a combination of increased monitoring and a scientific understanding of toxicity, prolonged exposure effects, and threshold values indicative of GES for those identified as of priority. Understanding the sources, pathways, distribution, and fate of these substances will also be key to management action across the lifecycles of these important healthcare compounds. The work towards BSAP action HL1 (Information Box 1) and other actions dedicated towards pharmaceuticals will likely support such developments in the future.

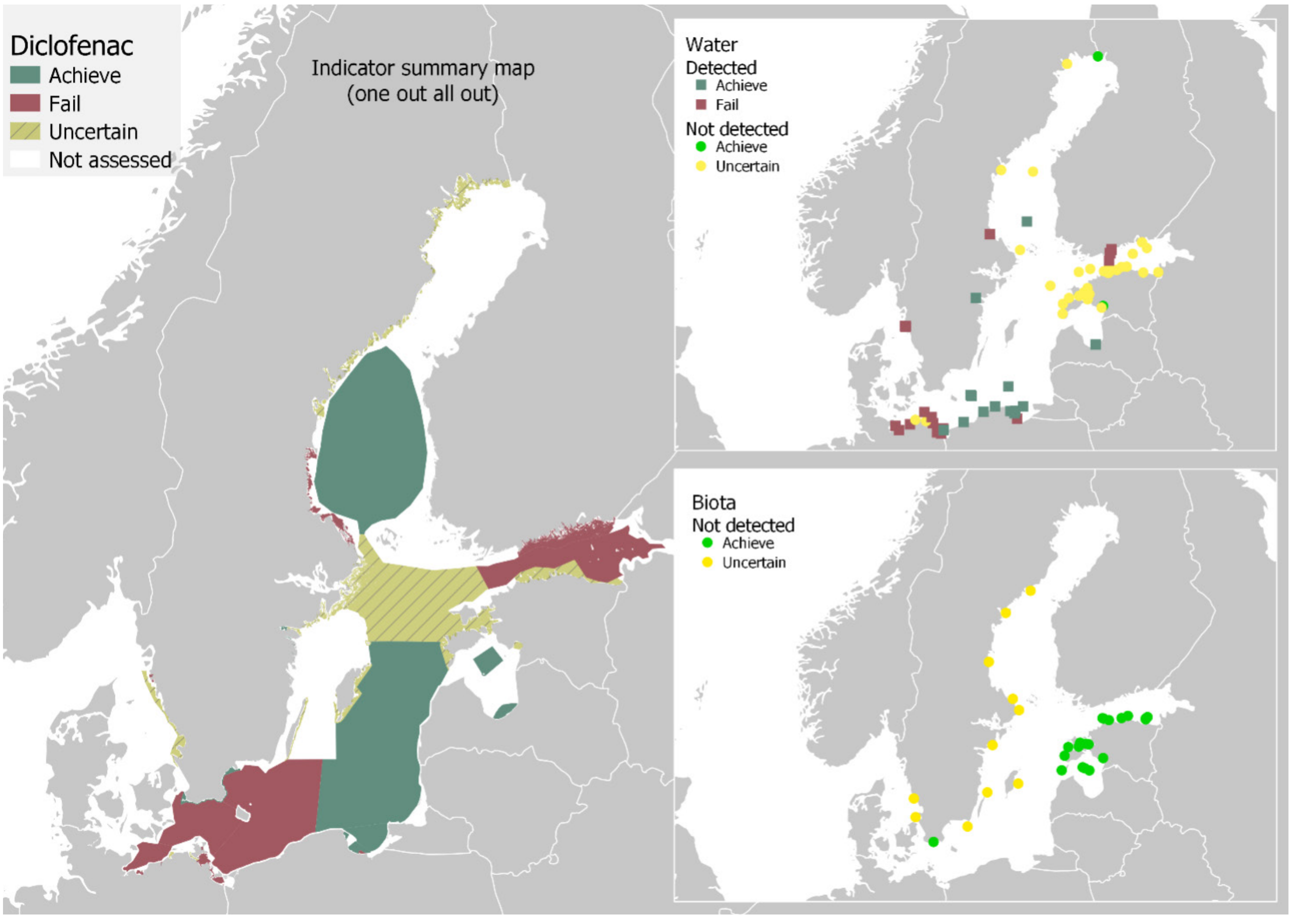
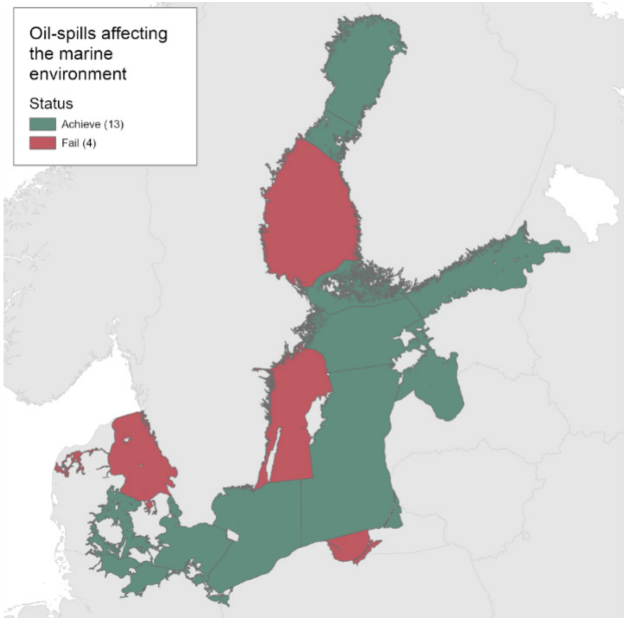


Figure 21. Status of the Baltic Sea, related to diclofenac, and data coverage for marine water and biota. Green colour indicates status is achieved (GES), which is reached when the upper 95 % confidence interval concentrations are below the threshold values. Red indicates sub-GES (concentrations exceed the threshold value). Beige/yellow indicates that status is uncertain, i.e., diclofenac has not been detected in at least one of the matrices, but the analytical limits are higher than the proposed threshold values.

Oil spills effecting the marine environment

Oil is the main fuel of ships in the Baltic Sea region, and large amounts of oil are commonly transported across the Baltic Sea. Oil and other petroleum products may be released into the sea intentionally, due to accidents, or due to negligence, for example as oil in bilge water or via dumping of waste oil. Most oil spills are detected along the main shipping routes, also in part due to the monitoring effort focusing on these locations. Oil spills are a serious threat to the marine environment, causing toxic effects and death of marine animals, especially where contact is direct. In addition, the dispersal of such contaminates after spill events can also add to the pool of hazardous substances in the marine environment (e.g., contribute to polyaromatic hydrocarbon, PAH, concentrations). Even small amounts of oil on the sea surface can harm waterbirds by coating their plumage, which reduces their buoyancy and thermal insulation. Oil spills (and spills of other chemicals) have been monitored using aerial surveillance since 1988 in the Baltic Sea area. Aerial surveys are conducted across the region with standardised methods and cover nearly the whole Baltic Sea area. Other methodologies have in recent years also become more applicable, such as satellite or drone monitoring, however, despite fluctuations in surveillance hours the overall evaluation has high confidence. Regular reporting of such information is caried out under the Expert Group on Aerial Surveillance (EG Surveillance) and the information is summarised in the Annual report on discharges observed during aerial surveillance in the Baltic Sea (HELCOM 2022b). This information may also provide a basis for future work on how to address other chemicals entering the Baltic Sea from spills, the need for better identification of other substances detected (e.g. unknown or non-oil spills), and the need for a definition of an acute pollution events plus the required follow up to such incidents.

The HELCOM core indicator ‘Oil spills affecting the marine environment’ fails the threshold values in the Bothnian Sea, Western Gotland Basin, Gdansk basin, and the Kattegat during the assessment period 2016–2021 (Figure 22). In several cases these failures to achieve the threshold value in sub-basins also link to a single accidental event (e.g., the Kattegat). The threshold values are set based on the volumes of oil spills into each sub-basin during a modern baseline status defined by the reference period 2008–2013, when the estimated volume of oil spills was at a



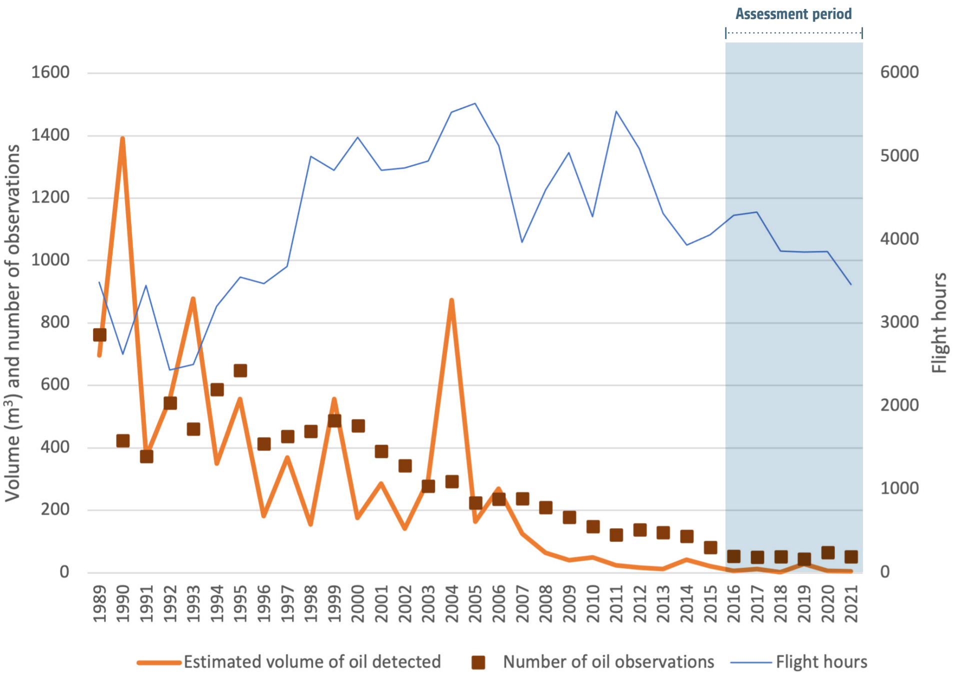


Figure 22. Status assessment of oils spills affecting the marine environment, utilizing Level 2 HELCOM Assessment Units (17 sub-basins) and the historic reference period of 2008–2013 as the threshold value (left). The estimated volume of oil from detected oil spills and the number of observations and flight hours between 1989 and 2021 (right). The current assessment period is marked with grey shading.

historically low level. The long-term goal in HELCOM is to reach a level of zero oil spills and the longer-term trends show good and continuing progress towards such an ambitious aim. Overall decreasing trends have been detected in both the number of spills and the size of a single spill, though in recent years the decreasing trend is less steep (even plateaued) due to the lower level of events occurring. Furthermore, the trend observed in HOLAS II (the 2011-2016 assessment period) of a lower occurrence of spills of a larger volume (i.e., spills larger than 10 cubic meters) remains true for the current assessment period. This decrease has been achieved despite no concomitant decrease in maritime traffic occurring, indicating that measures conducted to decrease oil spills to the environment have been successful (both in accident or release prevention and also in response to such events) (Oil indicator report).

Biological effects of contaminants

Biological effects, as a stand-alone topic, is not currently formerly assessed in HELCOM processes, however, a number of relevant components with direct relevance are evaluated within existing indicators. Furthermore, there are also currently some regional projects underway exploring this topic, in particular in its more integrated overview form, and progress related to these are also provided. These projects are the EU Interreg co-funded BEACON project and a branch within the HAPhazard project (the branch focusing on Biological Effects being termed H-BEC) that is co-financed by HELCOM, the NEFCO Baltic Sea Action Plan Fund, Germany and Sweden. A new Biodiversa+ project (Detect2Protect) will also shortly initiate having been funded in the 2021-2022 call on 'Supporting the protection of biodiversity and ecosystems across land and sea'. The ultimate aim of such work, though these projects are initial steps in the process, is to work towards the development of an Integrated evaluation of the Biological Effects of Contaminants (I-BEC) and thereby support the fulfilment of BSAP action HL13 (By 2028 develop further relevant monitoring for the biological effects of hazardous substances in order to facilitate a reliable ecosystem health assessment). Inclusion of other Contracting Parties that were not able to partner in the applications will also be explored, in particular via the EG HAZ sub-team on biological effects.

The current work builds on earlier discussion in the HELCOM Expert Group on Hazardous substances (EG HAZ) and utilises the following working definition: 'a biological effect is the response of an organism, a population, or a community, due to the presence of hazardous substances in the Baltic Sea'. This working definition provides a way to frame the ongoing work on biological effects.

White-tailed sea eagle productivity

White-tailed sea eagles are top predators in the coastal food web, which makes them highly vulnerable to hazardous substances that accumulate and biomagnify. Marked impacts were apparent since the 1950s and it was identified at that time that widely used insecticides (DDTs) and possibly polychlorinated biphenyls (PCBs) were major causes. Bans on the use of these substances have been in place for decades and positive development (survival and abundance) has occurred since the 1980s. Due to the position in the food web and the bioaccumulation of certain substances the negative effects of legacy, as well as emerging or new contaminants, can become apparent in white-tailed sea eagles before they are visible in other species or habitats. The close association between hazardous substances in the environment and the productivity of the white-tailed sea eagle make this a valuable indicator on the biological effects of contaminants. Parameters describing the number of hatchlings in nests (brood size) and the proportion of nests producing young (breeding success) can inform on overall productivity (productivity) and can rapidly signal effects from contaminants. While changes in the abundance of adult birds might only occur over a period of several years, an increased mortality of eggs or chicks, and thus a lowered productivity, is often an early warning signal of elevated concentrations of hazardous substances. The assessment shows that the white-tailed sea eagle productivity reached the threshold value (i.e., was in Good Environmental Status, GES) in relatively few coastal assessment units (Germany, Latvia and Finland (for the Gulf of Finland), Figure 23). In coastal areas where sub-GES conditions were recorded it was commonly a single parameter (i.e., either breeding success or brood size) that was below the threshold value. In addition, where parameters were sub-GES the evaluation results were often just below the threshold value for both parameters, particularly so for the brood size parameter (Eagle indicator report). The current evaluation (HOLAS 3, 2016-2021 assessment period) represents an apparent deterioration in status compared HOLAS II (2011-2016 period) as more coastal areas are in sub-GES condition and this may reflect a need for greater clarification of the situation as such changes may represent early warning signs of impacts from new or emerging substances but may also be in part due to other associated changes such as resource limitation (including in relation to carrying capacity or pressures related to habitat and other key life cycle components) or impacts from other food web changes (e.g., insufficient or poorer food availability/quality).

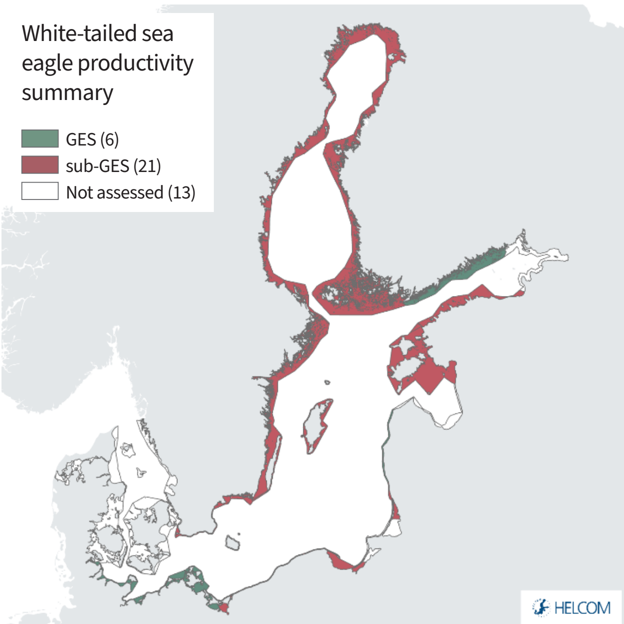
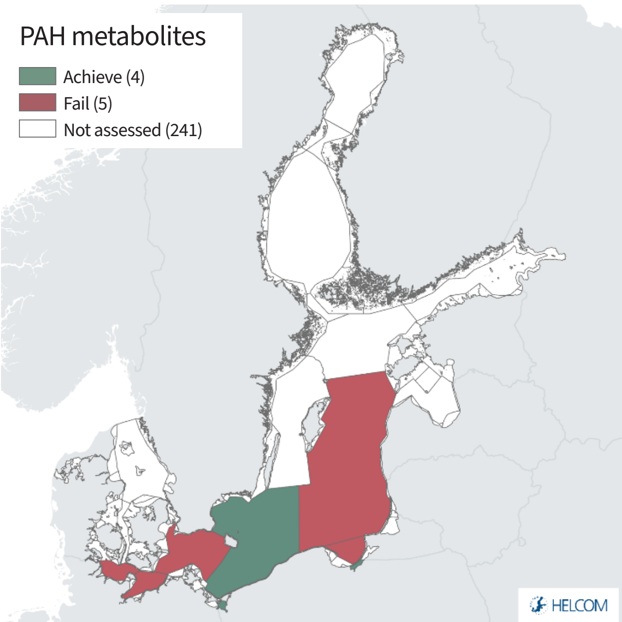


Figure 23. Status evaluation of the indicator 'white-tailed sea eagle productivity'. The assessment was carried out using aggregated Scale 3 HELCOM assessment units (see appendix 4 and the HELCOM Monitoring and Assessment Strategy Annex 4).

Polyaromatic hydrocarbon (PAH) metabolites

Polyaromatic hydrocarbon (PAH) metabolites (1-hydroxypyrene) are generated due to the active breakdown of PAH parent compounds in biota and can be detected for example in the bile of fish. PAH metabolites in fish bile reflects the level of exposure during the last few days before sampling, varying to some degree depending on the feeding activity of the fish. The presence, and concentrations, of PAH metabolites can therefore provide an insight into recent exposure to contaminants as well as the level of exposure. Discussion under the HELCOM Expert Group on Hazardous substances (EG HAZ) concluded that this component was best represented as an element of the biological effects work and thus the outcome of the evaluation is not included in the integrated assessment of hazardous substances (CHASE) but presented as additional information within the indicator report (PAH indicator report). Monitoring data was available from Germany and Poland for the evaluation in this assessment period and is spatially limited to the Eastern Gotland Basin, Gulf of Gdansk, Bornholm Basin, Arkona Basin, Kiel Bay and Bay of Mecklenburg sub-basins. In general, the evaluation outcome does not achieve Good Environmental Status (sub-GES), with the exception of the Bornholm Basin (Figure 24). Future harmonisation work across methodologies and species has been identified for this indicator component as the apparent mismatch between GES evaluations at the station level and the assessment unit level relate to the wide range in station level evaluation outcomes that influences the parametrisation of the assessment unit level outcomes (PAH indicator report).



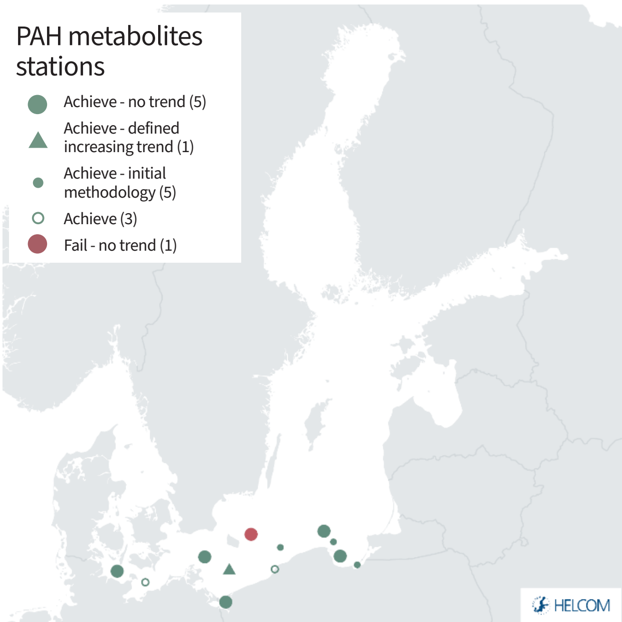
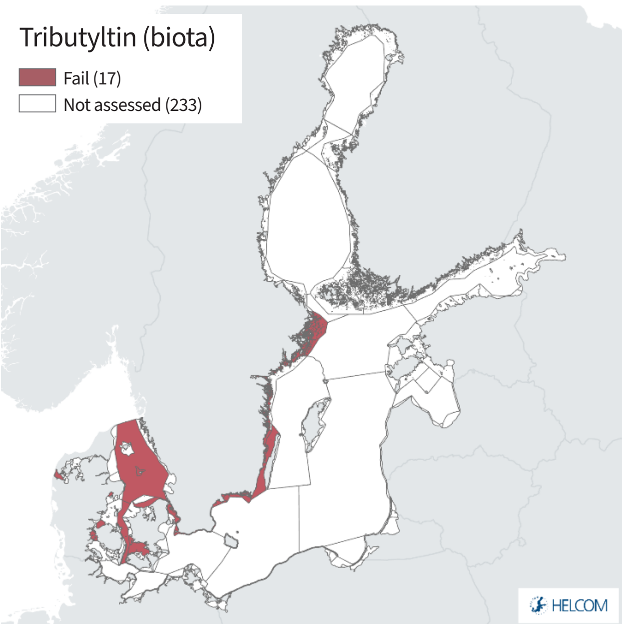


Figure 24. PAH metabolite 1-hydroxypyrene concentration status per station (right) and assessment unit status evaluation (left). Green indicates that the threshold value is achieved and red that the threshold value is failed. Small open circles indicate a status assessment based on only 1–2 years of data (initial data), small filled circles indicate that data is not suitable to assess a trend (treated with initial methodology), large filled circles that no detectable concentration trends can be identified during the whole monitoring period (full data), and the filled arrow indicate that there is a statistically defined upward or downward trend during the monitoring period.

Imposex (biological effects of organoitin compounds)

Organotin, and in particular tributyltin (TBT), has been shown to be very toxic to marine life, resulting in changes in oyster shells and interfering with the marine gastropods female reproductive organ, an effect known as imposex, causing sterility in some sensitive species. TBT is bioaccumulated by marine organisms causing harmful effects that mainly depend on the level of its final concentration in the tissues. Despite a ban on the use of TBT in antifouling paints (782/2003/EC (EC, 2003)) effective from 2008 (OSPAR, 2014) the concentrations remain high in the environment and exceed acceptable levels, meaning that individuals and species are exposed to potentially harmful levels (TBT indicator report). Since imposex is a biological effects component and is evaluated with very different methodologies to other hazardous substances concentration indicators it is not included in the integrated assessment (CHASE) but presented as additional information within the TBT and imposex indicator (TBT indicator report). Monitoring data is mainly available for imposex in Danish and Swedish waters and often in more coastal localities, the latter aspect also reflecting the distribution of the species of relevance and the higher levels in such areas (e.g., associated with ports). In general monitoring stations and also the evaluation at the assessment unit level fail to achieve the threshold value for Good Environmental Status (sub-GES). A few stations do also achieve GES when evaluated at the individual time series level, though generally in the Kattegat area, and the few recorded distinct directional trends at individual stations generally show downward trends (decreasing concentrations), though such trends are only detected at a few stations (Figure 25, and TBT indicator report).



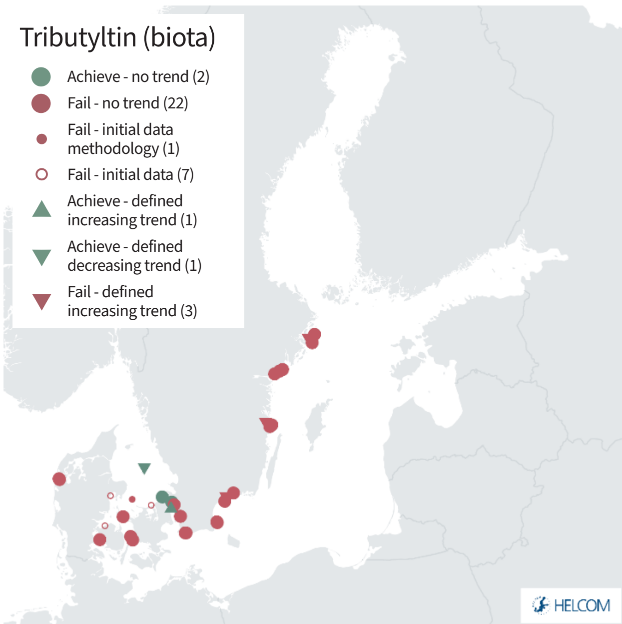


Figure 25. Map presenting status based on imposex effect in (biota, left) marine gastropods at each sampling station (right). Green colour represents achieving the threshold value (i.e. GES) and red colour represents failing the threshold value (sub-GES). Filled large circles represent results based on five or more years of data, full evaluation, small filled circles represent results based on three-four years and empty circles represent results based on <2 years, initial status assessment. Triangles indicate trends: downward (decreasing concentrations) or upwards (increasing concentrations). The evaluation is carried out using Level 4 HELCOM assessment units.

Reproductive disorders: Malformed amphipod embryos

The elevated frequencies of malformed embryos are regarded as a significant biological response for assessing the population-relevant effects induced by the combined exposure to environmental contaminants in Baltic Sea sediments. The indicator provides information on reproductive success and thereby population health, persistence and stability. In the Baltic Sea, malformed embryos in *Monoporeia affinis* and *Pontoporeia femorata* have been used as a bioindicator for reproductive toxicity caused by pollutants for the last 20 years. These are the keystone species in the Baltic Sea and freshwater ecosystems below the highest coastline. M affinis is one of the most abundant macrofauna species in soft bottoms (10 to 150 m), provided that oxygen conditions are sufficient (Kuparinen *et al.* 1996). Amphipods are very important for the oxygenation of the sediment by bioturbation (Lindström 1992), they are also food for fish, such as herring, eelpout, cod and flounder, as well as other invertebrates i.e., *Saduria entomon*, *Halicryptus spinulosus* and *Bylgides sarsi* (Ankar and Sigvaldsdottir 1981, Aneer 1975, Sparrevik and Leonardsson 1995). The Baltic *M. affinis* populations have decreased dramatically during the last 30 years, and currently the species abundances in the Gulf of Finland and Gulf of Gdansk are very low. The population crash in the year 2000 resulted in dramatically decreased populations in the Gulf of Bothnia (Eriksson Wiklund *et al.* 2008). Other amphipods used in the monitoring (*P. robustoides, G. tigrinus, G. fasciatus*) belong to so-called alien species, but they are also important components (30-40% of the total biomass) in the benthic communities in coastal areas of the Baltic Sea (Gulf of Riga, Gulf of Finland, Curonian and Vistula Lagoons) since 1990s and are the main prey for local fish and birds. These species are omnivores, with more than 50 % of detritus in their diet (Berezina 2007). These gammarids are widely used as test indicators for sediment toxicity (Berezina *et al.* 2017; Strode *et al.* 2017). All of them have a life span of 1.5 year; mating begins in April-May, embryogenesis takes 2-3 weeks, and juveniles of the 2-3 generations are released during summer (Panov and 11 Berezina 2002; Bacela and Konopacka, 2005, Berezina *et al.* 2011).

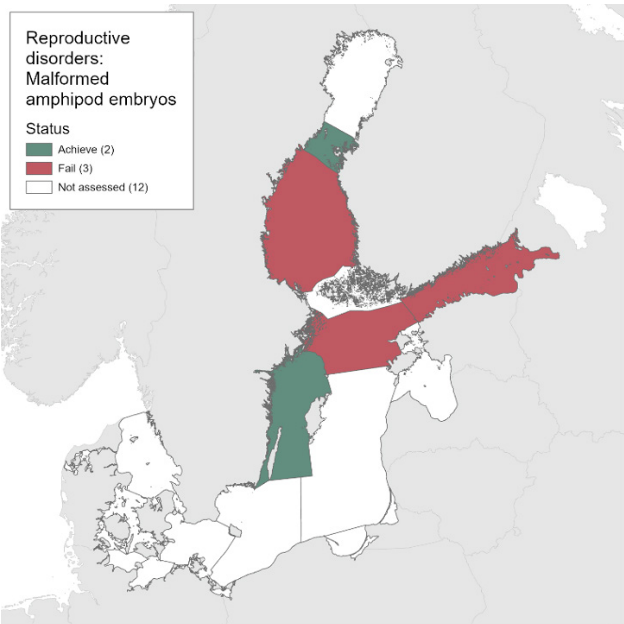


Figure 26. Status evaluation results for HOLAS 3 are based on the evaluation of the indicator Reproductive disorders: malformed embryos of amphipods. The evaluation is carried out using scale 2 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment Strategy Annex 4), combining coastal and offshore amphipod species and using species-specific target values. *Not assessed is used for areas in which no agreement on the application of this indicator have currently been made.*

The indicator evaluation results are based on the monitoring data on malformations in several Baltic amphipod species (*Monoporeia affinis, Gammarus salinus, G. zaddachi, and G. tigrinus*) carried out by Sweden, Latvia and Estonia, with complementary data for *M. affinis* in the Gulf of Finland provided by Russia. In 2016-2021, the indicator was applied to the waters of Finland, Sweden, Latvia, and Estonia, and the evaluation was conducted for The Quark, Bothnian Sea, Northern Baltic Proper, Western Gotland Basin, and Gulf of Finland. The threshold value has not been achieved at all stations within each basin, indicating that toxic effects of contaminants are considered to be present. The evaluation for the assessment period 2016-2021 concluded that the Quark and the Western Gotland Basin have achieved good environmental status (GES), whereas the Bothnian Sea, Northern Baltic Proper, and the Gulf of Finland were not in good status. In areas where GES was failed during the assessment period, most of the observations were above the BAC values, i.e., GES was not achieved (Figure 26). Deviations in frequencies of embryo malformations and of females carrying malformed embryos were apparent in all assessment units, except the Quark. Thus, the results indicate high reproductive and developmental toxicity in the amphipod populations inhabiting most of the evaluated areas. For the Gulf of Riga, only two-years of data were available. As at least three years of observations are needed to conduct the evaluation, thus it was not possible to assess the status in this sub-basin. Provided that local indicator species and the threshold values are identified, the approach is potentially applicable in all Baltic Sea areas (sub-basins) because amphipod species are present ubiquitously across the region (ReprodIND report).

Integrated biological effects of contaminants pilot study

This pilot study has been developed by the H-BEC project (HELCOM Biological Effects of Contaminants project, a sub-section within the HAPhazard project).

The approach to quantifying chemical pollution and status of the marine environment purely based on concentrations of single chemicals (even if integrated/aggregated) has become broadly questioned. There is thus a specific need to include biological effects in any assessment of contaminant impacts, as is reflected under the BSAP action HL13 and also under the EU Marine Strategy Framework Directive (MSFD), in particular Descriptor 8 Criteria 2 (D8C2). This requires data on biological effects to evaluate whether harm is occurring due to the the environmental status of contaminants (ICES, 2021). Accordingly, OSPAR has recommended a core set of biological effect techniques and assessment criteria (JAMP, 2012), following a comprehensive process over the last few decades, resulting in several broadly applicable methods and biomarkers that can be included in an integrated approach (Vethaak *et al.* 2017). This general approach developed in OSPAR forms a solid starting point for further development or adjustment for the HELCOM region.

The H-BEC project aims to carry out a pilot study to show the validity of such methods and promote the integration of the biological effect methods into the overall chemical pollution (hazardous substances) assessment in the Baltic Sea. By conducting an inventory of these methods applicable to the Baltic Sea system and demonstrating how biological effect data can complement the contaminant-based approach the pilot study should provide a basis for future development on the topic in the HELCOM area. Here, we show how the generalized concept (Figure 27) and how the results from the pilot study can be utilized for evaluating biological responses as well as linking alterations in these responses to putative contaminant effects, and how such information can be utilized in the assessment of hazardous substances to support policy requirements.

The data used in this pilot study originate from an Effect Screening Study (2017-2019) commissioned by the Swedish Environmental Protection Agency (SEPA) to investigate the biological effects of environmental contaminants in relation to the contaminant levels in biota and sediment in eight polluted hot spot areas along the Swedish coast, from the Bothnian Bay to the Kattegat. Established and ecologically relevant test species and corresponding reference sites with no known point sources were also sampled. The primary task was to evaluate the performance of a large panel of biomarkers in fish (perch and eelpout) and benthic invertebrates (amphipods, snails, and mussels) currently used in the Swedish national monitoring programme to evaluate the biological effects of contaminants (Förlin *et al.* 2019).

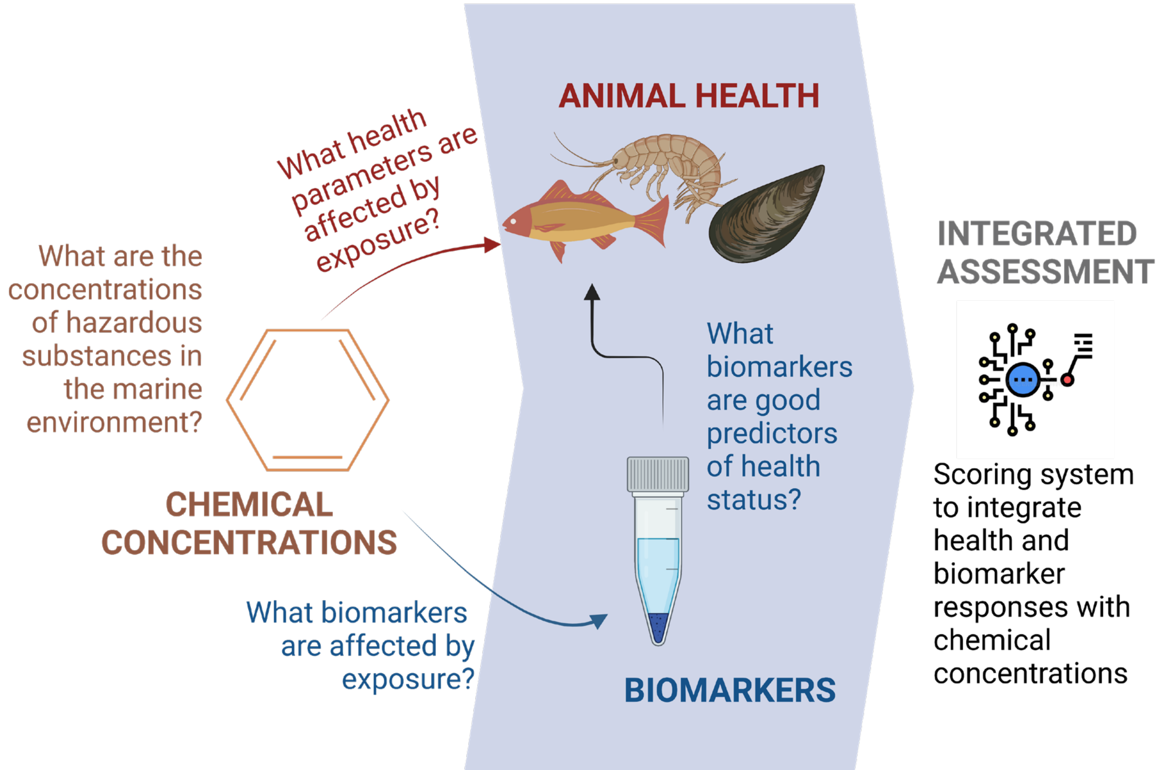


Figure 27. Conceptual diagram linking relationships between the chemical and biological datasets: Chemical concentrations (data on contaminant levels in sediment and biota), Biomarkers (suborganismal parameters, e.g., concentrations of enzymes involved in detoxification and essential physiological functions, blood count, ion concentrations in serum, etc.) and Animal Health (physiological condition parameters measured at the organism level, e.g., body mass, growth, reproduction, etc.). The statistical evaluation and Integrated assessment focus on the prediction models and combining information on the influential biological effect variables and chemical concentrations.

Relationships between biological effects and contaminants were significant, and biomarkers were related to animal health. It is therefore possible to conclude that biological endpoints are informative and should be used in environmental status assessment in concert with chemical data. More specifically:

— *In amphipods*, reproductive aberrations and biomarkers were driven by polychlorinated dibenzofurans (PCDD/F), dioxin-like polychlorinated biphenyls (dlPCB), Polyaromatic hydrocarbons (PAHs) and metals. Moreover, the biomarker model had a stronger association with the chemicals (38% of the biomarker variability explained by contaminants) than the model for organism-level responses, i.e., reproduction (20%). However, when the most influential biomarkers and reproductive variables were used together to classify study sites in the Bothnian Sea and Baltic Proper according to their contamination status (Figure 28), the polluted sites were identified with 97% accuracy. By contrast, the prediction accuracy for the reference sites was only 76%, suggesting that relatively low concentrations of chemicals in a mixture can also exert adverse biological effects, thus, supporting the joint use of biological and chemical data for an overall chemical pollution assessment.

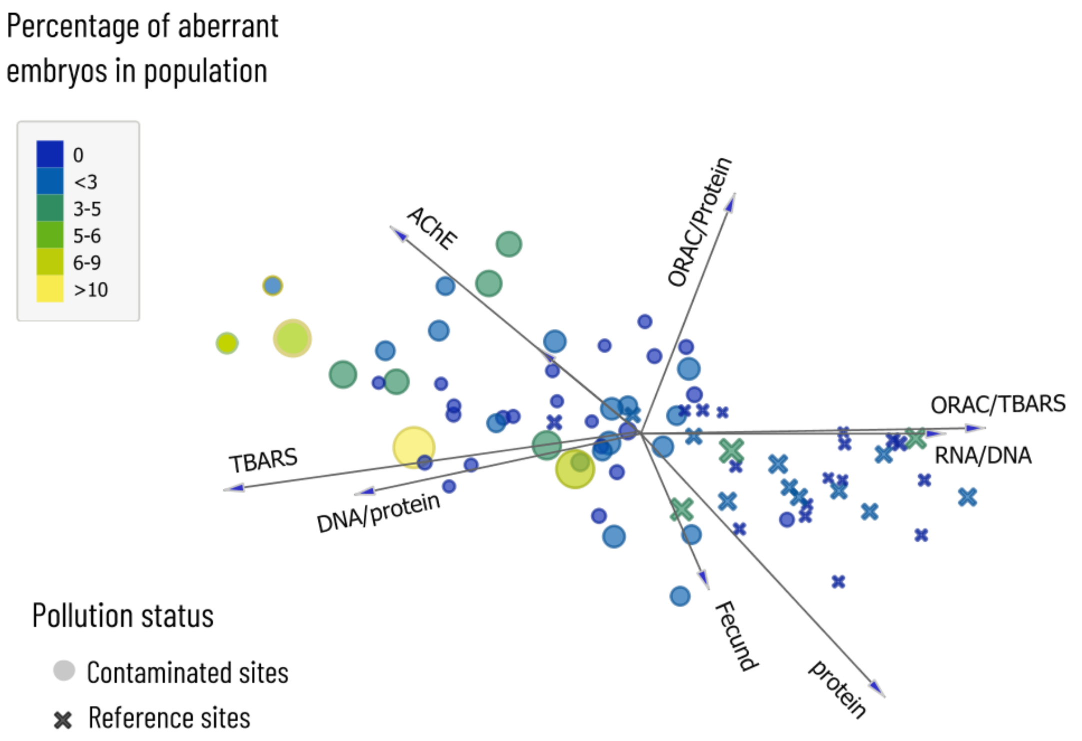


Figure 28. FreeViz ordination for biomarkers (vectors) showing how biomarker and physiological responses (Fecundity [Fecund] and Percentage of malformed embryos in the population) in Monoporeia affinis vary between the areas with different pollution loads. Biomarkers: ORAC (Oxygen radical absorbance capacity, marker of antioxidant capacity) normalised to protein and DNA (ORAC/Protein and ORAC/DNA, respectively), TBARS (Thiobarbituric acid reactive substances, marker of lipid peroxidation), ORAC/TBARS ratio (the oxidative balance biomarker), AChE (Acetylcholinesterase activity, neurotoxicity marker), and RNA/DNA and RNA/protein, ratios between RNA content and DNA (indicative of RNA per cell) and rRNA per synthesised protein molecule (markers of growth and metabolic activity assessed as protein synthetic capacity and requirement of ribosomes for protein synthesis, respectively). The percentage of malformed embryos is shown as a colour scale, and the percentage of females carrying malformed embryos is indicated as the size of the circle. In DistLM, the most influential predictors of the pollution status were TBARS, ORAC/TBARS ratio, RNA/DNA ratio and proportion of malformed embryos.

— *In perch*, the body condition variables and biomarker profiles differed significantly between females and males. Therefore, a separate model was generated for each gender using the measured contaminant types and TEQ-based indices for metals and organic contaminants as predictors and physiological variables or biomarkers with the cross-correlation coefficients <0.7 as a multivariate response. The contaminants explained 54% and 62% of the variability in the perch physiological condition for females and males, respectively, and 31% and 30% in the biomarker profiles for females and males, respectively. Thus, the models for the physiological response had a stronger association with the contaminant concentrations than the biomarker response models. In both genders, contaminants consistently identified as influential for both physiological conditions and biomarkers were hexachlorobenzenes (HCBs), polyfluoroalkyl substances (PFAS) and Polychlorinated biphenyls (PCBs) (Figure 29). When biomarker and physiological responses were combined, the classification accuracy was greatly improved, with classification accuracy similar to that in the amphipod models.

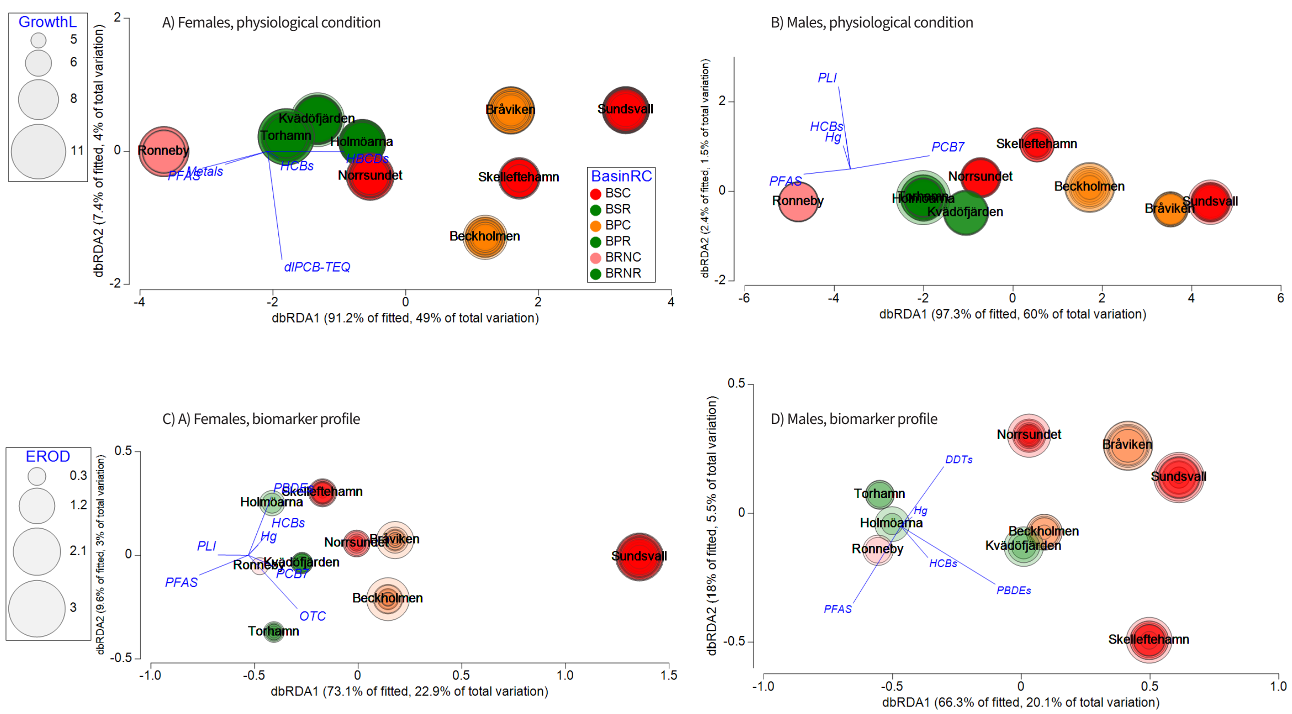


Figure 29. Distance-based redundancy analysis (dbRDA) ordination plots showing effects of contaminants (blue vectors, identified as significant predictors by Distance-based multivariate linear regression models (DistLM) for (A and B) perch physiological condition in females and males, respectively, and (C and D) the biomarker profiles in females and males, respectively; the most influential health parameters and biomarkers were EROD, GLU, Vtg and GST activities, Growth and GSI. The direction and length of the vectors indicate an association between the contaminants and biological profiles characteristic of each sampling site. The bubble position is ordination based on the biological variables, and bubble size indicates the variation for the most influential response variable, Growth (A and B panels) and EROD (C and D panels). The sub-basin (BS: Bothnian Sea, BP: Baltic Proper, and BRN: Bornholm; sampling sites are indicated, see Figure 30 for the map) and Pollution status (C: contaminated [different shades of red] and R: reference [green]) are shown in the figure legend to facilitate the interpretation of the plot; however, these variables were not used in the models.

Application of the OSPAR integrated biological effects of contaminants (I-BEC)

An integrated assessment according to the OSPAR Joint Assessment & Monitoring Programme (JAMP) guidelines was also attempted, using the biological effect and contaminant data from the same survey (i.e., Swedish national monitoring) and following the approach for integration developed in OSPAR (Vethaak *et al.* 2017) and recommended as potentially suitable for the assessment of Good Environmental Status (GES), for example under Descriptor 8 of the MSFD. The approach is based on a multistep traffic-light data aggregation to assess contaminant and biological effects (effects and exposure) data together and use coherent sets of assessment criteria for chemical and biological measurements (determinants). As most of the determinants in the OSPAR developed system were derived for North Atlantic species in European waters, we complemented them with the biological measurements from the Swedish survey.

The assessment criteria used as threshold values for chemical components and biological effects of the chemical contaminants were OSPAR Background Assessment Criteria (BACs) and Environmental Assessment Criteria (EACs) estimated as the 90th percentile of lognormal distribution based on the sample mean and standard deviation of the data from reference sites. Note that unlike the EACs used in the OSPAR system, the EAC values applied in this pilot study are provisional and not yet regionally agreed. Initial comparisons detected whether the chemical concentration or response for any species or matrix at any site was less than BAC, between the BAC and EAC, or above EAC, these three 'status divisions' can loosely be considered as acceptable status, concern, and clear impact, respectively. Biological responses were grouped as either Exposure (Biomarkers; Figure 27) or Effect (Animal Health, Figure 27) based on the different methodologies or impacts, and in all cases the outcome represents a share of the components included in the assessment that falls per provisional status division.

The matrices chosen for the assessment were fish (perch and eelpout), for which both chemical and biological data were available, as well as amphipods, snails and mussels (biological responses only). As determinants for fish and amphipods, we used the significant predictors identified by the DistLM models (Figures 28 and 29), and imposex and lysosomal membrane stability (LMS) as determinants in snails and mussels, respectively. The responses at each location were scored, collated and aggregated into the three categories for the assessment across individual sites by integrating matrices into a single schematic showing proportions of determinants in each category in relation to their BACs and EACs (Figure 30).

We found that in four out of 11 locations, the chemical assessment resulted in a higher proportion of determinants exceeding their EACs (red) than the effect-based categories (EX or EF), which means that the chemical concentrations do not always give rise to measurable biological effects, at least not immediately. Both relatively unpolluted (e.g., Uddevalla and Torhamn) and heavily polluted (e.g., Skelleftehamn) were in this group, which highlights the need for further development of such approaches especially if further integration or overview outcomes are utilized (e.g., how to determine if effects are not occurring or if the effects of load is simply not yet seen). However, in five cases, the opposite was observed, i.e., the assessment based on biological determinants resulted in more substantial evidence for severe pollution than the chemical-based assessment (e.g., Landskrona, Beckholmen, Ronneby, Norrsundet and Bråviken; all are hot-spot pollution sites).

The assessment of chemical contaminant and biological effects data against predefined criteria provides information on the contaminant load likely to give rise to effects and the presence/absence of significant adverse effects in marine biota, which is the ultimate goal for example of the MSFD Descriptor 8 overall assessment. The need for the integrated evaluation is supported by the fact that most biological effects in fish and amphipods were best predicted by several chemical substances, usually from more than one contaminant class, implying that mixture effects govern the responses. Therefore, ecological impact assessment relying exclusively on chemical measurements that are assumed to reflect the health of biota is insufficient for environmental health risk assessment and pollution control.

The integrated assessment of contaminants and their effects requires the coordination of monitoring effort and methodologies for biological and chemical data. Here, we tested the integration methodology proposed by OSPAR (Hylland *et al.* 2017; Lyons *et al.* 2017), however, other methods and approaches adapted to the available monitoring, sentinel species, and data types collected in the Baltic Sea need to be explored in addition. Moreover, relevant batteries of the biological effect determinants and assessment criteria, such as BAC and EAC values, must be established and validated, which remains a significant challenge for monitoring design, data acquisition and aggregation. Overall, biological effects of contaminants approach show significant promise and harmonized efforts to further this work will likely offer a cost-effective complement to substance concentration-based assessments whilst also increasing the environmental relevance of the overall outcome. Approaches akin to the pilot study above, that is currently applied on concentrations and effects data collected at the same monitoring stations (as proof of concept), could, with further development, logically also be applied on the basis of HELCOM assessment units and thereby offer a regional assessment.

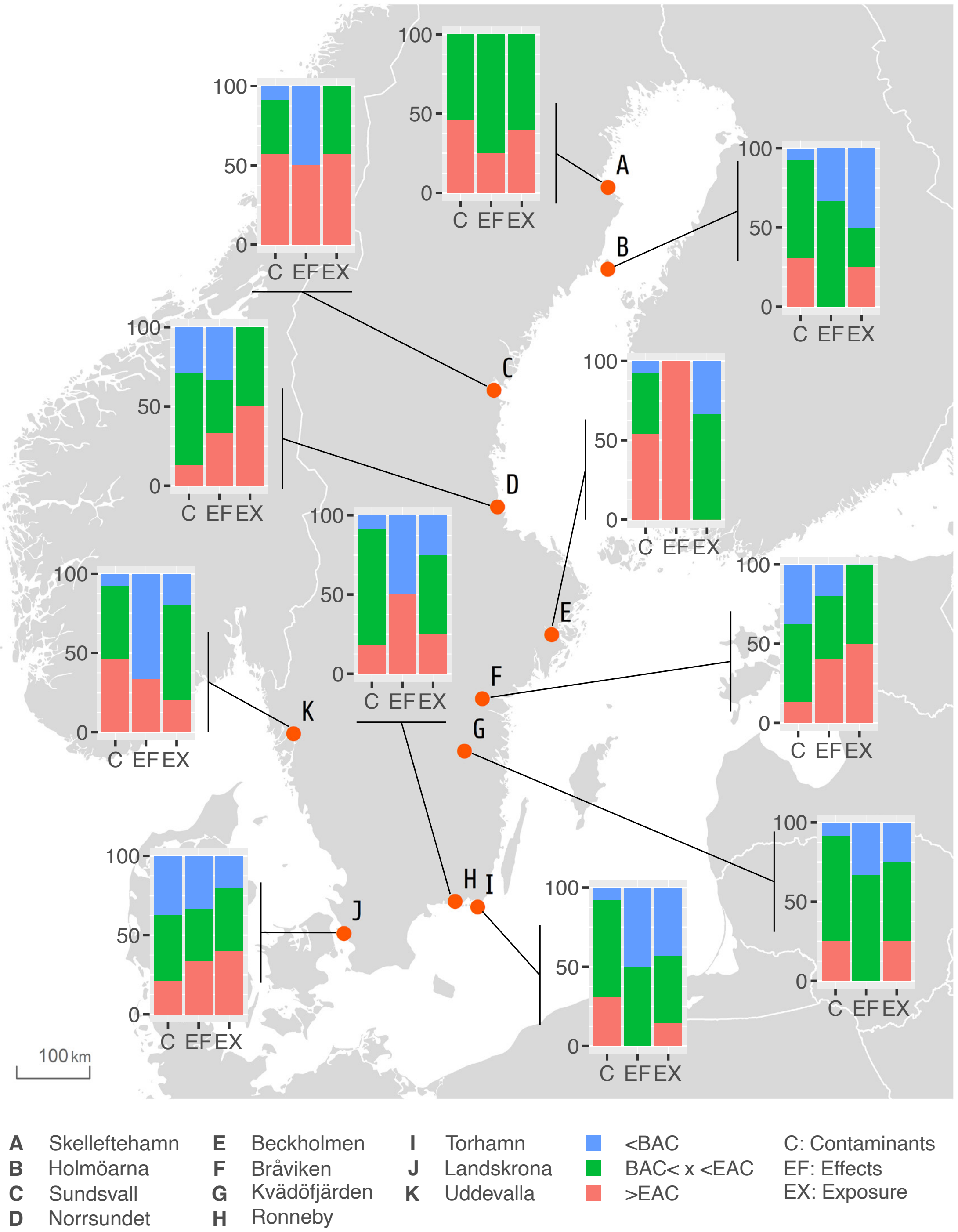


Figure 30. Assessment of contaminants (C), exposure (EX) and effects (EF) at several locations in the Swedish coastal waters of the Baltic Sea in the Effect Screening Study (Förlin *et al.* 2019). The integration by matrix and determinant category is presented as three-coloured bars showing the proportions of determinants that exceed the BAC and EAC. Values exceeding EAC are shown in red, values below the BAC are in blue, and concentrations or biological responses between the BAC and EAC are in green. The critical boundary for GES assessment is the red boundary, representing comparisons with assessment criteria.

Screening and other emerging substances or risk identification

There is an increasing pool of evidence to suggest that a genuine understanding or approximation of Good Environmental Status (GES) cannot be achieved simply by addressing concentration of a selected, and generally small, number of high priority substances (e.g., as expressed for example just by the current list of HELCOM indicators above). While such approaches are vital in identifying and monitoring substances known to cause harm (often substances detected at high concentrations in the environment) and can also show trends that reflect the measures taken or the persistence of the substances, it does not alone provide a sufficient understanding of other key issues such as the overall pool and potential impacts, the risk from new or emerging substances, or provide the possibility to take early action and prevent serious degradation of the Baltic Sea environment. In addition to the biological effects related development described above the first regional target and non-target screening of hazardous substances has been carried out in the Baltic Sea region. A brief overview of the process and key findings is provided in this section and the detailed outputs will provide important information that can also support the preparatory steps in the development of the HELCOM strategic framework for hazardous substances.

The first regional screening campaign was co-financed by the NEFCO Baltic Sea Action Plan Fund under the 'Pre-empting pollution by screening for possible risks' project (PreEMPT). This project, with additional samples (and expert time) contributed by the HELCOM Contracting Parties and close cooperation of the NORMAN Association resulted in screening being carried out for circa 100 samples. The final project included samples from every HELCOM country, targeted biota (mussels, or fish where mussels were not readily available) and sediment samples to harmonised the findings (approximately an equal division of all sample types), included reference and contaminated stations, and provided a high level of spatial coverage (Figure 31). In addition to this project similar studies have also recently examined contaminants in higher trophic level species using closely aligned methodologies. This includes work carried out on the white-tailed sea eagle and also a study on marine mammals that was supported by the German Chairmanship of HELCOM and carried out with the LIFE APEX project.

The analysis of the samples took place in cooperation with the NORMAN Association and one of its member laboratories, the Laboratory of Analytical Chemistry of the National and Kapodistrian University of Athens (NKUA), using established and harmonized techniques that have been internationally developed and tested. Two analytical processes were applied to the samples (each individually), wide-scope target screening analysis for circa 2,500 substances (using liquid chromatography electrospray ionization high resolution mass spectrometry, LC-ESI-HRMS, and Gas Chromatography Atmospheric pressure chemical ionization high-resolution mass spectrometry, GC-APCI-HRMS) and suspect screening of more than 65,000 compounds including their semi-quantification (using LC-ESI-HRMS). The resulting data generated were processed with a NORMAN Association prioritization and risk evaluation tool.

Wide-scope target screening

Wide-scope target screening of sediment samples detected 52 identified contaminants. The risk associated with the exceedance of toxicity threshold values was assessed by comparing the measured concentrations with predicted no effect concentration (PNEC) values from the NORMAN Ecotoxicology Database. Most of the detected compounds were Industrial chemicals (including PAHs and PFAS, overall 22 substances), Personal Care Products (PCPs), and pharmaceutical related compounds (n=13 substances). Other categories such as antipsychotic and antidepressant drugs, and Plant Protection Products (PPPs) were also commonly detected (n=17 substances). The polyaromatic hydrocarbons (PAHs) benz(a)anthracene, benzo(a)pyrene, chrysene and fluoranthene were omnipresent in the tested samples, while acenaphthylene, anthracene, fluorene, phenanthrene and pyrene were detected in more than 21 of 30 samples. High frequency of detection was also observed for PPPs prometon, simazine, terbumeton and fludioxonil, pentachlorophenol (PCPs), as well as for the PCPs methylparben and galaxolide and the PFAS perfluorooctane sulphonate (PFOS, perfluorooctane sulphonate). Of these regularly occurring substances 22 also exceeded their ecotoxicological threshold value in at least one sample, with most exceeding these levels in less than 5 samples. Anthracene and benzo(a)pyrene seem to be of high environmental concern, as their concentration exceeded respective PNEC values in 24 samples. Perfluorooctane sulphonate (PFOS) and prometon exceeded their ecotoxicological threshold in 18 samples, whereas terbumeton and methylparaben were detected at concentration levels above their PNECs in 17 and 16 samples, respectively. Anthracene and PFOS exhibited the highest extent of exceedance of the ecotoxicological threshold values applied. 12 compounds had maximum detected concentrations up to ten times higher than their respective PNEC values and 6 compounds (prometon, fluorene, N-methyldodecylamine, acenaphthene, caffeine and venlafaxine) were found in concentrations of 13 to 63-fold higher than their respective PNEC values.

In total, 50 compounds were determined by wide-scope target analysis in the 33 fish samples. Most of the detected compounds were Industrial chemicals (including PAHs, PCBs and PFAS, n=23 of 33), followed by PPPs (n=10) and pharmaceuticals (including antipsychotic and antidepressant drugs), and PCPs (n=10). PFOS was omnipresent in the tested fish samples, followed by perfluorononanoic acid (PFNA), methylparaben and 3,3-pentamethylene-4-butyrolactam. Fluorene and p,p'-DDE, were determined in more than 60% of the tested samples. 23 compounds also exceeded their ecotoxicological threshold value in at least one sample, with the majority of determined compounds only exceeding in less than five samples. Known Persistent, Bioaccumulative and Toxic (PBT) substances, exceeded the respective PNEC values in the majority of the analyzed fish samples. Perfluorooctane sulphonate (PFOS) seems to be of high environmental concern, as in 22 fish samples the concentration levels were higher than its respective EQS (9.1 µg/kg w.w.), established by Directive 2013/39/EU for fish tissue. Dichlorodiphenyldichloroethylene (p,p'-DDE), a DDT breakdown product exceeded its ecotoxicological threshold in 14 samples and showed the highest extent of exceedance. Methylparaben, pyrene, and N,N-dimethyldecylamine also regularly exceeded their respective threshold values with pilocarpine also showing a high extent of exceedance. For 10 compounds the maximum detected concentrations were up to ten times higher than their respective PNECs, whereas for 13 compounds (lopinavir, pilocarpine, caffeine, venlafaxine, fipronil, methylparaben, PFOA, p,p'-DDE, pyrene, PCB 101, PCB138, PCB 153, N,N-dimethyldecylamine) the maximum detected concentrations varied in the range from 20 (methylparaben) to 1110 (p,p'-DDE)-fold higher levels compared to their respective PNECs.

In mussels 47 compounds were determined by the wide-scope target analysis, many of which were industrial chemicals (includ-

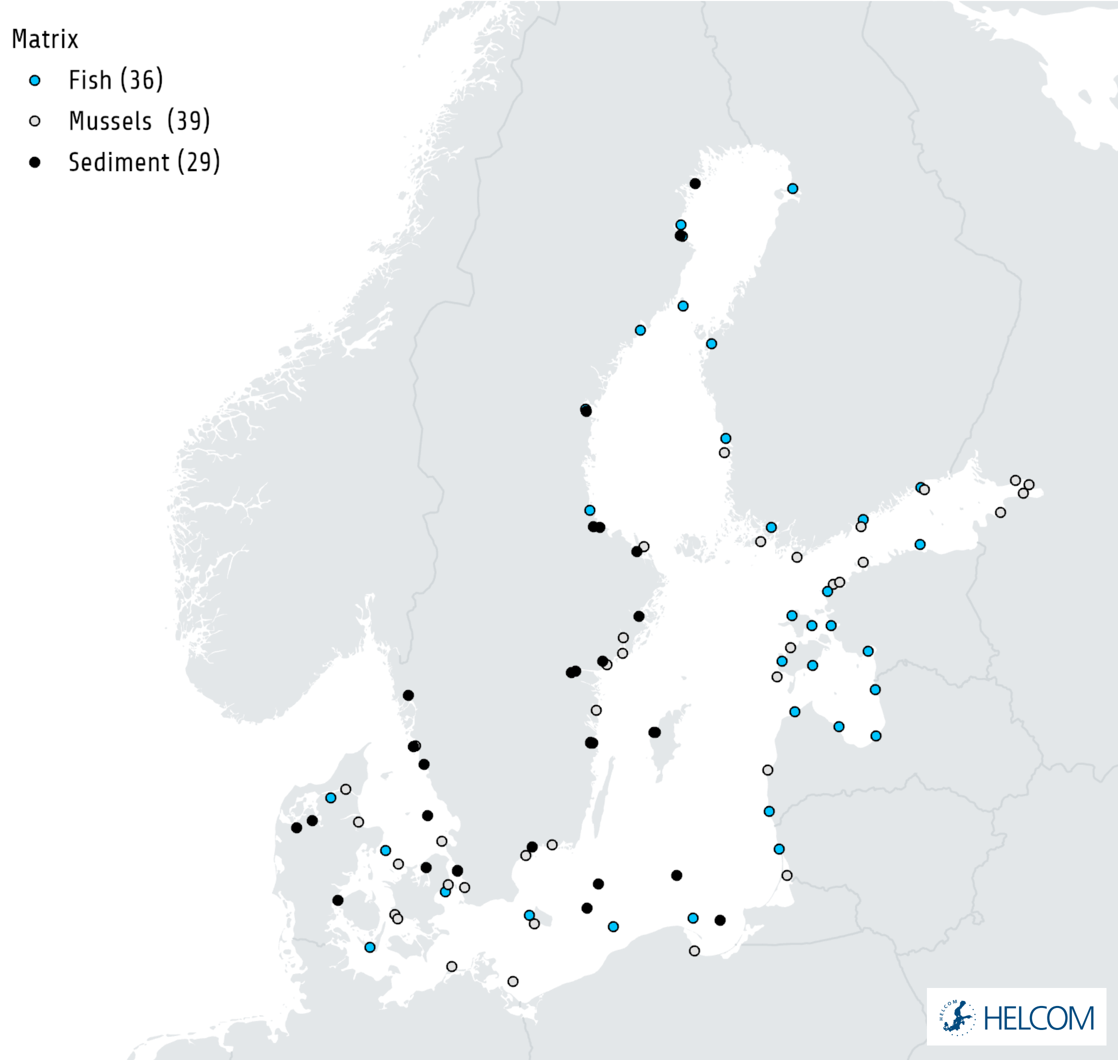


Figure 31. A visual overview of samples collected in the Baltic Sea region under the overall PreEMPT project. The spatial spread, as well as the distribution of sample matrix type (e.g. mussel, fish or sediment) is considered to be of good quality.

ing PAHs, PCBs and PFAS, n=17 of 31 samples), PCPs (n=16), pharmaceuticals (including antipsychotic and antidepressant drugs, n=10) and PPPs (n=8). Methylparaben was omnipresent in the analyzed mussel samples, followed by 3,3-pentamethylene-4butyrolactam and tributylamine, which was detected in almost 60% of the samples. 20 compounds exceeded their ecotoxicological threshold value in at least one sample, with most exceeding in less than five samples. Methylparaben seems to be of high environmental concern, as the observed concentration levels exceeded the ecotoxicological threshold value in all analyzed blue mussel samples. The PAHs pyrene and phenanthrene, exceeded their ecotoxicological threshold in 8 and 7 samples, respectively, while pilocarpine and butylparaben exceeded their ecotoxicological threshold value in 5 samples. The extent of exceedance was high for 6 compounds (methylparaben, pyrene, pilocarpine, p,p'-DDE, caffeine, naproxen) and the highest for pyrene, pilocarpine, p,p'-DDE. For 9 compounds the maximum detected concentrations were up to ten times higher than the respective PNEC, whereas for 11 compounds (diethofencarb, pilocarpine, pindolol, caffeine, butylparaben, methylparaben, naproxen, p,p'-DDE, clomazone, pyrene, 1-3-dimethyl-2-imidazolidinon) the maximum detected concentrations varied in the range from 14 (clomazone) to 1839 (pyrene)-fold higher levels compared to their respective PNECs.

Overall, from the wide-scope target screening there appear to be a number of substances (around 50) that either regular occur in a large proportion of samples and/or exceed the applied environmental threshold values used in the risk evaluation (circa 20) (PreEMPT project). In cases were substances are regularly encountered and they exceed the applied environmental threshold values (for example PFOS, prometon, or p,p'-DDE) there may be indications of a need for greater scrutiny. Other substances that also occur across multiple monitoring matrices (e.g., Methylparaben that appears to be detected in mussels, fish and sediments with high regularity) may also represent cause for scrutiny, though in such processes it is vital that chemical behaviour is also considered to ensure action is scientifically rooted and ecologically relevant. It is therefore vital that future utilization of these findings is appropriate and evaluated in detail.

Wide-scope suspect screening

In sediment samples 98 substances of potential relevance were detected with suspect screening. The risk associated with the exceedance of toxicity threshold values was assessed by comparing the measured concentrations with the PNEC values from the NORMAN Ecotoxicology Database. The detected compounds were included in the following categories: industrial chemicals with a wide number of uses (n=26), surfactants (n=17), plasticizers (n=13), chemicals used in cosmetic products (PCPs; n=12), pharmaceuticals (n=8), Plant Protection Products (PPPs n=8), dyes (n=7), phosphate esters (n=4) and phthalate esters (n=3). The PCP 3a,4,5,6,7,7a-Hexahydro-4,7-methano-1Hinden-5-yl propionate and pharmaceuticals dacarbazine and 5'methylthioadenosine were detected in all samples. A number of other substances across these categories were also detected in more than half of the analyzed samples (e.g., trimethylolpropane trimethacrylate, N-methyl-2-pyrrolidone, 2-[2(dimethylamino)ethoxy]ethanol and methacrylamide, musk and pentanedioic acid). 44 of these detected compounds exceeded their ecotoxicological threshold value in at least one sample. The PCP 3a,4,5,6,7,7a-hexahydro-4,7-methano-1H-inden-5-yl propionate exceeded its PNEC in all samples and other substances such as the industrial chemical 4-morpholinecarboxaldehyde and the PPP 4,4-dimethyl oxazolidine were also commonly in exceedance of the applied PNEC values.

A slightly higher number (123) of substances of potential relevance were detected with suspect screening in biota (fish and mussels). 76 out of the 123 detected contaminants are also registered in the European Chemicals Agency (ECHA) database, indicating that they are produced in or imported into the EU in amounts of more than 1 ton per year, with many also classified as produced at very high tonnages. 112 of these substances were detected in fish, with a slightly higher number (121) being detected in mussels. In fish surfactants (22 out of 112), pharmaceuticals (14 out 112 compounds), plasticizers (13 out of 112 compounds), PCPs (11 out of 112 compounds), PPPs (9 out of 112 compounds), dyes (7 out of 112 compounds) phosphate esters (3 out of 112 compounds), phthalate esters (3 out of 112 compounds) and PFAS (1 out of 112 compounds) were relevant. The following compounds were detected in all fish samples: the industrial chemicals butyl acrylate and 1-butanol, 3methoxy-3-methyl-, acetate, surfactants N-dodecyl-4-methoxybenzamide and 2(2-(2-(4-nonylphenoxy)ethoxy)ethoxy)ethanol and the pharmaceuticals misoprostol and threonate. The Industrial chemical Butyl acrylate and the surfactant 2-(2-(2-(4-nonylphenoxy)ethoxy)ethoxy)ethanol exceeded their PNECs in all samples. The pharmaceuticals misoprostol and 5'methylthioadenosine also exceeded applied PNEC values in the majority of samples and 57 other compounds also exceeded their ecotoxicological threshold value in at least one sample. In mussel samples a similar distribution across broad chemical groups was recorded but a larger number substances exceeded the applied PNEC values as compared to fish (83 as opposed to 57). The following compounds exceeded PNEC in all samples: PCP 2propen-1-yl 2-(cyclohexyloxy)acetate, surfactant octylphenol diethoxylates (OP2EO) and the pharmaceuticals misoprostol and telbivudine.

Screening in higher trophic level species

A recent study in livers of 30 white-tailed sea eagles from northern Germany (Badry *et al.* 2022) utilized the same wide scope target approach as described above and identified 85 chemicals. Most the detected chemicals were medicinal products (27.1%), with oxfendazole (veterinary) and salicylamide (human) being most frequent, despite generally low predicted PBT scores (Persistent, Bioaccumulative and Toxic). The large representation of medicinal products (and transformation products) is suspected to be influenced by their large representation (45%) among the 2,441 target analytes. Medicinal products were followed by chemicals of the Stockholm Convention (23.5%) with 4,4′-DDE (DDT metabolite) and PCBs being present in samples below toxicity threshold values. Among perfluoroalkyl and polyfluoroalkyl substances (PFAS), especially perfluorooctane sulphonate (PFOS) showed elevated concentrations compared to other studies. Among plant protection products (PPPs) (20%), approved (e.g. spiroxamine) and expired (e.g. simazine) substances were frequently detected with increasing concentrations in agricultural landscapes. Stable isotope analysis (δ15N, δ13C) confirmed that the investigated white-tailed sea eagles consumed mainly aquatic food (fish, waterfowl) and only a small proportion of terrestrial prey.

The same approach was applied to evaluate marine mammals. The aim of the project was to screen for potentially hazardous contaminants in marine mammals from the Baltic Sea with wide-scope target and suspect screening. For this purpose, 11 pooled liver samples and one non-pooled muscle sample from 11 marine mammals (harbour porpoise (Phocoena phocoena), common dolphin (Delphinus delphis), grey seal (Halichoerus grypus), harbour seal (Phoca vitulina)) were provided by HELCOM Contracting Parties from Germany, Sweden, Denmark and Poland, with 47 substances being detected 18 in the wide-scope target screening (EG HAZ 2022, UBA, 2022). Most of the detected compounds were PFAS, followed by plant protection products (PPPs), industrial chemicals and pharmaceuticals. The most predominant compounds were PCB 101, l-PFOS, hexachlorobenzene and 4,4-DDE (a DDT breakdown product), which were detected in all studied samples. The measured concentration levels of individual substances were benchmarked against their Predicted No-effect Concentration (PNEC) values for marine fish retrieved from the NORMAN Ecotoxicology Database and 33 compounds exceeded these ecotoxicological threshold values indicating potential adverse effects on the affected marine mammals health. Five flame retardant compounds (OPFRs) were found in at least one sample, with tris(3-chloropropyl)phosphate being present in ten out of 12 samples. Suspect screening revealed the presence of an additional 30 substances in the studied samples. These compounds included industrial chemicals 12-aminododecanoic acid and 1,3-dimethyl-3-phenylbutyl acetate (most regularly occurring in samples) followed by the UV filter octinoxate. The majority of the detected chemicals were registered in the ECHA database indicating their annual high tonnage production.

Value of and future development related to screening

The findings from this first Baltic Sea regional screening, as summarized in the forthcoming PreEMPT project report, provide the first step in achieving BSAP action HL28 to 'address substances of emerging concern by commencing recurrent screening campaigns starting from 2021 including broad analytical techniques such as suspect screening and non-target screening methods'. These results are also direct evidence of the extensive nature of pollution by hazardous and potentially hazardous substances and thus support the need for a thorough and preemptive approach to their management. The overview of substances provided by this initial regional screening study is significant and offers useful insights for scientists and managers alike. While the information gathered in such processes is a major development step it is also important to note that no detection cannot from such studies alone be taken as absolute absence (due to detection limits etc.), relevance of the applied PNEC values may need further consideration, absence in the current evaluation does not preclude future inputs or detection, and there are also substances detected for which no identity can currently be assigned. Therefore, the findings require further analysis to appropriately utilize them beyond this generalist level, a process currently underway within the HELCOM Expert Group on Hazardous substances (EG HAZ). The process may for example result in the development of a surveillance indicator that can provide an early warning in relation to substances that are not currently extensively monitored but require action of scrutiny (I.e., an evaluation of risk). To achieve such ends a close examination of the ecotoxicological threshold values currently used would be needed, longer term data may be required, more details may be needed across the management framework or lifecycle of a substance (e.g., understanding of sources, inputs and pathways or compartmentalization within the ecosystem (selective accumulation in biota or sediment, etc.)), designated follow up on selected substance may be required (including a prioritization process) or in certain cases monitoring effort may be needed to carry out full scale evaluations of substances or substance groups. The possibility to also explore the value of such data and approaches in food web studies is also likely relevant for the future. Thus, this initial study will provide significant input to the science driven management of the Baltic Sea and will also contribute directly to the work on BSAP actions HL1 and HL10 (see Information Box 1).

3.4. Relationship of hazardous substance to drivers and pressures/biodiversity

Placing status evaluations, such as the indicator evaluations and integrated assessment outcomes described above, within a conceptual management framework such as DAPSIM (Drivers-Activities-Pressures-State-Impact-Measures) can provide added value. Since humans are part of the ecosystem and use it for their own ends and in essence humans can only place measures on our own activities (with the exception of some, often costly and complex, restoration approaches) then these conceptual management frameworks provide the possibility to understand where our activities influence the balance and health of the marine environment and thus ultimately where we need to place measures (actions). Since degradation of the environment, especially by factors that are all permeating like hazardous substances, is generally accepted to be more complex and costly (and on occasions impossible) to reverse, then such management or casual frameworks can provide an insight into the linkages between the components, for example how human activities lead to pressures and influence state or create impacts, and thus how such chains can be mitigated or prevented from causing a deterioration of ecosystem health. The reality of the issue is however far more complex and for hazardous substances a number of issues need to be considered in relation to the following sections. Firstly, the level of information and data needed to solidly and appropriately create links in such conceptual management frameworks needs to be high and in most cases the knowledge and data simply does not exist (or at least not in suitable form) currently. Secondly, the vast pool of hazardous substances with occurrence in the environment makes this process increasingly complex especially if attempting to trace these to uses or source. Lasty, the following section explores this topic in general terms and only provides a few concrete examples for selected sections where information is available.

3.4.1 Drivers and activities

Drivers are often large and disparate entities that are hard to identify and quantify, for example globalization, consumer trends or political will. To identify drivers and attempt to evaluate and qualify/quantify them, the use of proxies is often useful. However, even this type and level of information or data is currently quite sparse for hazardous substances in general. In addition, drivers (or driver indicators and proxies) are reliant on complex and often multiple interactions (e.g., product demand requiring manufacture and thus use of a new substance) as well as operating on differing scales within this network, making their definition and direct quantification problematic. Other issues that need to be considered is the separation between drivers and activities, especially when applying proxies, in the development of driver evaluations, and that political or societally sensitive issues (e.g., many pharmaceuticals are vital for human health) may also be encountered. The general concept plus a methodology and approach established for HOLAS 3 to explore drivers and potential driver indicators is also set out in the Thematic Assessment on Economic and Social Analyses and a few examples of how such work can be useful are available for other topics such as nutrients (Agricultural Nutrient Balance and Wastewater Treatment) and fish (Fishery Operation and Total Allowable Catch).

In general terms drivers motivate changes in human activities and thereby alter pressures such as inputs of substances to the marine environment. It can therefore be difficult to uncouple the proxies for driver indicators from the activities in question. Certain human activities such as appropriate waste disposal (including medicines) or avoidance of certain chemical containing products have more obvious connections to reducing potential releases of hazardous substances, however others are far more complex due to the network of activities through production of a substance to application of it in a product and then subsequent release during use and appropriate disposal. All steps in the lifecycle of the substance therefore play a role in the potential impacts on, or health of, the environment, in addition to the fate of the substance(s) across the relevant pathway(s) prior to reaching the Baltic Sea.

Certain trends may be indicative of drivers and activities, for example, the sales or prescription of pharmaceuticals or the sales/usage of plant protection products (PPPs). Since these types of substance have a clear and direct link between components in a conceptual management framework such as DAPSIM then they may represent the more straightforward substance types on which such driver and activity work could be better developed in the future, however even these are complex and need to be handles carefully. Under the MetDev project the consumption and sales of the pharmaceutical diclofenac and the level of advanced wastewater treatment were both explored as possible proxies for driver indicators with relevance for hazardous substances, but in both cases regional experts concluded that the underlying data could not support substantial conclusions. However, the work is briefly summarised here to provide a conceptual overview on the topic.

As described in the HELCOM pre-core indicator on Diclofenac and in other summaries the substance is regularly found in wastewater treatment processes and also recorded in the marine environment (Undeman, 2020, HELCOM 2022). One widely available statistic in relation to the use of diclofenac is the Defined Daily Dose (DDD, Figure 32), a value also commonly used for other pharmaceuticals. However, while DDDs provide solid data for regional and temporal trends there are complications in using such statistics alone as they do not cover all products (e.g., topical creams for example), changes at the sub-regional level may be relevant (e.g., country specific aspects), changes in prescription levels and sales of over the counter products are not reflected (Undeman, 2020), and when applying such approaches to other pharmaceuticals there may also be a need to consider multiple Active Pharmaceutical Ingredients (APIs). Moreover, in addition to adequately covering all uses, to make such information relevant there is a need to be pair it with an understanding of the pathways between use (e.g., DDDs) and the Baltic Sea marine environment as a change in DDDs is not per se a direct reflection of a change in status or impact in the marine environment. A further complication in such processes is also comprehending and defining the link with drivers as multiple components may be at play simultaneously, for example such medication may be more utilised in an aging population or during certain seasons, regulation of prescription may be counterbalanced by sales of over the counter options containing the same API, advertising of certain products may influence their sales/use, and the balance between political will to regulate use and the significance for human health are relevant.

A vast array of micropollutants have been detected in various phases of the wastewater treatment process and dependant on the type of treatment system employed substances are more or less effectively eliminated prior to release of effluent waters. In certain cases some substances are also unchanged by the process and are transferred to the environment relatively unaltered and even at similar concentrations to that at which they entered the process (HELCOM 2022). Advanced wastewater treatment technologies, and improved development of such processes, has been identified as one option that can be utilised to impact on emissions of hazardous substances and thus reduce the chemicalisation of the environment (Baltic Eye policy brief, 2017). Such information, i.e., the type, effectiveness and scale or connectivity of the system could represent a viable and relevant proxy worthy of application as a driver indicator. In the current process towards HOLAS 3 the expert community involved concluded however that the quality of the available data was unfortunately not sufficient to further develop the analysis as reported information was not available for all components, the characteristics of advances treatment plants (from which effectiveness could be derived) is not currently gathered, and harmonisation is needed in data reporting so that effectiveness can be appropriately classified. The concept however does have significant promise and if data quality and harmonisation were improved it may also offer a clear path for setting target input levels to limit the release of hazardous substances from wastewater treatment processes.

3.4.2 Inputs, pathways and pressures

Inputs of hazardous substances may not be direct to the Baltic Sea marine environment and prior to entering the Baltic Sea they may transfer along certain pathways, such being processed through wastewater treatment plants (WWTPs), passage along rivers, or even long-range atmospheric deposition. There are also other sources that result in diffuse or uncertain inputs, such as those from historic wrecks or for example from dumped conventional or chemical munitions (see Information Box 2). Irrespective of the input source or pathway, once substances enter the Baltic Sea they have the potential to have direct and indirect harmful impacts on the species, habitats or environment as a whole by individually and/or cumulatively (potentially even at low concentrations) exerting pressure. Some relevant inputs are also addressed in Baltic Sea Environmental Fact Sheets (BSEFS).

Inputs and pathways of hazardous substances reaching the Baltic Sea environment and even the pressures they exert, or at

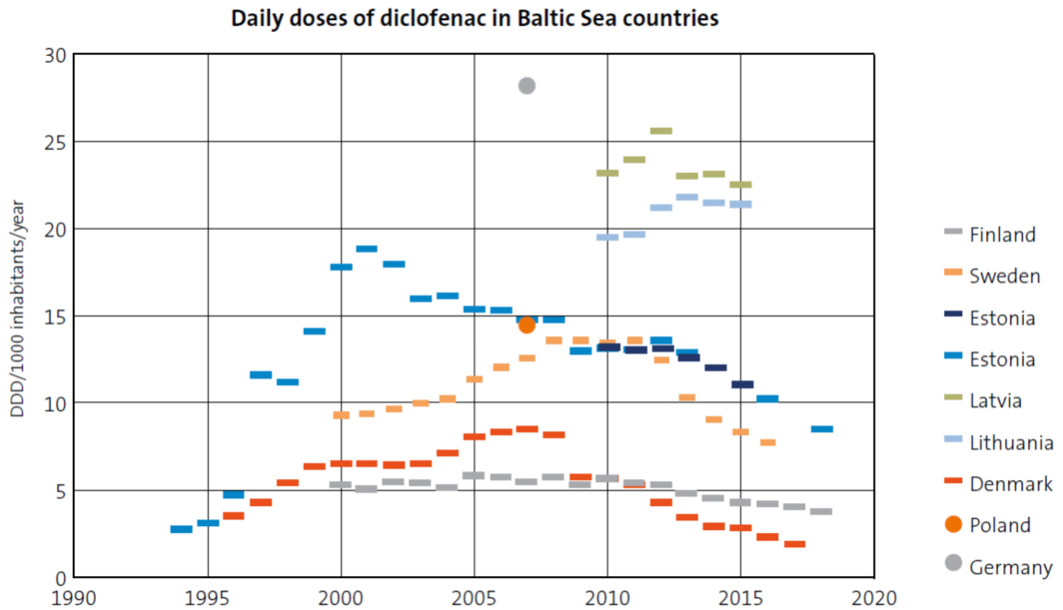


Figure 32. Defined daily doses (DDD)/1000 inhabitants/year for Baltic Sea countries. The ATC codes included are given below. The ATC code that contributes the majority of the total DDDs in all countries is M01AB05. For Estonia, data were available from two different sources that differed slightly. Note that topical use of diclofenac (e.g., in gels) is not included as these applications lack a DDD. Source: Undeman, 2020.

least the process by which they are exerted, differ widely. They may differ between substances or substance groups and in cases there may be multiple channels even for a single substance or group of substances. For example, due to their chemical nature and behaviour certain substances (or groups) may associate more strongly with organic carbon and therefore accumulate in sediments whereas others may be lipophilic and thus associate more strongly with biota. Such factors influence not only the appropriate monitoring required but also the impact and role of substances in the environment as in addition to pressures from direct exposure aspects such as bioavailability and bioaccumulation (or biomagnification in food webs) is key. However, one factor that remains straightforward is that concentrations of manmade substances, in particular where those concentrations exceed known quality or risk levels, exert pressure on the Baltic Sea ecosystem and its species and habitats and that such pressures may be exerted independently and/or as multiple mixed (cumulative) effects.

While no over encompassing synopsis of all inputs and pathways leading to pressure is available for the pool of hazardous substances in the Baltic Sea, certain selected sources, pathways and inputs can be characterised to provide an understanding of some key areas. Inputs may for example be through riverine inputs, wastewater treatment plant (WWTP) effluents, atmospheric transport and deposition, redispersal of substances in dredged material, releases from shipping, spill events, or submerged items.

There remains however a need to further develop a stronger understanding of hazardous substances (as a whole and individually in certain cases) at all stages of a conceptual management framework to better support the achievement of Good Environmental Status (GES). Filling of such knowledge or data gaps, aligned with improved conceptual development of relevant tools will support better management, for example the work on BSAP action HL1 or further development of work under the Economic and Social Analyses horizontal topic in the BSAP (e.g., Sufficiency of Measures).

Wastewater treatment processes

Wastewater treatment plants (WWTPs) have been identified as a key point source for contaminants entering the Baltic Sea. The large population in the surrounding catchment area in associated with generally high levels of connectivity to the municipal wastewater system result in a large number of hazardous or potentially hazardous substances (including new and emerging substances) occurring at elevated concentrations. Since WWTPs also act as a fairly direct pathway between abundant human populations and the Baltic Sea environment they also provide a rapid route for the transfer of, for example, household or personal care products to the environment. Furthermore, to enhance efficiency it is not uncommon for industrial wastewaters to also be combined in municipal treatment facilities. A combination of these factors results in WWTPs being focal points for the accumulation, and subsequent release, of hazardous substances, especially if no effective breakdown or removal occurs. Although the role of WWTPs in relation to nutrient inputs has broadly been explored there remains some distance to go comprehend the complexity and fate of the pool of hazardous substances that enter treatment processes and in particular to covert such knowledge into policy and action (e.g., upgrading WWTPs to adopt best available technologies, adapted to the influents).

The scope and complexity of the issue is highlighted by the published studies that document large volumes and large numbers of substances. It is estimated that ~5.8 billion m^3 of wastewater are emitted annually in the Baltic Sea catchment (by the end of the 2010s, Undeman *et al.* 2022b) and within a large regional data set 280 substances were found to regularly occur. The same study also highlighted the array of substance groups occurring, including: metals, organophosphates, pharmaceuticals (pharma), fluorescent whitening agents, phthalates, bisphenols (BPs), phenols, pesticides, polyaromatic hydrocarbons (PAHs), ultraviolet filters (UV), organotin compounds, hormones, per- and polyfluoroalkyl substances (PFASs), polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins and dibenzofurans (dioxins). Mass loads to the Baltic Sea were also estimates for commonly occurring substances, for example indicating loads of pharmaceutical in the range of tens of kg per year (paracetamol, 17) to thousands (Diclofenac 1168), and also identified other chemicals potentially of emerging concern, such as fluorescent whitening agents and UV stabilizers, sometimes at levels of substances that are monitored in depth, but that are broadly not evaluated in the region (Undeman *et al.* 2022b).

The HELCOM report on micropollutants in wastewater and sewage sludge (HELCOM 2021b) explores substance groups and the impacts of the wastewater treatment process on their concentrations. Some substances are markedly depleted or transformed in the process while others remain relatively unaffected, with high concentrations retained in effluent waters or sludges. Phenolic substances are generally measured in relatively few samples, though are often detected in a high percentage of samples in which they are measured. However, they generally occur at levels below current environmental quality standards. Polyfluoroalkyl substances (PFASs) were detected regularly (in particular PFOS and PFOA) and in relatively high concentrations in influents, effluents or sludge. The partitioning of them across the WWTP process indicated that many are not removed, with PFOA even appearing in higher concentrations in effluents than in influents. For PFOS, the group for which an environmental quality standard is available, these often also exceeded the current environmental quality levels significantly. Metals on average did not show exceedance of relevant environmental quality standards, however individual samples did. Pharmaceuticals were also widely detected, with over 100 substances within 11 main groups being encountered. Of these the concentrations of number of substances (e.g., diclofenac and estrone) across all therapeutic groups were shown to remain relatively unimpacted by the WWTP process and also exceeded current environmental quality standards.

Riverine inputs and Atmospheric deposition

Information on the key components and pathways of riverine inputs and atmospheric deposition are available for a few selected priority substances, with some additional substances also having relevant data (e.g., decreasing trends in atmospheric deposition of PCBs or dioxins; HELCOM 2021b). The data collated for the period 2015-2017 suggest that inputs of cadmium most strongly come via riverine inputs while mercury and lead predominantly occur as a result of atmospheric deposition. The actual total amount of input also differs markedly between the substances, with 27, 5.3 and 356 tonnes per year being recorded for cadmium, mercury and lead, respectively. Only a small amount is considered to come from point sources (Figure 33).

It is also important to note that atmospheric deposition has also generally declined for these substances since the 1990s (Ilyin *et al.* 2020; and HELCOM 2021b). Riverine inputs are generally harder to evaluate for clear trends due to inter-annual variation (e.g., associated with rainfall), but where near complete data series exists for the period of 1995-2018 there are indications of some decline in inputs (HELCOM 2021b). Another trend that prevails in such data is also that the larger rivers generally result in larger relative inputs.

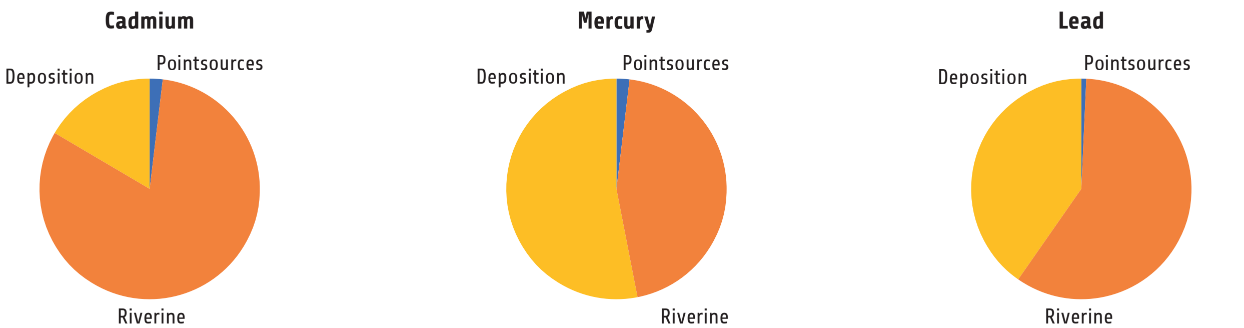


Figure 33. The division of inputs of cadmium, mercury and lead from point sources, via rivers, and atmospheric deposition to the Baltic Sea based on average inputs 2015–2017 (HELCOM 2021b).

Dumped munitions (conventional munitions)

In addition to dumped chemical munitions (Information Box 2) a large amount of conventional warfare materials also contribute to the abundance of hazardous submerged objects in the Baltic Sea. These legacy point sources of pollution are not specifically considered under pollution evaluations or policy (for example the EU Marine Strategy Framework Directive, MSFD) due to the fact that they are often explosives that may represent a direct risk to ships or fishermen encountering them. As such the responsibility often lies with shipping administration, maritime spatial planning offices, police authorities, and national marine protection authorities. The Baltic Sea Action Plan 2021 included action S34 to carry out a comprehensive risk assessment and action S35 on gathering data and mapping underwater munitions. Based on such assessments, resources could be deployed in the future to focus on the most urgent sites for remediation operations as well as devising appropriate monitoring to evaluate their contribution to the contaminant pool of the Baltic Sea.

Dumped warfare materials and munitions deployed during combat pose a direct risk of explosion, especially in their aging and corroded state, with this latter aspect also representing a potential source of release of hazardous substances into the marine environment. Compounds related to explosives and their degradation products have also been detected in fish close to dumping sites (Koske, 2020, Maser *et al.* 2023). Explosives and their degradation products are toxic, mutagenic and carcinogenic (Bolt *et al.* 2006) and therefore harmful to the marine ecosystems. As well as mapping these submerged objects and developing risk assessments the issue of action will also need careful consideration as standard techniques such as removal may be unsuitable, while detonation can have significant consequences for noise sensitive species. It is however also vital to understand the consequences of simply leaving them undisturbed as such an approach could result in significant releases of hazardous substances to the marine environment, the biological effects and food web transfer effects of which are broadly poorly understood (forthcoming HELCOM 2023 - Hazardous Submerged Objects in the Baltic Sea report). Further work on this issue is maintained under the Expert Group on Environmental Risks of Submerged Objects (EG SUBMERGED).

Dredging and dredged material

Dredging commonly takes place in areas around ports or shipping lanes to maintain safe access. These areas are by nature of their use prone to being influenced by human activities and can be expected to have loads of hazardous substances associated with for example maritime traffic or leisure boating, for example historic tributyltin (TBT) deposits, copper or other heavy metals. Thus, the disturbance and re-depositing of the moved sediment material may also transfer or re-release hazardous substances to the surrounding area at both the extraction and dumping site. There is, however, likely a significant sub-regional variation as the specificities of each dredged zone, including the type and load of hazardous substances present will differ. This is also reflected in the outcomes of published studies that indicate a range of conclusions from dredged sediment being relatively uncontaminated (Staniszewska and Boniecka, 2018) to the potential for dredged

Box 2

Dumped chemical munitions in the Baltic Sea – action required to prevent environmental impacts

The Baltic Sea Bornholm Deep was the main recipient of chemical warfare materials after the demilitarization of Nazi Germany in 1947. A total of approximately 32,000 tons of chemical warfare materials containing approximately 11.000 tons of actual chemical warfare agents (CWAs), such as mustard gas, Adamsite and others, were dumped in the Bornholm Deep in designated primary, secondary and tertiary dump sites. Since then, re-dumping of incidentally caught gas lumps and munition fragments by fishermen has taken place in the vicinity of Bornholm. The Bornholm Deep has therefore also been subject to most environmental studies. However, it is currently not possible to provide sound quantification of the amounts of CWAs which have or have not yet been released due to corrosion of their metal casings and thus the scale and seriousness of future environmental risks remains a knowledge gap. All published and peer-reviewed data on water and sediment measurements across the Baltic Sea from known dumped chemical warfare agents (CWAs), and their degradation products, since 2006 has been collected in a review (submitted to the Journal of Hazardous Materials, by Fauser *et al.* 2023). In the review the environmental risks of the 872 sampling sites where CWAs have been identified were screened. Potential cumulative CWA risk was currently identified for multiple sites. The organoarsenic CWAs such as trichloroarsine, Adamsite and Clark I have the highest potential aquatic risk profiles due to their high toxicity towards crustaceans. These CWAs have detection frequencies in the samples collected in the sediments surrounding the dumping areas of 48%, 6%, and 1.5%, respectively. The mustard gas degradation products 1-oxa-4,5-dithiepane and 1,2,5-trithiepane, both indicate a potential aquatic risk – these two compounds have the highest detection rates among the mustard gas degradation products at 27% and 26% occurrence. There is generally sparse environmental toxicological data regarding CWAs and their degradation products. This results in high uncertainty (assessment) factors between 500 and 10000 in the marine environmental risk assessment. Hence, the marine environmental risk assessments should be improved by generating more comprehensive toxicological data on select CWAs. The assessments could lead to the generation of Environmental Quality Standards for these compounds and thus significantly reduce the uncertainty factors and improve the risk assessment. The improved risk assessment should inform the potential risk management options and ensure that the risk management is both; risk-based, quantitative, scientifically sound, and cost-effective relative to desired environmental protection objectives.

material to have harmful effects on the Baltic Sea environment and biota (e.g., Kucharski *et al.* 2022).

The HELCOM Expert Group on Dredging/depositing Operations at Sea (EG DREDS) collects and summarises the reported regional information on volume and location of dredged material in the Baltic Sea on an annual basis in the form of a Baltic Sea Environmental Fact Sheet (e.g., HELCOM 2020b). These summaries also include information on the load of selected priority substances. The amount of material dredged varies between years but in 2020 for example around nine million tonnes was deposited at 106 sites, with a little over half of this material being from capital dredging compared to maintenance dredging. Of this around seven million tonnes came from harbours and river estuaries. In general, the dredged material in 2020 was deposited at locations offshore, however some dredging does also occur for the purpose of beach nourishment and such activities. In the dredged material levels of mercury, lead, cadmium, copper, tributyltin and polycyclic aromatic hydrocarbons were reported. In general concentrations of these hazardous substances in the current assessment period remained somewhat stable and lower than values recorded in 2014 or before (mercury 0.5-1 tonne, lead 60-140 tonnes, copper 70-140 tonnes and polyaromatic hydrocarbons <2.2 tonnes), however cadmium has increased from around 1 to 6 tonnes since 2017 and although lower (20 tonnes) in 2020 TBT increased from <10 in 2016 to >60 tonnes in 2019. The large majority of the pollutant load originates from sediments transported from harbours and rivers and these values represent a significant contribution to the potential contaminant pool, though it is important to note that to truly evaluate the topic some form of source apportionement evaluation would be needed.

Maritime activities

Maritime activities such as shipping can contribute hazardous substances to the marine environment through spills of oil, as addressed for example under the Oil spills effecting the marine environment HELCOM core indicator (Oil spill indicator), through other unidentified substances spilt in the Baltic Sea or released during cleaning activities (for which little information on identity is generally available), through the release of substances in grey and bilge waters (sewage release banned under MARPOL convention Annex I, with final exemption to expire in June in 2023), and also via releases from exhaust and scrubber fumes. In 2021 the total volume of discharge water from Exhaust Gas Cleaning Systems (EGCSs or scrubbers) was circa 286 million cubic meters and mainly the product of open loop systems. In general, these discharges also appear to be increasing. These discharges may represent important contributions of certain hazardous substances to the marine environment and further evaluation may be warranted. For example, a recent study concluded that open loop scrubber systems generate as much as 8.5% of the total load of the Polyaromatic hydrocarbon (PAH) anthracene to the Baltic Sea (Ytreberg *et al.* 2022).

3.4.3 State and impacts, including relationship with biodiversity and humans

Pressures and status are broadly covered in the main section of the report that provides the results from the indicator evaluations, integrated assessment and pilot studies on screening and biological effects. The indicators evaluating substance or substance group concentrations and the integrated assessment of these provide an insight into the level of pressure as a result of hazardous substances concentrations in the Baltic Sea. These pressures are generally above, in many cases markedly above, acceptable conditions (sub-Good Environmental Status, sub-GES) for most assessment units in one or more of the monitored substances (see section 3.3). These pressures also have clear consequences for biodiversity, as highlighted by the biological effects pilot study (see section on 'Integrated biological effects of contaminants pilot study') and by clear exceedances of threshold values for acceptable concentrations in biota (e.g., within indicator evaluations). The outcomes for example of the biological effects evaluation (and future developments of it) can also reflect the state of biodiversity and are also reinforced by screening studies in higher tropic level species (see section on Screening and other emerging substances or risk identification) and research studies that document the consequences of exposure to hazardous substances, including on sentinel species (e.g., Sonne *et al.* 2020). From such evaluations, in addition to the designated status assessment of biodiversity (see Thematic Assessment on Biodiversity), it is possible to determine what the impacts on biodiversity and habitats (i.e., the Baltic Sea ecosystem) are, and thereby determine what measures are relevant to employ to lessen or eliminate these impacts. Likewise, hazardous substances may also impact on human wellbeing. In the case of hazardous substances these impacts may be reflected for example by the failure to achieve threshold values in indicators that apply human health or food stuffs, or may be derived from economic and social studies that reflect the financial implications of failing to achieve GES (see Thematic Assessment on Economic and Social Analyses). Both routes of impact, on biodiversity and humans, offers a clear stimulus and direction for potential measures.

3.4.4 Recovery and understanding trends and natural conditions

Hazardous substances in the Baltic Sea environment can be categorised in a number of different ways. In broad terms they are often prioritised on the basis of knowledge related to their concentrations and/or toxic effects (i.e., making them 'priority substances'), as well as aspects related to their chemical behaviour. Among the broad categories applied there are legacy substances (substances generally with historic levels but often restrictions or measures and low or zero current inputs) or substances of emerging concern (new substances where concentrations are increasingly detected in or connected to the marine environment), and these substances are often described based for example on their propensity to be Persistent, Bioaccumulative and Toxic (PBT substances). Thus, in addition to addressing the vast abundance of different substances in the Baltic Sea, substances categorised as hazardous are by nature rarely easy to rapidly rectify in terms of status. This further reinforces the need for holistic and precautionary or pre-emptive management as once such substances hit the marine environment, and especially if they become widely dispersed, remediation or recovery can be problematic or prolonged.

For the hazardous substances and marine litter segments the BSAP 2021 has the goal of a 'Baltic Sea unaffected by hazardous substances and litter", supported by objectives that include that aim of having 'concentrations of hazardous substances are close to natural levels'. Due to the extensive chemicalisation of the environment and the persistent nature of many hazardous substances this is a complex task to navigate. While defining effect concentrations and establishing threshold values with appropriate protective properties can be achieved for example via experimental studies natural conditions can be more complex to define, especially for substances or substance groups that also have natural levels in the environment (e.g., metals) or in certain cases substances that also have a biological purpose (e.g., copper is an essential element at low levels). Sediment cores dated and analysed systematically can however offer such insights by providing an evaluation of background concentrations of hazardous substances at pre-industrialised levels. This information can also support the development for example of background assessment concentrations (BACs). Furthermore, such approaches can also provide insights into trends in hazardous substances that can highlight accumulation (e.g., of new and emerging substances) or decreases in substance concentrations that may reflect recovery (see Information Box 3).

Trends within the indicators (e.g., trends over time at a station) and also between this current (HOLAS 3) and prior (HOLAS II) assessment period are outlined above (section 3.3.1). There are also published examples showing improving trends, such as long time series studies of PAHs in mussels (Ek *et al.* 2021). Due to the persistent nature of many of these substances the rate of improvement is also often slow and can be influenced by local or sub-regional factors (e.g., anoxia or other physicochemical factors as well as human induced ones). It is therefore vital to also understand the potential lag phases in recovery, in particular when it comes to establishing or considering new measures. For some of the legacy contaminants that are well regulated, mercury being a good example, the local or regional measures may in general be well applied yet long range atmospheric transport (from waste disposal, combustion and artisanal gold mining in particular) still represent new inputs. However, despite overall clear reductions in inputs for certain substances it is apparent that recovery is not a rapid process and time lags often extend beyond the periodic time scales of standard management cycles (e.g., BSAP or MSFD processes generally occurring every six years). Such information can also be important for HELCOM Contracting Parties that are also EU Member States as it can contribute to the reporting of exceptions (reasons for not achieving GES) that are scientifically justified (for example under MSFD Article 14 in cases where all viable measures are already implemented yet GES is still not achieved).

The issue of recovery lags will also be influenced by the enclosed nature of the Baltic Sea (acting as a sink for contaminants and with limited water exchange), the large catchment area (including areas not directly under the jurisdiction of the fill Contracting Parties), long range atmospheric inputs, as well as the likelihood for certain parameters to accumulate for example in sediments. Activity 5 of the HELCOM ACTION project explored such issues for certain priority substances (HELCOM ACTION 2021). For mercury a number of issues have been identified that can influence recovery. These include runoff from historic contamination within the catchment, changes in land use, replacement of natural surfaces in urbanised areas, and storm or flooding events. Such issues have been shown to influence the coastal environment due to (in the Atlantic Ocean) the long residence time of Hg in catchment soils (Cossa and Tabard, 2020; Burgess *et al.* 2013). In the Baltic Sea increases in terrestrial matter resulted in increased methylmercury (MeHg) bioaccumulation in zooplankton (Jonsson *et al.* 2017). Precipitation (Bełdowska *et al.* 2014; Saniewska *et al.* 2014c, 2018; Saniewska, 2019a), snow melt (Gębka *et al.* 2019), river flow

Box 3

Sediment cores show the time trends of hazardous substances

Sediment cores provide an archive of pollutant levels in the aquatic environment over time, providing the substances in question are not degraded in the sediment. This is the case in accumulation areas, where particles with associated pollutants continuously sediment from the water column and form new layers on the sea floor. Pollutant levels in the sediment surface layer reflect the most recent years, with gradually older sediment downwards in the sediment core. By analysing and dating different levels in the core, the levels of hazardous substances and corresponding years can be determined. This reveals if trends are decreasing or increasing in the environment. The retrospective time trend analysis of sediment cores is therefore useful to assess the efficiency and sufficiency of implemented measures, as well as providing signals for new and emerging compounds.

Priority metals have been analysed in several sediment cores throughout the Baltic Sea, and many metals display decreasing trends over time. One example is mercury, whose levels have decreased in many locations from the high levels in the 20th century, for example in the Bothnian Bay where levels were highest around the 1960s (Figure 3.1). This is a result of the bans and restrictions on the use of mercury that have gradually been implemented. On the other hand, mercury levels are still elevated compared to the lowest (background) measured levels in different locations, and in the southern basins of the Baltic Sea, levels are not decreasing in all cores.

Compared to metal core studies, few studies on organic pollutants exists, leading to a lack of data encompassing many Baltic Sea basins. Often the studies have been performed on a few sediment cores in one country. Persistent organic pollutants concentrations are usually stable over long time in anoxic sediment and cores are thus suited for documenting trends in the environment. One group of substances of concern are the fluorinated compounds, the PFAS. A recent study in the Gulf of Finland showed that PFAS levels are increasing, with the highest levels occurring in the surface layer of two of the four cores (Figure 3.2). For two of the cores there appears to be a maximum level around 2010, in one case increasing again. These results show that more efforts are needed to decrease emissions of PFAS to the Baltic Sea.

In the future, sediment core studies on substances of interest should be coordinated among HELCOM member countries to ensure larger geographical coverage. This can provide vital information on the efficiency of measures or the need for further restrictions, particularly for emerging substances that have not been routinely monitored in surface sediments.

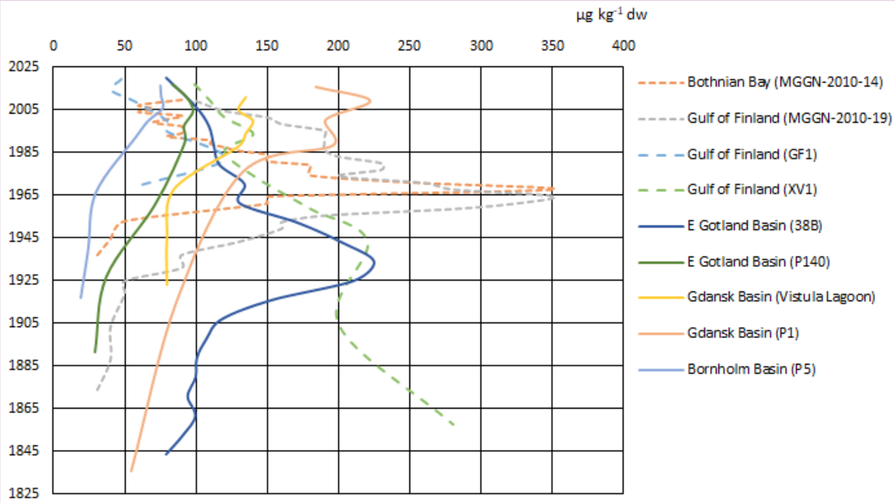


Figure Box3.1. Levels of Mercury(Hg) in sediment cores from different parts of the Baltic Sea. Analytical and normalisation methods may differ between cores. The dating of core XV1 in the Gulf of Finland is uncertain and data from before 1986 are approximate. Data from Vallius 2014, Zalewska *et al.* 2020, and unpublished data from V. Junttila, R. Poikane and T. Zalewska.

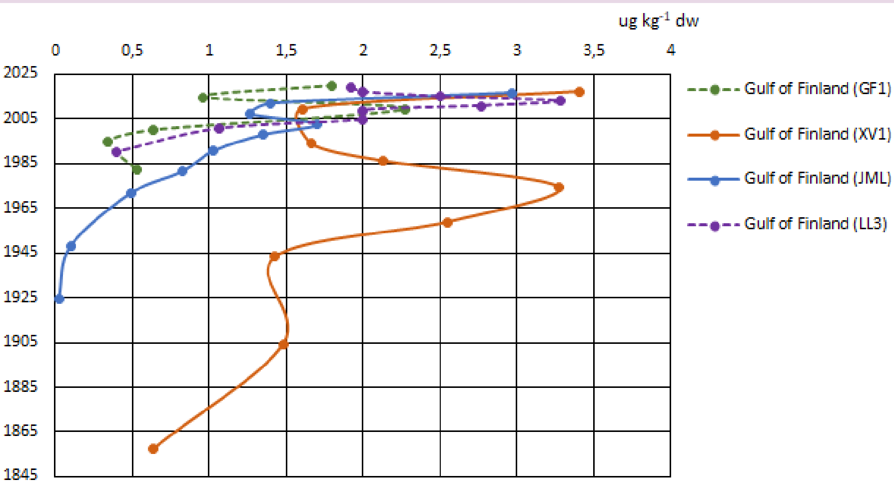


Figure Box3.2. Levels of per- and polyfluorinated alkyl substances (PFAS) in four sediment cores from the Gulf of Finland. Levels calculated as sums of all analysed PFAS compounds. Unpublished data from V. Junttila.

(Lawson *et al.* 2001; Saniewska *et al.* 2014a, 2018; Saniewska, 2019a; Bełdowska *et al.* 2014), storm events (Kwasigroch *et al.* 2018) and retention capacity of the catchment area (Lawson *et al.* 2001; Babiarz *et al.* 2012; Bełdowska *et al.* 2014; Saniewska *et al.* 2014a, 2018; Saniewska, 2019a) can also influence inputs and thus status. Moreover, despite concentrations of Hg in the white-tailed eagle (body feathers of a Swedish sub-population) showing a clear decline of 70% from 1967 to 2011 the concentrations still remained well above natural background concentrations (Sun *et al.* 2019). Several of these parameters also have potential relevance in a changing climate.

Information is also provided in the 'Conditions that influence Good Environmental Status (GES) in the Baltic Sea' report (HELCOM ACTION 2021) on other heavy metals (Cadmium and lead), Polyfluoroalkyl substances (PFASs), some pharmaceuticals, and tributyltin (TBT). TBT has been shown to have wide ranging retention times in the marine sediments that might last from months to tens of years depending on the specific conditions (Jokšas *et al.* 2019; Takeuchi *et al.* 2004; Viglino *et al.* 2004), while for pharmaceuticals and PFAS there is a need for more information to make clear predictions on time lags. However, PFAS compounds have increasingly become recognised as substances that persist and are widespread (e.g., John *et al.* 2022), being regularly referred to as 'forever chemicals'.

3.4.5 Climate change

Climate change is expected to have significant effects on the Baltic Sea (HELCOM and Baltic Earth 2021), however the detailed understanding of how climate change interacts with hazardous substances is relatively limited. In the Baltic Sea there are somewhat few studies that explore the issue (e.g., Schiedek *et al.* 2007), but many focus on very specific topics or interactions, for example dissolved organic carbon and temperature-contaminant interactions (Ripszam *et al.* 2015), fish-contaminant interactions (Hansson *et al.* 2020), or bacterial community- contaminant interactions (Rodríguez *et al.* 2018). Moreover, most of these studies are more conceptual in their approach, exploring effects on or related to biota, and few look purely at changes in inputs or compartmentalisation in the environment. This lack of a detail regional overview is also acknowledged by the Joint HELCOM/Baltic Earth Expert Network on Climate Change (EN CLIME) group which they aim to address in future work.

A number of physiochemical parameters that are directly affected by climate change (termed direct parameters, HELCOM and Baltic Earth 2021) are likely to have relevance for hazardous substances, for example: water temperature, atmospheric circulation, solar radiation, stratification, precipitation, river runoff, and sediment transportation. Changes in pH may also influence the solubility and re-release of metals. Similarly, some of the indirect parameters (HELCOM and Baltic Earth 2021) identified are also relevant, such as: oxygen concentrations, microbial processes, non-indigenous species, and ecosystem function. In general terms temperature influences chemical and biological processes, atmospheric circulation could change established deposition patterns, solar radiation may influence biological processes (e.g., primary production) and breakdown rates of sensitive substances, and precipitation, runoff, stratification, and sediment transport may influence inputs or mixing and compartmentalisation of substances in the marine environment. Indirect parameters such as changes related to non-indigenous species, microbial process or ecosystem function (e.g., food web structure and function) all have the potential to markedly alter substances (e.g., methylmercury production) or influence transfer of substances in within the ecosystem.

The HELCOM hazardous substances indicator reports generally provide a short overview of climate change in relation to the specific substance or substance group addressed, and this section aims to provide some generalised linkages of relevance. Elevated rainfall (and storm events) is expected to increase river discharge in the northern Baltic, while result in decreases in the south (HELCOM 2021b). Heavy or increased rainfall is likely to disturb areas where historic contamination may exist (e.g., areas around ports where TBT may be deposited) and increase the runoff and transport through rivers for those substances where riverine inputs are high (e.g., PFOS, cadmium or lead). For PFOS, cadmium and lead approximately 80, 80 and 55% of their total current inputs is via riverine inputs (Johansson and Undeman, 2020; Filipovic *et al.* 2013; HELCOM 2021b). Such changes could reverse recent reductions in inputs that have been achieved and thereby increase the pressure on the Baltic Sea ecosystem. Increased water temperature will influence biological processes such as metabolism, growth rates, recruitment, and mortality. Increases in growth rate (already a factor today across monitoring data covering a wide range of average temperature from the northern to the southern Baltic Sea; Soerensen and Faxneld 2022) may alter biomagnification through increased growth dilution. Altered food web structure, both though changes in native biota (loss of species, ecological shifts or changes in species distributions) or through the instruction of non-indigenous species (as already identified for certain fish species; Hansson *et al.* 2020) may also influence flows of contaminants within the food web. Such changes may alter the type, level and occurrence of biomagnified substances and the biotransformation of these substances as well as the potential biological effects from these interactions with the hazardous substance pool.

3.5. How was the assessment of hazardous substance carried out?

The integrated assessment of hazardous substances was carried out using the Chemical Status Assessment Tool (CHASE). A detailed overview of the approach is presented in Annex 1.

3.6. Follow up and needs for the future with regards to hazardous substance

Future work on hazardous substances is likely quite extensive due both to the level of current knowledge and the breadth of substances/components under this umbrella. Here a brief review of known aspects in relation to the following four themes are discussed: the Baltic Sea Action Plan (BSAP), the EU Marine Strategy Framework Directive (MSFD), the UN Sustainable Development Goals (SDGs), and technical or scientific work to improve knowledge, evaluations or assessments.

3.6.1 Future work in relation to the Baltic Sea Action Plan (BSAP)

The BSAP has 30 actions devoted to hazardous substances, 13 of which are joint actions (i.e., to be developed at the regional level), 11 of which are national (i.e., require national processes to implement), and 6 of which are both (national and joint). The focus here is placed on the joint actions where regional work can create significant benefits, though added benefit is also anticipated as the sub-teams within the HELCOM Expert Group on Hazardous substances (EG HAZ) offer the opportunity for information sharing on experiences or best practices that can support national or national/joint actions. In practice, all relevant actions have been provided a home within EG HAZ sub-teams (or other relevant groups) to encourage progress towards their achievement.

Action HL1 to 'develop a regional strategic approach and, on the basis of that approach, an action plan for HELCOM work on hazardous substances by 2024' is an ongoing work that will be vital in forming the basis of future work in the region. Several other actions in the BSAP are also directly relevant or interlinked with the work under HL1. The work related to this framework and action plan is briefly presented in Information Box 1 but in general terms the aim is to provide systematic approach that can integrate existing policies, prevent duplication of them, and thereby focus on key issue for the region or those aspects where stronger regional action may be of benefit. Several other BSAP actions, for example HL10 (Establish a mechanism for managing the HELCOM list of priority substances starting from 2025 and respond to screening and assessment results pointing out regional challenges for the Baltic Sea environment and contaminants of emerging concern), HL13 (By 2028 develop further relevant monitoring for the biological effects of hazardous substances in order to facilitate a reliable ecosystem health assessment), and HL28 (Address substances of emerging concern by commencing recurrent screening campaigns starting from 2021 including broad analytical techniques such as suspect screening and non-target screening methods) will likely contribute or influence the work on HL1. During the development of the strategy and action plan under HL1 it is possible that new or more specific actions may also be proposed.

Action HL4 to 'strengthen and update HELCOM recommendations for industrial releases of hazardous substances by applying information produced under the EU Industrial Emissions Directive and other sources in order to sufficiently protect the Baltic Sea environment' is being led by Finland, building on experience from previous project such as HAZ BREF. Strengthening the control of industrial emissions, for example through information on best practices, would reduce the occurrence and risk accidental or standard releases of harmful substances, lowering inputs and thereby contributing to an improved state of the sea. Finland has currently applied funds to specifically focus on this action and support regional cooperation on the topic.

Action HL10 to 'establish a mechanism for managing the HELCOM list of priority substances starting from 2025 and respond to screening and assessment results pointing out regional challenges for the Baltic Sea environment and contaminants of emerging concern' has links to HL28 and is also a core component of building and conceptualising a strategy (i.e., action HL1). Associated with the work on action HL1 the basis for addressing this action is also being developed. To develop and utilize a strategic approach the issues (or substances) or relevance are an important consideration as this facilitates efficient and effective measures (e.g., some measures may be applicable for a large group(s) of substances and other substances may require very specific measures).

Action HL13 requiring 'by 2028 develop further relevant monitoring for the biological effects of hazardous substances in order to facilitate a reliable ecosystem health assessment' will facilitate a more appropriate and ecologically relevant linkage of contaminant concentrations to biota and ecosystems. This is also an aspect that is relevant for the MSFD. Currently, EG HAZ members have been successful in securing project funding to support this action and initial work has recently initiated (see section on 'Integrated biological effects of contaminants pilot study'). The projects include the Interreg funded BEACON project, the Biodiverssa+ project Detect2Protect, and the H-BEC project co-financed by the NEFCO Baltic Sea Action Plan Fund. These projects will also explore approaches not just to evaluate biological effects but also how biological effects can be compared with and work in harmony (e.g., be integrated) with status outcomes from contaminant concentrations.

Actions HL20, HL21, HL29 and HL30 all target measures on the release of mercury, perfluorinated alkyl substances (PFAS, including specifically from firefighting foams), phenolic compounds with endocrine disrupting effects, chlorinated paraffins, and biocides from antifouling systems. Work has just been initiated in the EG HAZ subteam focusing on measures to address such topics, starting with those actions with the earliest fulfilment deadline. Action HL21, to 'introduce by 2027 measures based on the best available scientific knowledge and technologies to restrict the use and prevent releases of perfluorinated alkyl substances, phenolic compounds with endocrine disrupting effects and chlorinated paraffins', has been included on a list of issues under EG HAZ that would benefit from external (e.g., national or international projects) to support its achievement. For PFAS some benefits through cooperation with the recently funded Interreg EMPREST project are expected.

Actions HL22, HL23 and HL24 all focus on pharmaceuticals. These three actions fall under the EG HAZ sub-team on pharmaceuticals and HL22 and HL23 are also considered as needing project support. HL22 to 'improve the knowledge base on occurrence of pharmaceutical substances in the environment, their persistence and harmful effects and ensure availability of this information for a broad expert community by 2025' will benefit from recent work under HL28 where the first regional screening survey has been completed and also from work on micropollutants in wastewater treatment process, but significant further work is necessary including in relation to toxicity or effects and persistence. Actions HL23 and HL24 will be possible to address based on initial work under the other related actions and the development of indicators and monitoring guidelines will be necessary for those priority substances or groups identified.

Action HL28 to 'address substances of emerging concern by commencing recurrent screening campaigns starting from 2021 including broad analytical techniques such as suspect screening and non-target screening methods' has been initiated with the first regional screening campaign (see section: Screening and other emerging substances or risk identification) that was co-financed under the PreEMPT project, a NEFCO Baltic Sea Action Plan Fund project. An initial overview of the project findings is presented above and there are plans in EG HAZ and relevant sub-teams initially develop a clear HELCOM report that can support regional action and subsequently a surveillance indicator. The key findings of this work will also inform future screening campaigns and the frequency at which they occur.

Future work in relation to the Marine Strategy Framework Directive (MSFD)

The MSFD is not the only relevant EU legislation for hazardous substances, but a key player. There is also for example relevance of the Water Framework Directive (WFD) for example in coastal and surface waters, food standards legislation, industrial legislation, and the EU Green Deal and associated Zero Pollution Act that will become increasingly relevant. Under the MSFD the Descriptors 8 and 9 are specifically relevant, these addressing environmental concentrations of contaminants and also contaminants in seafood. Under Descriptor 8 the four required Criteria are however addressed to different levels. At the regional level D8C1, that requires evaluation of substance concentrations, is well addressed for the substances where operational indicator exists, but the BSAP actions to review priority substances may influence this. D8C2 that addresses effects on health or condition will be supported by ongoing work in relation to BSAP action HL13 (above). However, D8C3 is only partly addressed by the indicator on oil spills but does not currently consider other substances nor the determination of a significant acute pollution event that would trigger work under D8C4 (follow up on the effects from acute events). Under MSFD Descriptor 9 certain elements of relevance are utilised in current status evaluations (e.g., threshold values with relevance to human health or food stuffs) but there is currently no clear evaluation directed specifically at this issue.

3.6.2 Future work in relation to the UN Sustainable Development Goals (SDGs)

The UN SDGs are in general relatively broad in comparison to some other policies or single HELCOM indicators, but the proposed targets (and potential indicators) associated with these are closer in their alignment to existing HELCOM tools (e.g., BSAP actions). The SDG most directly relevant to HELCOM hazardous substances work is SGD 14, Life below water (Conserve and sustainably use the oceans, seas and marine resources for sustainable development). Target 14.1 of ‘by 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution’ for example is relevant point of connection for the existing HELCOM concentrations of hazardous substances indicators. Other SDGs are also relevant, such as SDGs 6, 7, 11, 12 and 13, where certain aspects of these will be increasingly important as work on understanding hazardous substances across conceptual management frameworks or chemical lifecycles develops, for example under work included in current BSAP actions including HL1. Improving the relevance and interlinkage of the existing HELCOM tools and outputs in relation to the SDGs would be a beneficial process beyond HOLAS 3.

3.6.3 Future work in relation to technical or scientific work

Some scientific issues of relevance for HELCOM hazardous substances processes were identified during the process to update the BSAP. These are listed in the HELCOM science agenda. There are also key scientific tasks that are relevant or incorporated in existing BSAP actions such as identifying new and emerging substances (e.g., screening), exploring priority (e.g., based on toxicity, risk, or effects) and the biological effects of contaminants. In addition, there is also planned or ongoing work in relation to major groups of substances that have already been identified as of importance, for example PFAS or pharmaceuticals. Development of a clear evaluation in relation to human health may also be relevant in the future.

During the development of this assessment and report a number of other issues were also identified. These are listed here to provide a basis for development towards future assessments. These are essentially topics that would warrant further review under EG HAZ to determine if changes are relevant to implement.

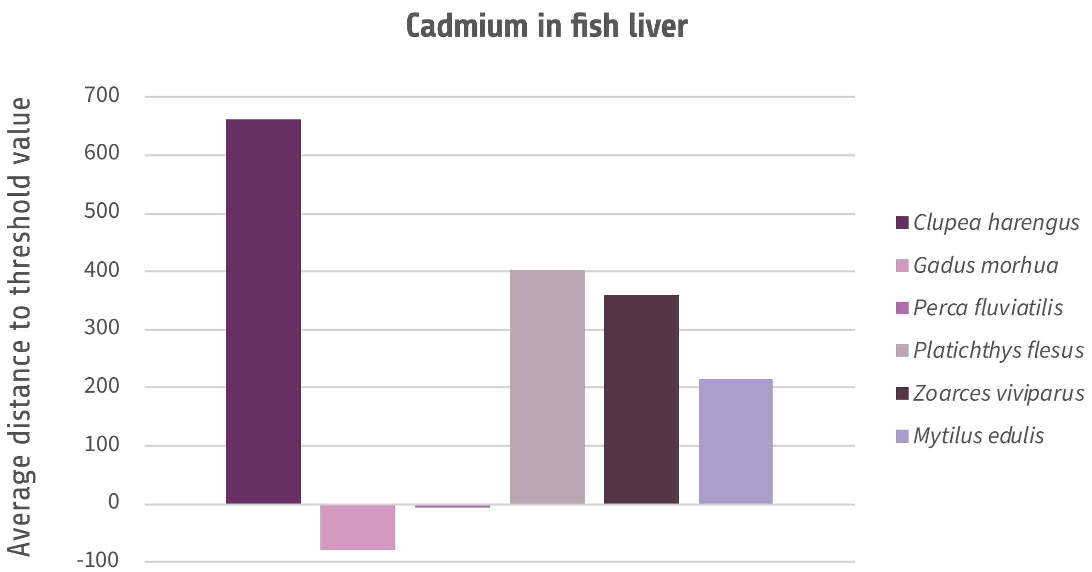


Figure 34. Averages distance to threshold values of Cadmium concentration in fish liver. Positive values represent sub-GES conditions. The difference in species outcomes show not only the relevance of including trophic conversion factors but also the need for such comparisons across different sampling matrices (e.g., liver, muscle, and whole body) as well as an improved scientific understanding of the transfer in food webs.

1. The applied threshold values should be reviewed, in particular to ensure all conversion factors are appropriate or applied where needed. This is particular relates to conversion factors and the correction between tissue types to allow correct interpretation of the threshold values applied.
2. Trophic conversion factors need to be developed to understand and implement appropriate balancing of the evaluations against threshold values within a food web. For this aspect both greater scientific knowledge (e.g., research projects) and technical implementation within indicators and assessments are needed (see example in Figure 33, note this is a preliminary review and needs a full expert evaluation).
3. Stronger evaluations of trends, in particular for sediments that are samples less frequently than other parameters, may be relevant to explore.
4. An evaluation of station trends at the assessment unit level (e.g., number of decreasing trends per assessment unit) may support an improved linkage of indicator evaluations to changes in the integrated assessment status.
5. A review and potential improvement of the confidence evaluation process may be relevant (including potential further automation of the process).
6. A stronger regional evaluation of biological effects and the additional incorporation into an overall summary assessment may be valuable, as long as all vital component parts of explanatory value are also maintained.
7. Similarly, a suitable way to also incorporate screening information, for example through a surveillance indicator, would be valuable as well as exploration of how to address unknown substances detected in such approaches.

As work related to understanding hazardous substances develops further, for example to support BSAP action HL1, data sources and evaluations that can provide information on hazardous substances across conceptual management frameworks (e.g., DAPSIM) and also across the lifecycles of these substances, may become increasingly valuable. Such information can provide a stronger basis for carrying out tasks such as analysis measure sufficiency, implementation of new measures, source apportionment, and potentially establishing input ceilings. A stronger understanding of these issues would provide the basis for improved and pre-emptive management of the Baltic Sea ecosystem by allowing measures to be placed at source (or as close to it as possible), likely reducing costs of recovery/restoration and also limiting adverse effects.

The existing pool of hazardous substances and the new substances that are frequently developed mean that regular review of such issues will continually be required. Such issues are particularly important for substances that are identified as of emerging concern. Addressing such issues under the BSAP is already planned, however it will require significant effort and will likely have implications for future holistic assessments of hazardous substances. Furthermore, it is not only the concentrations of such substances that need to be considered but also their effects in the environment.

One topic that is increasingly of concern in this respect is antimicrobial resistance (AMR) which has been the topic of recent review but in HELCOM and under the UN (UNEP 2023; HELCOM 2023, forthcoming).

4. Results for the marine litter assessment

Assessment results in short

- The status assessment of beach litter in the Baltic Sea for 2016-2021 shows that eleven out of sixteen sub-basins are above the HELCOM threshold value of 20 litter items per 100 m beach. One sub-basin does not conduct beach litter monitoring and therefore cannot be assessed. Three sub-basins do have median values well above the threshold value, but one of them only includes one beach and thus the results may not be representative for the entire sub-basin. For the other two sub-basins, negative trends indicate improving environmental conditions. Eight sub-basins are close to the threshold value, ranging between 23-33 litter items per 100 m beach. Three of the sub-basins are improving and the others do not show significant trends. Only one sub-basin showed a deteriorating littering trend, but the median value is still below the threshold value.
- The most commonly found category of litter is various plastic items and fragments larger than 2.5 cm. Several of the items on the top-ten list are related to single use plastics and other types of plastic. Marine litter from sea-based sources is only contributing slightly to littering on Baltic Sea beaches.
- The assessment also indicated that there is a need for better geographical coverage with improving monitoring efforts to evaluate the effect of actions against marine litter. Harmonisation of beach litter protocols is key and more research on identifying sources of litter is essential. Likewise, more attention should be paid to exploring how the sub-basin assessments are influenced by types of included monitoring beaches, e.g., remote vs. urban/semi-urban beaches. Resources are required for expanding monitoring programmes and for research on sources and impacts.
- Data on the amount of litter collected in trawls during fish stock surveys is only available for some Baltic Sea regions. The data set covers years from 2012 and forward in areas from the Northern Baltic proper and south. This data is used as an indication of the amount of litter on the seafloor. When doing so, there are differences depending on whether density is measured in weight or in number of litter items. Thus, when litter density was measured in weight, the categories “other”, plastic and fisheries related litter increased significantly in the period from 2015 to 2021 whereas when density was measured in numbers, only “other” and plastic litter increased significantly and thereby failed the preliminary threshold of no significant increase from 2015 to 2021 in both weight, numbers and probability of catching litter. Fisheries related litter passed the threshold when measured in numbers per km^2 but not when measured in weight per km^2. The categories glass, metal, natural, rubber and single use plastics (SUP) showed no significant increase in weight and numbers per km^2 and hence passed the preliminary threshold of no significant increase.

4.1. Introduction to marine litter

Litter on the coastline is one of the most obvious signs of marine litter. Surveys of litter on the beach allow for a detailed evaluation of litter in terms of amounts and composition. Their strength lies on the provision of information on potential harm to marine biota and ecosystems as well as social harm (aesthetic value, economic costs, hazard to human health) and, to some extent, on sources of litter and the potential effectiveness of measures applied. The beach litter indicator considers a wide range of types of marine litter, so new findings and possibly new sources of pollution can be quickly detected.

Litter on the seafloor can cause anoxia to the underlying sediments, which alters biogeochemistry and benthic community structure (Goldberg, 1994). Furthermore, litter (such as glass bottles, tin cans) may provide substrata for the attachment of sessile biota in sedimentary environments and increase local diversity (Mordecai *et al.* 2011; Moret-Ferguson *et al.* 2010; Pace *et al.* 2007). This may replace existing species and leads to non-natural alterations of faunal community composition (Bergmann & Klages, 2012). Heavy plastic items may be colonized by bacteria or loaded with sediments and sink to the seafloor (Thompson, 2006; Ye & Andrady, 1991) where they can persist for centuries (Derraik, 2002), or may be ingested by organisms. Litter containing hazardous substances can act as a source to these, and thereby contribute to pollution effects in the ecosystem. The monitoring of seafloor litter is required to close the loop of marine litter monitoring in the aquatic environment.

4.2. Details on the assessment results for marine litter

4.2.1 Beach litter

The status assessment of marine beach litter in the Baltic Sea for 2016-2021 shows that 11 out of 16 sub-basins are above the HELCOM threshold value of 20 litter per 100 m beach. One sub-basin does not conduct beach litter monitoring and therefore cannot be assessed. The sub-basins with high median values, that stand out from the other results, are The Sound (313 litter items per 100 m), Gulf of Riga (156 litter items per 100 m), and Eastern Gotland Basin (96 litter items per 100 m). The number of litter items present in these sub-basins are all higher than the Baltic wide baseline level of 40 litter items per 100 m from 2015-2016 (Hanke *et al.* 2019). Such baselines have, however, not been derived for each sub-basin in the Baltic Sea.

Eight sub-basins are above but close to the threshold value, ranging between 23-33 litter items per 100 m beach.
The sub-basins below the threshold value are Kiel Bay, Bay of Mecklenburg, Gdansk Basin and the Western Gotland Basin. The Quark also has a median value below the threshold value but includes only limited data for one beach and less than 40 surveys, and consequently the results are less robust. Results are shown in the map (Figure 35) and in Table 10.

Except for median values of total count (TC) for the different sub-basins, calculations have been done for single-use plastics (SUP), and fisheries related litter (FRL) (Table 10). Litter items were categorised for SUP and FRL according to “A Joint List of Litter Categories for Marine Macrolitter Monitoring” (Fleet *et al.* 2021). The median of SUP litter items varies between 0-26 litter items, accounting for 0-28% of the total litter. The proportion of

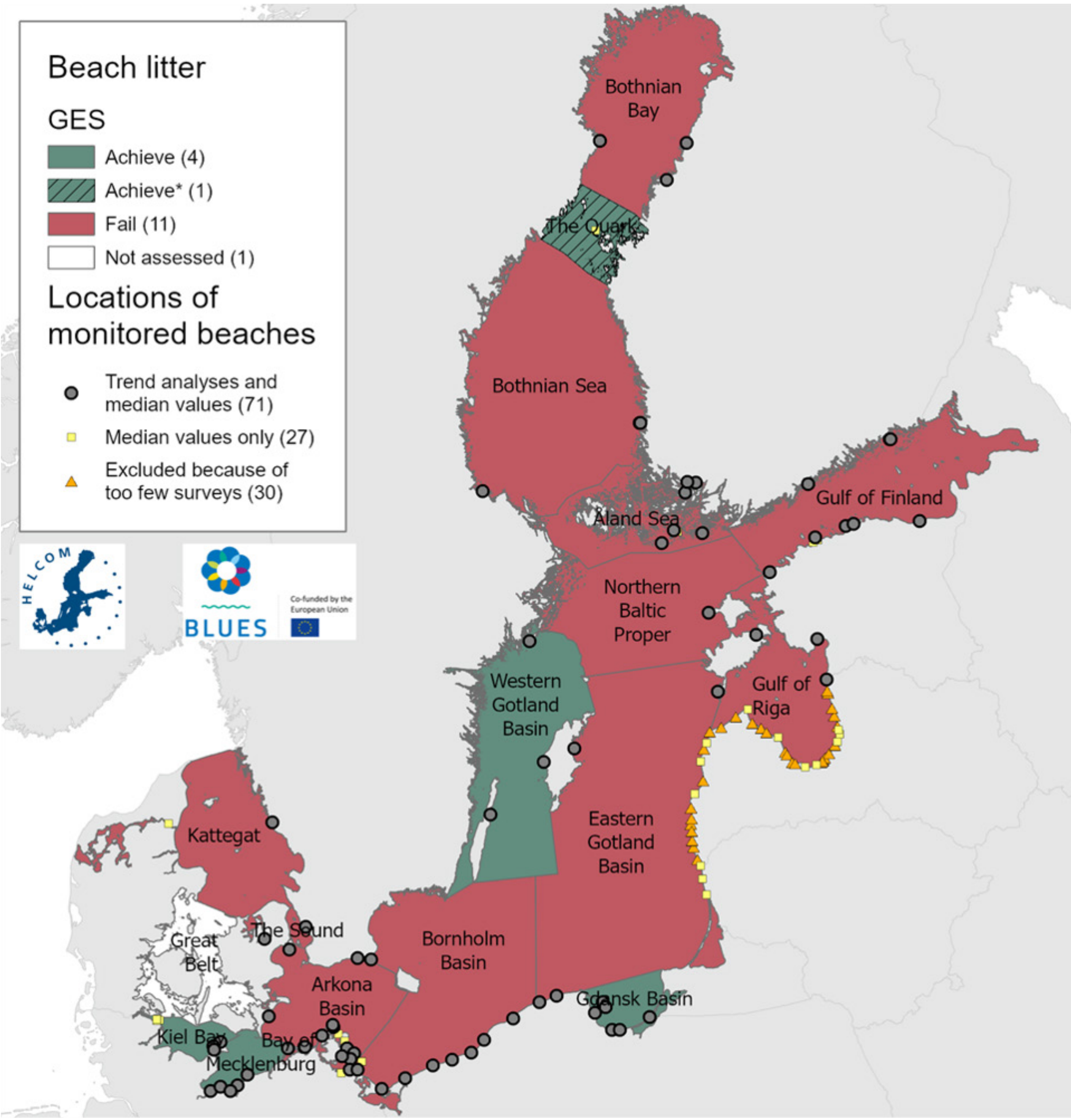


Figure 35. Beach litter assessment of sub-basins of median values below (green) or above (red) the threshold value of 20 litter items per 100 m. The Quark (marked with *) also has a median value below the threshold value but includes only limited data for one beach and less than 40 surveys, and consequently the results are less robust. The assessment has been carried out using Scale 2 HELCOM assessment units (defined in the HELCOM Monitoring and Assessment strategy, 2013, Attachment 4). Different signatures are shown for national monitoring beaches depending on if they have sufficient data for determining robust median values, or also trend analyses or if they are excluded due to too few surveys. To access interactive maps at the HELCOM Map and Data Service: Marine litter [Web link].

plastic litter (including SUP items) in relation to the total number of litter ranges between 32 and 93%. The highest value was recorded for the Quark, which includes only one beach (in Finland). Median values for FRL litter categories are also generally low, ranging between 0 and 20 litter items per 100 m beach.

Results for other materials (Rubber, Metal, Glass, Paper, Textile, Wood, Sanitary and medical items, and Various materials) are found in Annex 5 (Table A5.1). Overall, the median values for each individual material per sub-basin are low. No median values are above 10 litter items per 100 m beach, except from the median value of 27.5 litter items per 100 m for Paper in the Gulf of Riga. Only one sub-basin, Kattegat, has a median value for Sanitary and medical items that is above zero (1 litter per 100 m beach), despite finding a total of 1038 sanitary and medical items on Baltic Sea beaches during the 6-year monitoring period. The same pattern is shown for Various materials where the Gulf of Riga is the only sub-basin that shows a value above zero, median of 1.5 litter items per 100 m. The data gives the impression that this category, only found in the Master List of Categories of Litter Items (JRC, 2013) and the MARLIN litter item list (MARLIN, 2013), is only used by some countries when reporting.

A list of the minimum and maximum median values per sub-basin is provided in Annex 5 (Table A5.2), to increase the understanding of the results. A list of litter items/categories and their relation to materials, as well as single-use plastics (SUP) and fisheries related litter (FRL), is found in Annex 5 (Table A5.3).

Table 10. Median values (2016–2021) for Total Count (TC), SUP, FRL and Plastic litter categories for each sub-basin, N=number of surveys.

Sub-basin	N	TC	SUP	FRL	Plastic
SEA-001 Kattegat	54	33	4	1	26
SEA-003 The Sound	18	313	26	20	250
SEA-004 Kiel Bay	83	19	3	1	12
SEA-005 Bay of Mecklenburg	132	15	4	0	9
SEA-006 Arkona Basin	330	30	3	1	23
SEA-007 Bornholm Basin	202	23	5	0	14
SEA-008 Gdansk Basin	143	13	2	1	8
SEA-009 E Gotland Basin	88	96	2	7	65
SEA-010 W Gotland Basin	54	11	2	0	8
SEA-011 Gulf of Riga	68	156	8	3	50
SEA-012 N Baltic Proper	31	27	2	0	16
SEA-013 Gulf of Finland	133	28	3	0	18
SEA-014 Åland Sea	107	23	2	1	15
SEA-015 Bothnian Sea	46	24	1	2	15
SEA-016 The Quark	5	5	0	0	5
SEA-017 Bothnian Bay	52	29	2	0	10

4.2.2 Seafloor litter

The temporal development in mass and number of litter items caught per km² and probability of catching litter in a haul in the surveyed area can be seen in figures 35, 36 and 37, respectively. By far the most numerous litter item in terms of number and probability was plastic, followed by natural litter (Table 11). The trends estimated for the different litter types differ depending on whether the early (poorly sampled) years are included as well as between densities measured by numbers and weight (Table 12). Among the plastic items counted, SUP (as defined in Table 12) accounted for 36% (32% by weight). As the changes in early years may be a result of differences in sample coverage and effort, the trends are examined from 2015 onwards. The spatial distribution of the assessed litter types can be seen in figure 38. The large differences in the distribution as measured by weight and numbers/probability of catch are likely due to differences in sample coverage and effort as all years are included in the estimation of the distribution of litter. Annual estimates from model 1 (see section 4.6.2 for further information) are given in Annex 5 (Table A5.5).

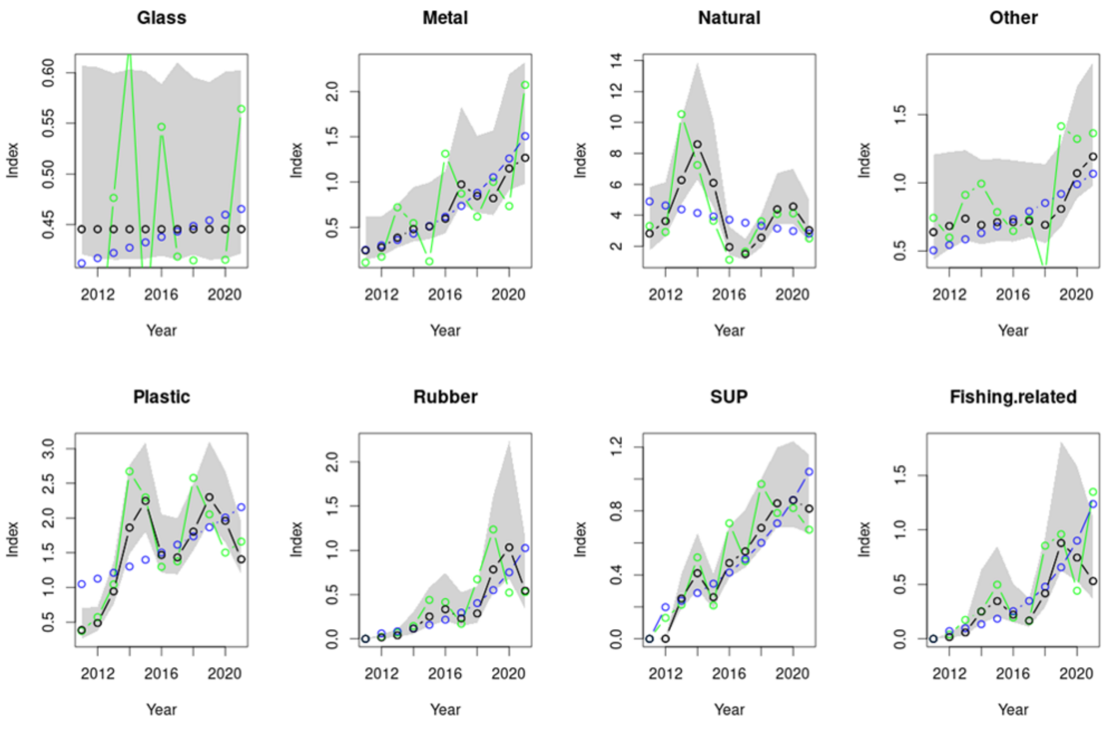


Figure 36. Temporal development in kg litter/km² as estimated by models 1 (black, grey is 95% confidence interval of the estimate), 2 (green) and 3 (blue). Top row from left to right: glass, metal, natural, other. Bottom row from left to right: plastic, rubber, SUP, fisheries related litter. Note difference in scale of the y-axis.

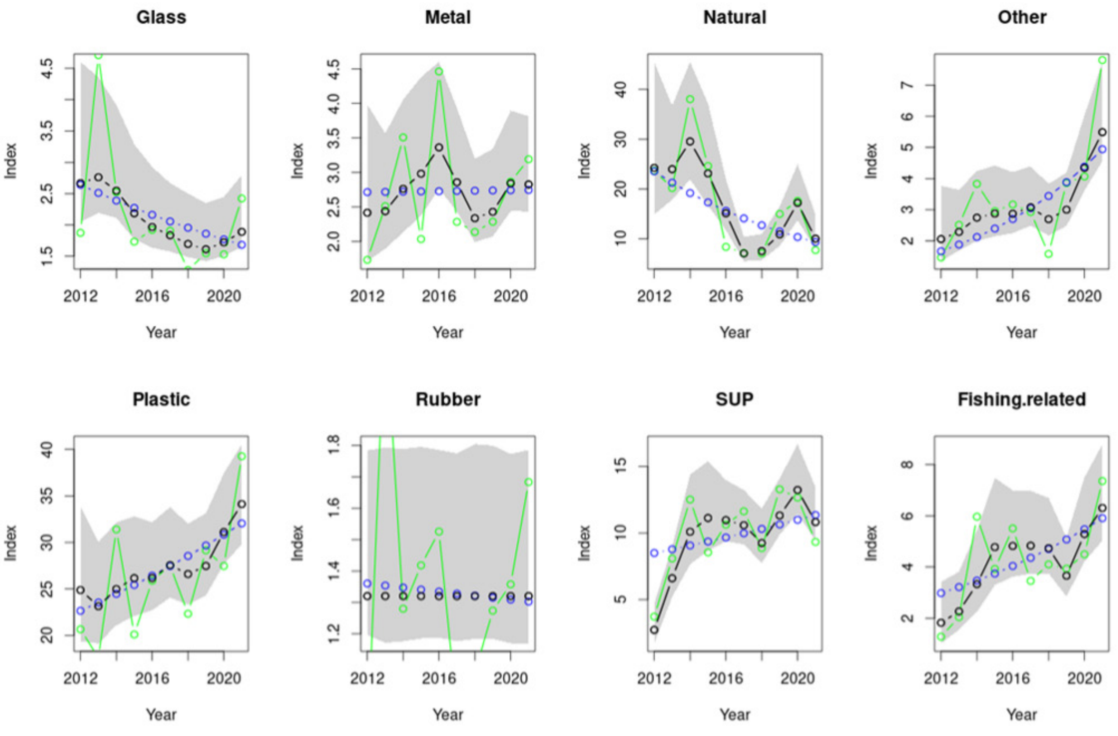


Figure 37. Temporal development in number of litter items/km^2 as estimated by models 1 (black, grey is 95% confidence interval of the estimate), 2 (green) and 3 (blue). Top row from left to right: glass, metal, natural, other. Bottom row from left to right: plastic, rubber, SUP, fisheries related litter. Note difference in scale of the y-axis.

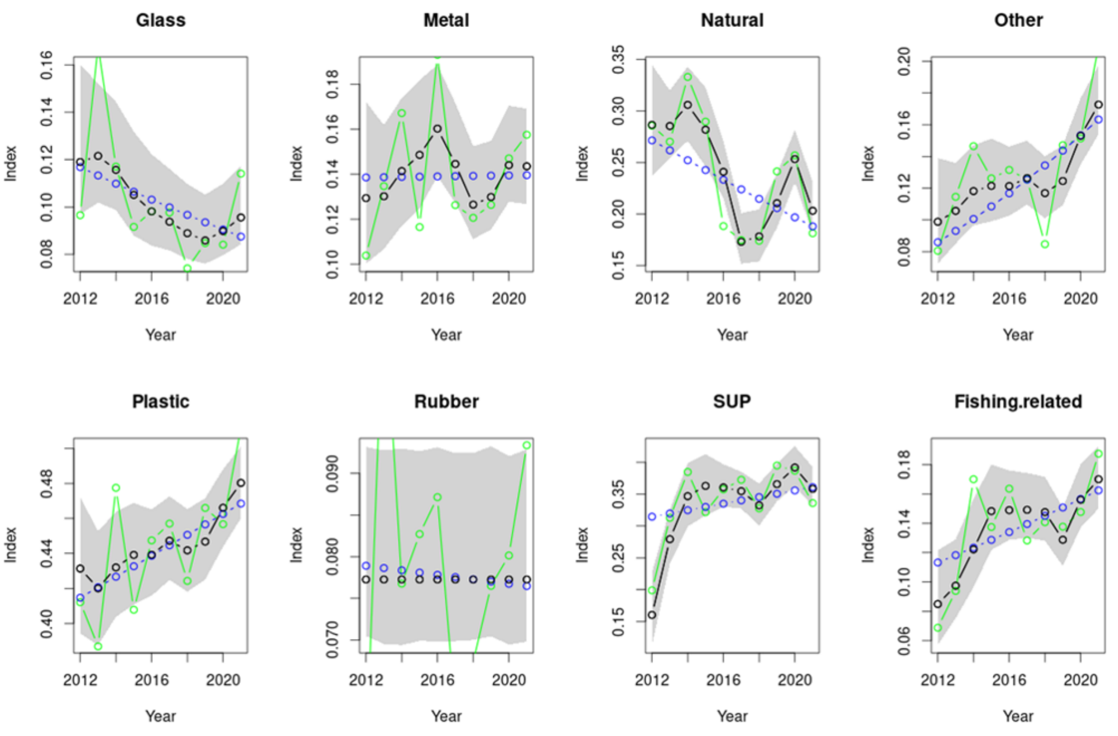


Figure 38. Temporal development in probability of catching litter as estimated by models 1 (black, grey is 95% confidence interval of the estimate), 2 (green) and 3 (blue). Top row from left to right: glass, metal, natural, other. Bottom row from left to right: plastic, rubber, SUP, fisheries related litter. Note difference in scale of the y-axis.

Table 11. Average weight and number of litter items per km² and probability of non-zero catch across all years. Note that the number of hauls analysed for weight and number differs, and hence the numbers are not directly comparable.

	Average weight kg/km²	Average Probability/haul	Average Number/km²
Glass	0.45	0.101	2.09
Metal	0.73	0.140	2.72
Natural	4.25	0.242	16.86
Other	0.80	0.126	3.15
Plastic	1.59	0.444	27.22
Rubber	0.36	0.077	1.32
SUP	0.52	0.331	9.67
Fishing related	0.36	0.135	4.181
Total	**1.13**		**8.40**

Table 12. Trends and significance level of trends in weight and number of litter items per km². Trends in probability of non-zero catch are identical to trends in numbers. Effects greater than 0 indicate increase and effects smaller than 0 indicate decrease. Values in bold indicate significant trends.

Litter type	Weight				Number			
	All years		2015 onwards		All years		2015 onwards	
	effect	P	effect	P	effect	P	effect	P
Glass	0.012	0.563	0.0234	0.451	-0.05	**0.0438**	0.0169	0.642
Metal	**0.179**	**<0.0001**	-0.015	0.558	0.0013	0.952	-0.0217	0.476
Natural	**-0.550**	**0.007**	**-0.0654**	**0.0177**	**-0.103**	**<0.0001**	-0.0439	0.146
Other	**0.075**	**0.00454**	**0.153**	**<0.0001**	**0.1206**	**<0.0001**	**0.1532**	**<0.0001**
Plastic	**0.072**	**<0.0001**	**0.0935**	**<0.0001**	**0.0386**	**0.0021**	**0.0432**	**0.0131**
Rubber	**0.311**	**<0.0001**	0.039	0.272	-0.0048	0.868	0.00947	0.816
SUP	**0.185**	**<0.0001**	-0.015	0.36	0.0321	0.01876	-0.00179	0.924
Fisheries related	**0.317**	**<0.0001**	**0.102**	**0.0016**	**0.0761**	**0.00158**	0.04431	0.169

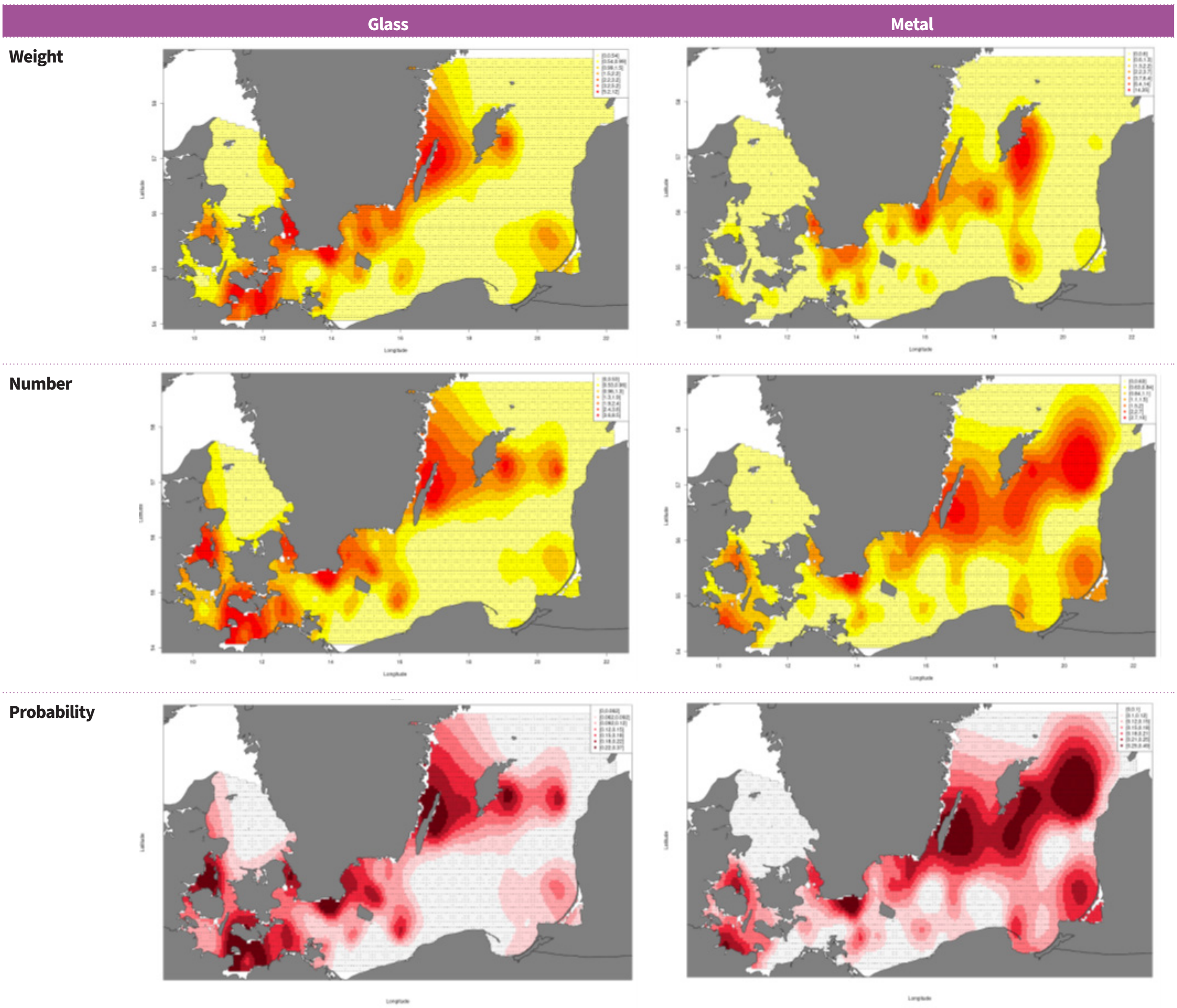


Figure 38a. Distribution of different litter types in weight, number and probability of catching litter. Colouring reflects amount relative to the mean, yellow/white is low amounts, red/dark red is high amounts. Note the limited sampling in deeper areas, see figure 3.

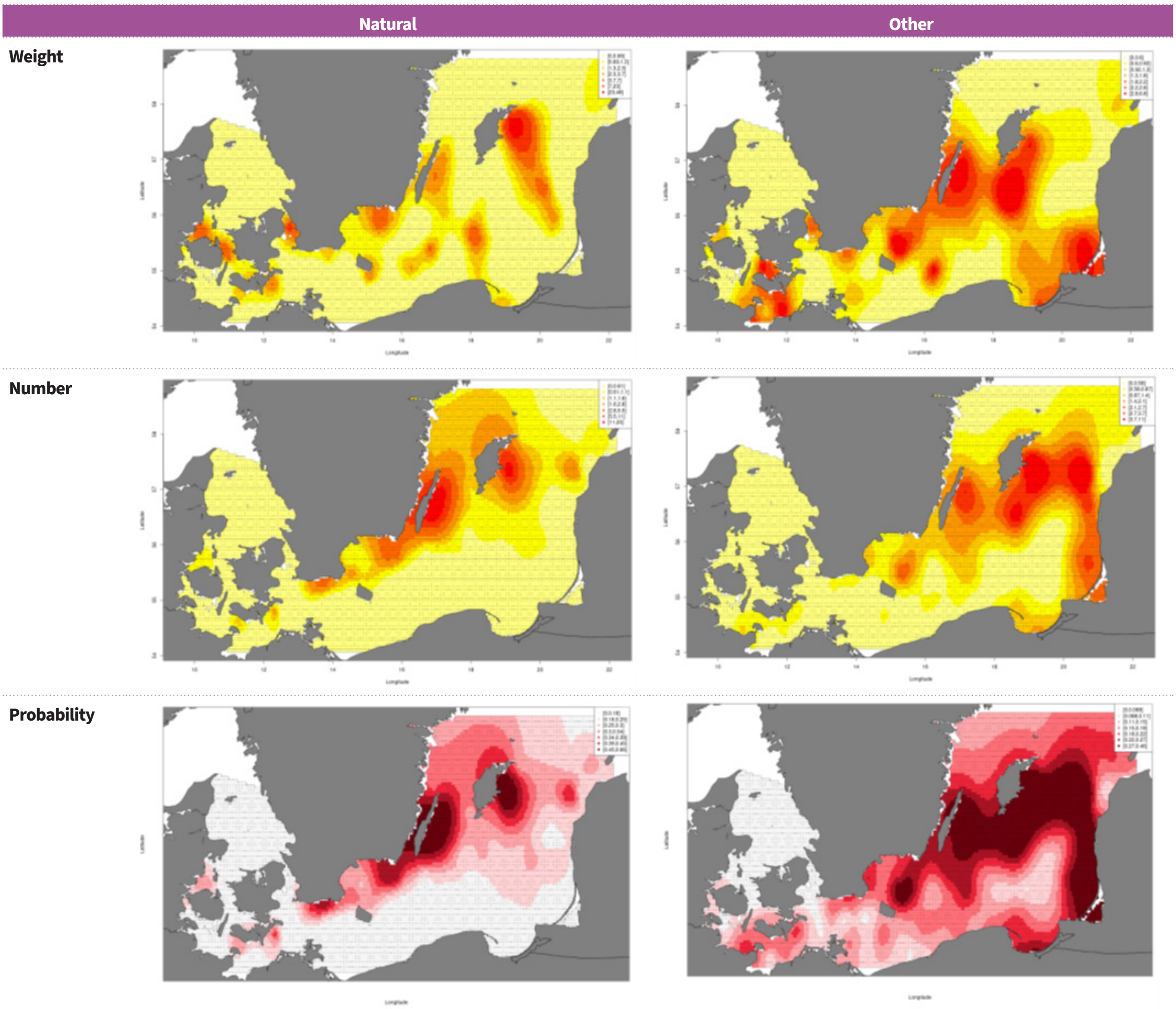


Figure 38b. Distribution of different litter types in weight, number and probability of catching litter. Colouring reflects amount relative to the mean, yellow/white is low amounts, red/dark red is high amounts. Note the limited sampling in deeper areas, see figure 3.

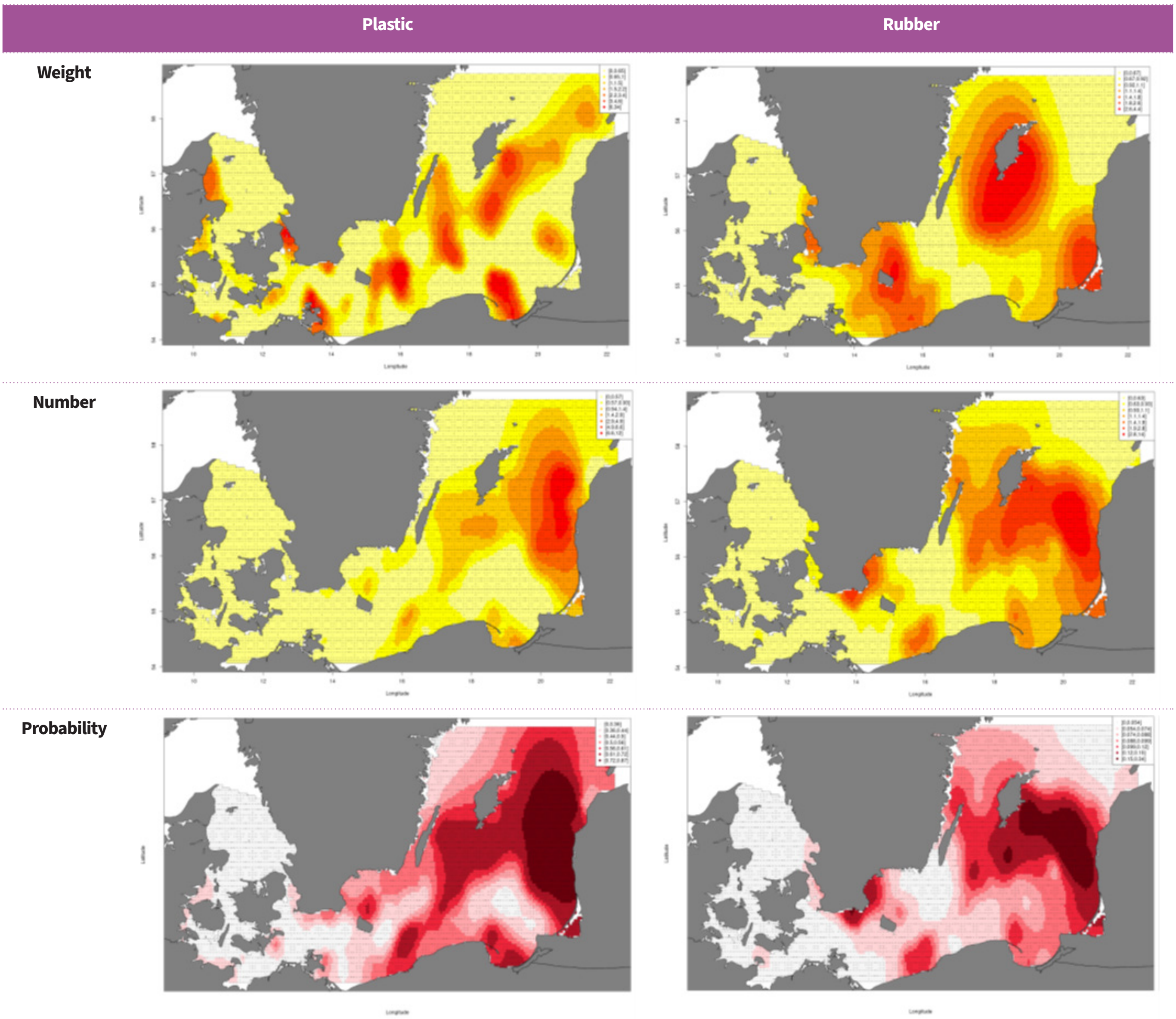


Figure 38c. Distribution of different litter types in weight, number and probability of catching litter. Colouring reflects amount relative to the mean, yellow/white is low amounts, red/dark red is high amounts. Note the limited sampling in deeper areas, see figure 3.

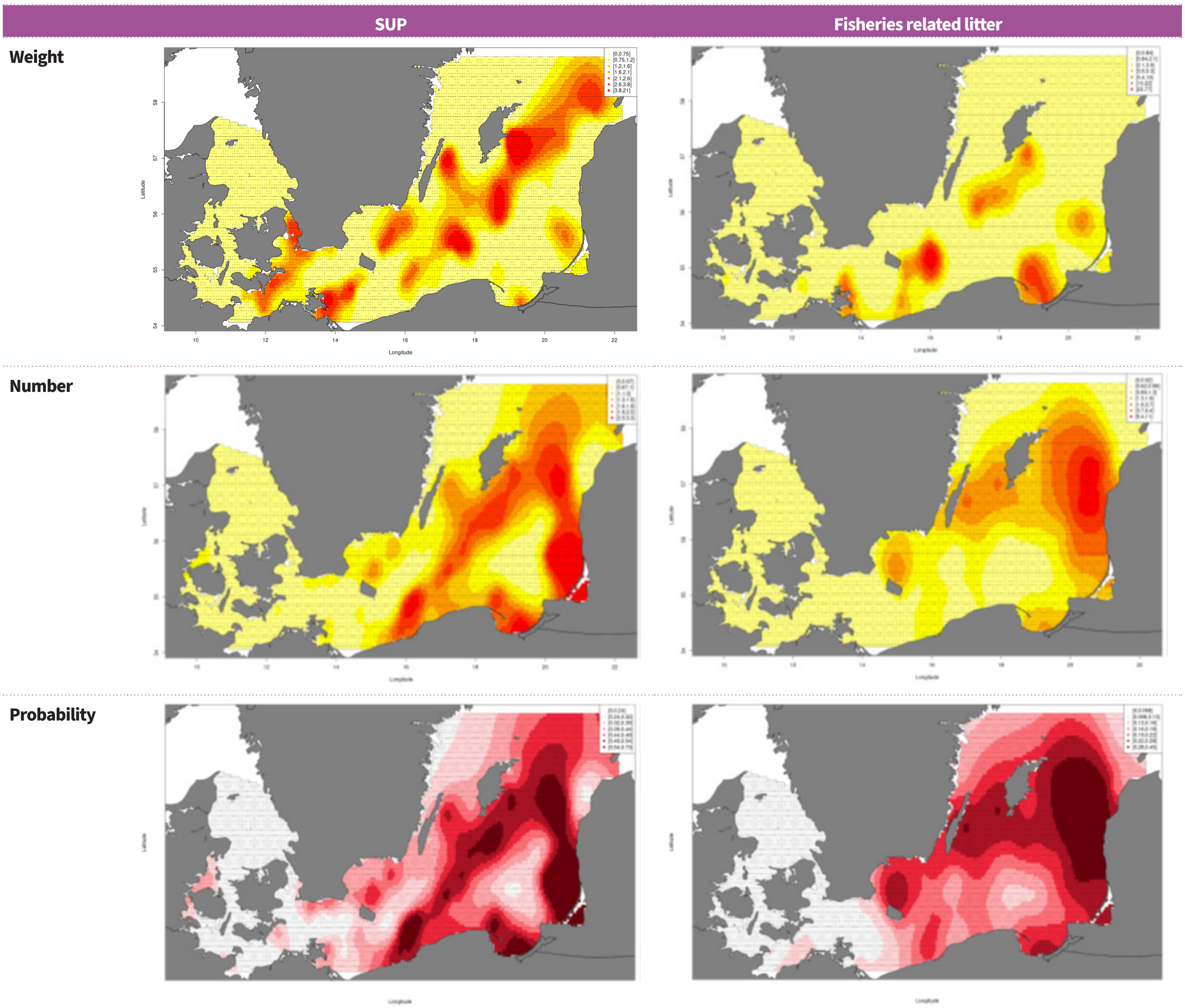


Figure 38d. Distribution of different litter types in weight, number and probability of catching litter. Colouring reflects amount relative to the mean, yellow/white is low amounts, red/dark red is high amounts. Note the limited sampling in deeper areas, see figure 3.

4.3. Changes over time for marine litter

4.3.1 Beach litter

The complete trend analyses on marine beach litter for the 6-year period between 2016-2021 is included in Table 13 (for numerical values see Annex 5 Tables A5.4 and A5.5). For several sub-basins, including the Bay of Mecklenburg, the Arkona Basin, the Bornholm Basin, the Eastern Gotland Basin, the Gulf of Riga, and the Gulf of Finland, the trends for total count (TC) show a significant decrease in the total count of litter, which correlates with a decrease in SUP and Plastic litter item categories. The significant decreases in TC for the different sub-basins range between 0.85 to 3.01 litter items per year. Only one sub-basin, the Gdansk Basin, shows an increase in TC, SUP, and plastic. Trends of SUP litter items for all other sub-basins, except for the Gdansk Basin, shows improving trends, with a slow decrease of litter items of below 1 litter per year.

For the FRL litter items, the Arkona Basin, and the Eastern Gotland Basin, show a significant decrease. The Gdansk Basin and the Bothnian Sea show an opposite trend, with slight increases between 0.14 to 0.27 litter items per year. The Bornholm Basin has a significant stable level.

Table 13. Significant trends (2016–2021) for Total Count (TC), SUP, FRL, and Plastic litter categories for each sub-basin, N=number of surveys. Test of significance is based on $p < 0.05$ for either downwards trends (arrow down), upward trend (arrow up) or no trend (arrow straight). The beaches that do not fulfil the requirements are excluded before the analyses are done. Empty cells indicate no significant trend.

Sub-basins	N	TC	SUP	FRL	Plastic
SEA-001 Kattegat	42				
SEA-003 The Sound	18				
SEA-004 Kiel Bay	61				
SEA-005 Bay of Mecklenburg	132	↘	↘		↘
SEA-006 Arkona Basin	270	↘	↘	↘	↘
SEA-007 Bornholm Basin	202	↘	↘	→	↘
SEA-008 Gdansk Basin	143	↗	↗	↗	↗
SEA-009 E Gotland Basin	62	↘	↘	↘	↘
SEA-010 W Gotland Basin	54				
SEA-011 Gulf of Riga	47	↘	↘		↘
SEA-012 N Baltic Proper	31				
SEA-013 Gulf of Finland	127	↘			↘
SEA-014 Åland Sea	104				
SEA-015 Bothnian Sea	46			↗	↗
SEA-017 Bothnian Bay	52				

For other materials or groups than Plastic, i.e., Rubber, Metal, Glass, Paper, Textile, Wood, Sanitary and medical items, and Various materials, the significant trends vary, and the changes are small. Most trends indicate an improving or stable status. Rubber, Paper, Sanitary and medical items, and Various materials do not change in number for any of the basins. Metal and Textile items are slightly decreasing, less than 1 litter item per year. Only Wood increases in two of the sub-basins, the Gdansk Basin and the Northern Baltic Proper. Results are shown in Annex 5, table A.4.

The HELCOM Regional Action Plan on Marine Litter (HELCOM, 2021) aims to reduce common litter items and it is partly based on findings from beach litter monitoring. To meet that need, a top ten list of the most common litter items for the entire Baltic Sea has been produced, based on medians of ranks for sub-basin top-ten lists (Table 14). The most common category of litter items is Various plastic items and fragments >2.5 cm. It was an expected result since many different plastic litter items (33 litter types) were aggregated in this category when the lists used by Contracting Parties around the Baltic Sea were harmonised. It is followed by several SUP litter items, Plastic packaging for food and beverage, Plastic bags and Plastic caps and lids. Plastic bottles are found on place number ten. The category 'Other glass and ceramics' ranked number 5 is also aggregated by seven other glass or ceramic litter items and fragments ≥ 2.5 cm. The same applies for paper, where all (12) paper and cardboard litter items except for new paper and magazines are aggregated into one category. Thus, this category gathers, for example, Paper bags, Paper cigarette packages, Cardboard boxes, Paper cups and Paper fragments. Fragments should, generally, be counted as one category if they originate from the same item, but this may be difficult to distinguish when conducting the monitoring. Therefore, the number of litter items in such categories can be high. It is also possible that the substitution of plastic for other materials may increase the amount of these other categories, e.g., cardboard litter. The Single Use Plastic Directive (EU, 2019) and corresponding downward trends in SUP litter items reinforces that hypothesis.

The overall impression is that beach litter is still found around the coast of the Baltic Sea (Table 15). Only four (five with the Quark) out of seventeen sub-basins do have median values below the threshold value of 20 litter items per 100 m beach. However, when looking at each sub-basin, eight of them are showing median values close to the threshold value, ranging between 23 to 33 litter items per 100 m beach. The litter levels are also lower than the Baltic wide baseline level of 40 litter items per 100 m from 2015-2016 (Hanke *et al.* 2019). Such baseline levels have, however, not been derived for each sub-basin. The sub-basins with high median values, that stand out from the other results are the Sound (313 litter items per 100 m), the Gulf of Riga (156 litter items per 100 m), and the Eastern Gotland Basin (96 litter items per 100 m). Both the Gulf of Riga and the Eastern Gotland Basin show an improvement of the beach litter situation between 2016 and 2021, while the Sound shows no significant trend. In addition, the beaches monitored in the Gulf of Riga and the Gulf of Finland consist mostly of urban and semi-urban beaches (90%). The litter is therefore expected to originate mainly from visitors, during the summer season. It is likely that the SUP Directive and other preventive measures within HELCOM's Regional Action Plan on Marine Litter, e.g., around sustainable consumption and production will reduce plastic waste in general but especially for this type of beaches.

The status of Russian litter in the Gulf of Finland has been reviewed by Ershova *et al.* (2021). They concluded that in the period 2018-2019, beaches at the inner parts of the estuary in the Neva Bay had the highest number of litter items, for all categories. Plastic pellets, broken glass and cigarette butts were the most common litter types. The proximity to St. Petersburg with its 5.2 million inhabitants obviously affects the results. Different methodologies were applied on beaches, and thus results cannot be directly compared with results from the current assessment. The unit used was litter pieces per square meter and included both macro-, meso- and microlitter. Beaches with both high numbers of visitors and less-visited beaches were included in the study.

Table 14. Top ten litter item list (2016–2021), Baltic Sea wide, based on medians of ranks for sub-basin top-ten lists.

Rank	Litter Code	Litter name
1	R2425	Various plastic items and fragments >2,5 cm
2	R4	Plastic packaging for food and beverage
3	R2	Plastic bags
4	R6	Plastic caps and lids
5	R50	Other glass and ceramics
6	R1	Plastic six-pack rings
7	R16	Ropes, strings, and cords
8	R33	Paper excluding newspaper and magazines
9	R10	Plastic syringes
10	R3	Plastic bottles

Table 15. Status assessments, trends, and outcomes on marine litter for Baltic Sea sub-basins.

Sub-basin, HELCOM Scale 2	Total count of litter items per 100 m (median values for 2016-2021)	Significant trends	Description of outcomes
SEA-001 Kattegat	33	No trend	Indicator evaluation failed to achieve the threshold value. No significant trend between the years of 2016-2021.
SEA-002 Great Belt	No data	No data	_
SEA-003 The Sound	313*	No trend	Indicator evaluation failed to achieve the threshold value. The median value is significantly above the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). No significant trend for the period 2016-2021.
SEA-004 Kiel Bay	19	No trend	Indicator evaluation achieved the threshold value. No significant trend for the period 2016-2021.
SEA-005 Bay of Mecklenburg	15	Improving	Indicator evaluation achieved the threshold value. The downward trend indicates an improving situation for the period 2016-2021.
SEA-006 Arkona Basin	30	Improving	Indicator evaluation failed to achieve the threshold value. The median value is below the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). The downward trend indicates an improving situation for the period 2016-2021.
SEA-007 Bornholm Basin	23	Improving	Indicator evaluation failed to achieve the threshold value. The median value is close to the threshold value of 20 litter items per 100 m and below the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). The downward trend indicates an improving situation for the period 2016-2021.
SEA-008 Gdansk Basin	13	Deteriorating	Indicator evaluation achieved the threshold value. However, there is an upward trend for the period 2016-2021 indicating that potential measures against littering have not been successful.
SEA-009 E Gotland Basin	96	Improving	Indicator evaluation failed to achieve the threshold value. The median value is significantly above the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). The downward trend indicates an improving situation for the period 2016-2021.
SEA-010 W Gotland Basin	11	No trend	Indicator evaluation achieved the threshold value. No significant trend for the period 2016-2021.
SEA-011 Gulf of Riga	156	Improving	Indicator evaluation failed to achieve the threshold value. The median value is significantly above the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). The downward trend indicates an improving situation for the period 2016-2021.
SEA-012 N Baltic Proper	27*	No trend	Indicator evaluation failed to achieve the threshold value. The median value is below the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). No significant trend for the period 2016-2021.
SEA-013 Gulf of Finland	28	Improving	Indicator evaluation failed to achieve the threshold value. The median value is below the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). The downward trend indicates an improving situation for the period 2016-2021.
SEA-014 Åland Sea	23	No trend	Indicator evaluation failed to achieve the threshold value. The median value is below the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). No significant trend for the period 2016-2021.
SEA-015 Bothnian Sea	24	No trend	Indicator evaluation failed to achieve the threshold value. The median value is below the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). No significant trend for the period 2016-2021.
SEA-016 The Quark	5*	N.a.	Indicator evaluation achieved the threshold value but includes only limited data for one beach and less than 40 surveys, and consequently the results are less robust. Trend analysis was not possible to calculate due too few surveys.
SEA-017 Bothnian Bay	29	No trend	Indicator evaluation failed to achieve the threshold value. The median value is below the baseline value for the entire Baltic Sea of 40 litter items per 100 m (year 2015-2016). No significant trend for the period 2016-2021.
GES <HELCOM threshold value 20 litter per 100 m			
No GES >HELCOM threshold value 20 litter per 100 m			
*=sub-basins within total <40 surveys are considered given less reliable results			
N.a.=not applicable because the beach(es) is not fulfilling the required criteria for a robust trend analysis			

4.3.2 Seafloor litter

When litter density was measured in weight, the categories “other”, plastic and fisheries related litter increased significantly in the period from 2015 to 2021 whereas when density was measured in numbers, only the categories “other” and plastic litter increased significantly (see table 16 below). Hence, the categories “other” and plastic litter failed the preliminary threshold of no significant increase from 2015 to 2021 in both weight, numbers and probability of catching litter. Fisheries related litter passed the threshold when measured in numbers per km^2 but not when measured in weight per km^2. The categories glass, metal, natural, rubber and SUP showed no significant increase in weight and numbers per km^2 and hence passed the preliminary threshold of no significant increase.

Table 16. Assessment of the preliminary threshold of no significant increase from 2015 to 2021.

HELCOM Assessment unit name (and ID)	Threshold value achieved/failed	Distinct trend between current and previous assessment	Description of outcomes, if pertinent
Baltic Sea	Achieved for glass, metal, natural litter, fisheries related litter (numbers only) rubber and SUP.	Stable/decreasing	Indicator evaluation failed to achieve the threshold value for some litter categories. Long degradation time for most litter types.
	Failed for plastic, fisheries related (weight only) and other litter.	Increasing	

4.4. Relationship of marine litter to drivers and pressures/biodiversity

4.4.1 Beach litter

Litter present on beaches comes both from land- and sea-based sources. Land-based sources are often linked to consumer behaviour, such as recreational/tourism activities (e.g., plastic bags, left-overs from beach picnics, cigarette butts). Other land-based sources are riverine inputs and inputs from storm water overflows. Important sea-based sources are professional and recreational ships (ship-generated waste) as well as fishing related activities (lost/abandoned fishing gear, foamed plastic, lost cages). Thus, beach litter monitoring can reflect trends of littering of the coast/beaches including coastal waters and possibly also litter transported over long distances. Beach litter can, to a certain extent (indicator item concept), be linked to sources and pathways, which is a fundamental step for a subsequent definition of measures aimed at acting on those sources and pathways to minimize the presence of marine litter in the aquatic environment. The pressure and activities are summarised in table 17.

Table 17. Pressure and activities. Brief summary of relevant pressures and activities with relevance for the indicator.

	General	MSFD Annex III, Table 2a
Strong link	Fish and shellfish harvesting (professional, recreational), aquaculture, shipping, urban and industrial uses, waste treatment and disposal, tourism and leisure	Substances, litter and energy - Input of litter (solid waste matter, including micro-sized litter)
Weak link	Extraction of living resources Hunting and collecting for other purposes	

In a recently published article by several researchers in the fields of climate and marine litter, strong connections between these two rapidly growing environmental problems have been established (Ford *et al.* 2022). The researchers highlight the importance of an integrated approach to the problems and their solutions instead of the issues surrounding plastic pollution in the ocean and the climate crisis competing for publicity and political attention. The authors also believe that a commitment against plastic littering in the sea can also increase interest in climate change and how these issues can be solved. According to the article, the four most important connections between climate change and plastic pollution in the oceans are:

1. Plastic contributes to the emission of greenhouse gases throughout its life cycle, including as litter in the sea,
2. Climate change and plastic pollution occur together everywhere in all environments,
3. Climate change will worsen the spread of plastic pollution,
4. There are already solutions today that stop both climate change and plastic pollution from reaching the environment.

Litter abundance on the coastline is depending on water currents, and prevailing wind conditions. Rivers are pathways for litter from inland littering. Climatological e.g., heavy rains and floods and oceanographic changes will alter the litter abundance and deposition of litter.

In the long term, it is conceivable that a warmer climate in the more northerly latitudes leads to increased tourism around the coasts of the Baltic Sea and thus also an increased risk of littering.

4.4.2 Seafloor litter

As the deep seafloor is thought to constitute a sink/accumulaAs the deep seafloor is thought to constitute a sink/accumulation area also for marine litter, most sources for marine litter can probably contribute to litter on the seafloor. Recent reviews of the amount and composition of litter on the seafloor show that items associated with maritime activities (e.g., fishing, shipping) dominate in some areas, but that items from land-based sources also commonly occur (Galgani *et al.* 2010; Galgani *et al.* 2015; Pham *et al.* 2014). In addition to the fact that seafloor litter can affect the ecosystem and its integrity, it should also be recognised that litter in the sea can have a socio-economic impact on human activities related to the sea, e.g., costs for, damage to or loss of fishing gear, obstruction of motors, beach clean-ups, and it can subsequently be washed ashore and have potential effects on tourism and recreation (Newman *et al.* 2015).

Fishing gear that has been lost, so called ghost nets, are a very special type of anthropogenic litter on the seafloor. Ghost nets are known to continue fishing and can be considered as posing an especially large risk to the environment compared to other types of litter. Static and bottom trawling fishing gear are known to be frequently lost and/or discarded. Studies have estimated the total catch of cod by ghost nets to 3-906 tonnes during a 28-month study period, amounting to 0.01-3.2% of the total weight of reported and landed cod catch from the same area and time period (Brown *et al.* 2005).

The types of gear lost and the reasons for the gear being lost are believed to differ regionally in the Baltic Sea, however comprehensive statistics are currently not available. In 2011, WWF Poland together with fishermen, scientists and divers conducted a pilot project financed by Baltic Sea 2020, with a view to work out the methodology for net removal and carry out activities to clean the Polish territorial waters from ghost nets. As a result, 6 tonnes of ghost nets were retrieved from the Baltic during 24 days of actions at sea – from sea bottom and two ship wrecks. In 2014, a ghost net project was conducted by the Ozeaneum Stralsund, archeomare e.V., Drosos foundation and the WWF Germany on Rügen. In that project, divers removed around 4 tonnes of ghost nets from two wrecks.

New data on the occurrence of derelict fishing gear (DFG) in the Baltic were collected through MARELITT Baltic, an EU-supported project involving partners from Estonia, Germany, Poland and Sweden. One of the aims of the project was to develop cost-efficient methods for mapping the occurrence of DFG, and to develop cost-efficient and environmentally sound methods for collecting DFG. The project ran for the period 2016-2019 (MARELITT, 2019).

When it comes to climate change, it does not impact seafloor litter except through possible changes in transport of litter by e.g., wind, rivers or currents.

4.5. How was the assessment of marine litter carried out?

4.5.1 Beach litter

Marine beach litter monitoring data from Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, and Sweden were extracted from the European Marine Observation and Data Network (EMODnet, 2022). Denmark and Sweden provided additional data directly for the purpose of this assessment. Beach types and the location of the monitoring sites for the period 2016-2021 are displayed in Figure 34.

As a first step, it was necessary to harmonise historical data to be able to calculate statistics on the beach litter abundance and trends. This was done by producing a separate list of litter items and categories where similar litter from the different lists has been given a new common code. In some cases, litter items/categories have been aggregated into one code due to the level of detail in the various lists. The common list, with unique reporting codes, and the relation to the Joint List of Litter Categories for Marine Macrolitter Monitoring (Fleet *et al.* 2021) is found in Appendix 5, table 5.3.

The different litter lists considered for the common list were:

- A Joint List of Litter Categories for Marine Macrolitter Monitoring (EU J-list) (Fleet *et al.* 2021),
- Guidance on Monitoring of Marine Litter in European Seas (EU Master list) (JCR, 2013),
- Guideline for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area (OSPAR Commission, 2010),
- Beach litter measurement method description (MARLIN, 2013) based on UNEP/IOC Guidance on Survey and Monitoring of Marine Litter (UNEP/IOC, 2009),
- Denmark, OSPAR/EU J-list,
- Germany, OSPAR/EU Master list, Meckl. Vorpommern/ Schleswig-Holstein area.

Some individual litter items were excluded from the statistical analysis. These are: R52 Organic food waste and R99 Other organic waste because their relatively short degradation time, R53 Chemicals because it requires other dedicated monitoring methods, R98 Micro- and mesolitter because of incomparable monitoring results, R23 Cigarette butts and R54 Snuff are excluded from Estonia and Latvia for all years, and for Sweden and Finland for the period 2016-2019.

All litter type abundances were normalised to 100 m.

Statistical analyses were done by using the statistical tool LitteR for calculating methodology for median values and trends, using national MSFD data (2016-2021). The same criteria as those for the determination of the threshold value were used (van Loon *et al.* 2020).

Below, there is a compilation of the most important steps in the assessment process:

1. Statistically analysing data as median values and trends for aggregated datapoints by HELCOM Scale 2 assessment units. This was done with the statistical tool, LitteR,
2. Analysing data in two ways:
   a. For median values all available monitoring data was included except from beaches with less than 3 surveys during the period 2016-2021. Subbasins with data including < 40 surveys are considered less reliable and are marked with pink in the table and with an * in supporting visuals,
   b. For time trend calculations, criteria of a minimum of 5 years and 10 surveys for a beach were used. This is recommended by the LitteR statistical programme to obtain statistically robust results,
3. Comparing the calculated median values of total count (TC) to the HELCOM threshold value to determine the status of beach litter in each subbasin,
   a. Median = or < threshold
      => Good environmental status achieved,
   b. b) Median > threshold
      => Good environmental status failed,
4. Providing only results with significant trends ($p < 0.05$):
   a. Improving trends ≤ 0
   b. Deteriorating trends ≥ 0
   c. Stable trends = 0
5. Calculating median minimum and maximum values per region to get increased understanding of the statistical results, and
6. Providing a top-ten litter item list, Baltic Sea wide, for beach litter based on medians of ranks for sub-basin top-ten lists.

The temporal scale used in this assessment is the predefined time of a six-years period between 2016-2021 in accordance with the MSFD reporting period (European Commission, 2022). On a spatial scale, Scale 2 of the HELCOM sub-divisions of the Baltic Sea for regional monitoring and assessment purposes, i.e., Scale 2 divides the Baltic Sea into 17 sub-basins for all beach types, was used.

4.5.2 Seafloor litter

Benthic trawls such as the ones used in the Baltic Sea International Trawl Survey (Figure 39) are designed to capture demersal fish species on the seafloor over a range of different seabed types that can be trawled. The trawl interacts with the seafloor in several places; hence, smaller litter and heavy litter can be carried into the water, and subsequently this litter enters the trawl where it may either pass through the mess or be retained. In the Baltic, the TV3 trawl is used in a small and a large version which are effectively scaled versions of the same gear. The widest part of the trawl is between the trawl doors (Figure 39). The ground gear consists of a series of 10 cm wide rubber discs that roll over the bottom, creating turbulence that may cause the trawl to pass over or lift litter into the net. The turbulence differs between soft and harder bottom types. The initial part of the net has large meshes (8-12 cm) and only the very final part of the net has small meshes (2 cm). Hence, smaller litter can be carried through the meshes of the initial part of the trawl and thus do not occur among the items brought onboard the vessel whereas larger litter once entering the trawl mouth will be retained. The water current will also affect how much of the litter is retained as a strong current may affect the amount of water

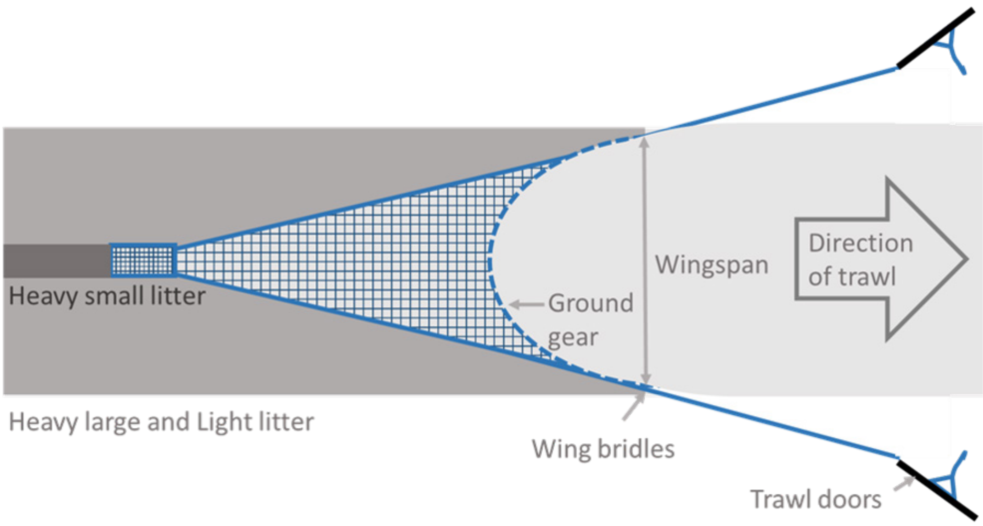


Figure 39. The active region of a benthic trawl net for light and heavy litter. Text indicates the types of litter not retained in each part of the trawl path. All litter except very small items are retained in the darkest grey part of the trawl path.

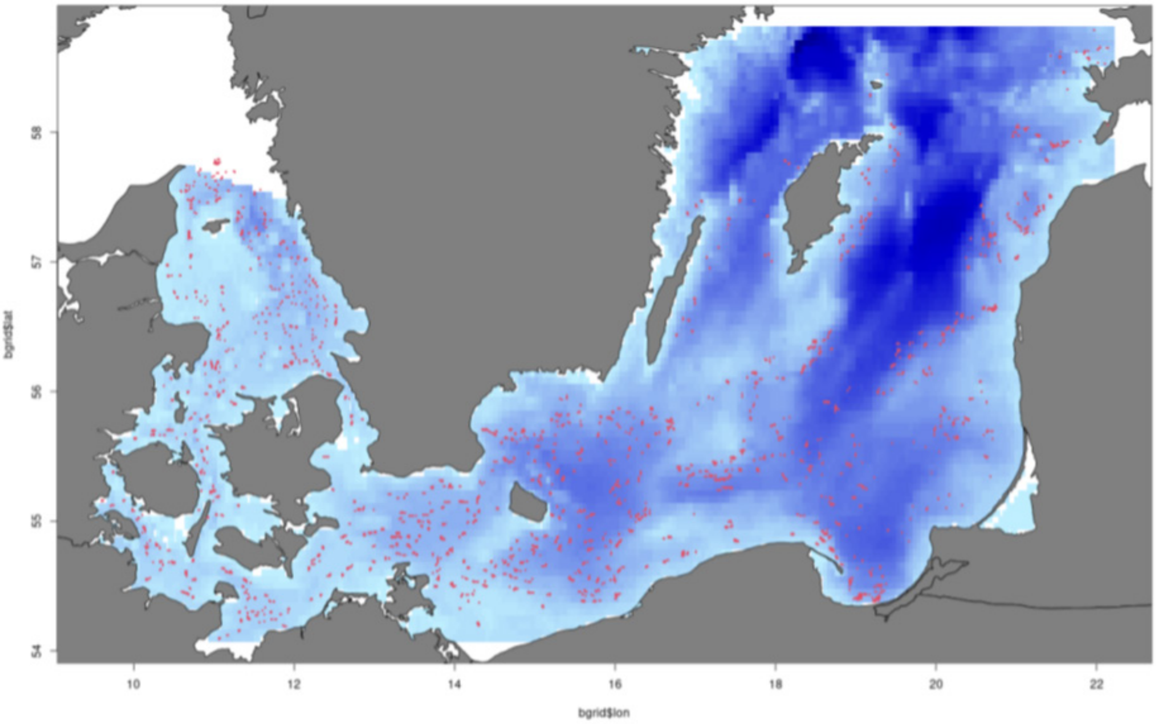


Figure 40. Sampling locations (red) and depth (shades of blue). Note that deep and the north and north-eastern part of the Baltic is not sampled. Please note that the depth map is not indicative of HELCOM agreed borders.

passing through the trawl and hence the amount of floating litter encountered. The trawl is therefore likely to under-represent the number of small and heavy items as these pass through the meshes of the net or do not even enter the trawl. As bottom trawls of different types are dragged at different distances above the sediment it is still difficult to predict how much of the actual litter on the bottom is caught by the trawl as this is not studied. Further, trawl surveys cover only sandy or muddy/clay areas and hence do not represent rocky substrates which may retain different amounts of litter. Finally, there are some concerns over the quality of the data submitted as the sampling guidelines and quality control have undergone continued development from the onset of litter sampling to today. The latest sampling protocol can be found at ICES (2022).

The sampling of litter in the Baltic Sea International Trawl survey commenced in 2011 but a description of the categories and sample codes was not fully standardised until 2015. A common description of how to sample litter did not appear until 2018. In the early years, some countries reported numbers while others reported weight. Further, the categories used initially were coarser than those currently used. As a result, data collected prior to 2015/2018 are considered less reliable. The locations sampled annually in the survey are shown in figure 40. There are minor variations in survey location within the surveyed area between years. The north-eastern Baltic is not covered by the available data. This area must therefore be monitored using other data if an assessment of the development over time in litter density is to be conducted.

Data for use in the analysis were extracted from the ICES website. The full code can be found here: https://github.com/DTUAqua/HELCOM-litter. Annual average values for each litter type and year are included in Annex 5 (Table A5.6). Litter data are recorded in the database by Denmark, Estonia, Germany, Lithuania, Latvia, Poland, Russia and Sweden. The years sampled for litter weight and litter number vary between countries (tables 18 and 19). From 2016 onwards, the proportion of hauls recording both litter weight and numbers has been above 85% (Figure 41).

Data are classified using one of the two formats C-TS (Original CEFAS trawl litter categories) and C-TS-REV (Revised CEFAS Trawl Litter Survey parameters). From 2019 onwards, only the latter of the two are used. The major categories are recorded in all years (plastic, metal, glass/ceramics, rubber, natural products and other) and are mutually exclusive (a litter item can only appear in one of these categories). Two further categories were also investigated (a litter item will appear in one of these categories only if it already appears in one of the above categories): Fisheries related litter and Single Use Plastic (Table 20). The aim of this categorization is to reflect estimates of SUP and Fisheries related litter as defined in EC (2019). As this represents a post hoc classification, the categories may contain litter that is not covered by the SUP Directive.

Table 18. Number of hauls sampled by country for weight of litter.

Year	Denmark	Estonia	Germany	Latvia	Lithuania	Poland	Russia	Sweden
2011	194	0	0	0	0	0	0	0
2012	203	0	51	0	0	0	0	80
2013	192	0	104	0	0	0	0	74
2014	146	0	115	0	0	0	0	70
2015	169	9	107	14	2	31	0	78
2016	95	10	116	41	10	95	0	76
2017	91	10	108	49	11	136	0	78
2018	205	10	111	56	9	118	16	63
2019	157	6	98	44	12	127	0	68
2020	222	8	108	37	12	106	0	68
2021	235	7	103	43	0	119	14	72

Table 19. Number of hauls sampled by country for number of litter items.

	Denmark	Estonia	Germany	Latvia	Lithuania	Poland	Russia	Sweden
2012	52	0	51	0	0	0	0	60
2013	0	0	104	0	0	0	0	64
2014	0	0	115	0	0	0	0	57
2015	15	9	107	14	3	31	0	57
2016	95	10	116	41	10	95	0	57
2017	91	10	108	49	11	67	0	78
2018	205	10	111	56	9	84	16	63
2019	157	6	98	44	12	121	0	68
2020	204	8	108	37	12	106	0	68
2021	221	7	103	43	0	119	14	72

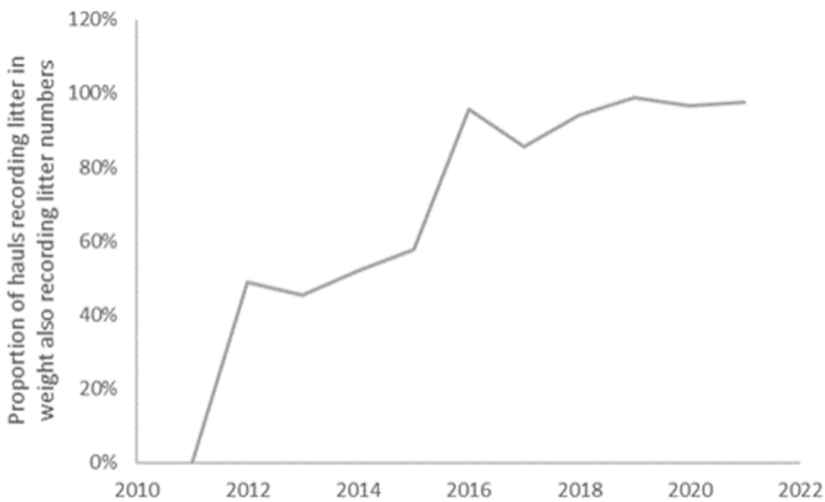


Figure 41. Development in the proportion of hauls recording litter in weight where number of litter items is also recorded.

Table 20. Litter categorisation and assignment of categories to Single Use Plastic (SUP) and Fisheries related litter. 'Yes' means the litter type is included in SUP or Fisheries related litter. Litter categorised as SUP does not include Fisheries related plastic.

	C-TS	C-TS-REV	Type	SUP	Fisheries related litter
Plastic	A	A	Plastic		
Plastic bottle	A1	A1	Plastic	Yes	
Plastic sheet	A2	A2	Plastic	Yes	
Plastic bag	A3	A3	Plastic	Yes	
Plastic caps	A4	A4	Plastic	Yes	
Plastic fishing line (monofilament)	A5	A5	Plastic		Yes
Plastic fishing line (entangled)	A6	A6	Plastic		Yes
Synthetic rope	A7	A7	Plastic		Yes
Fishing net	A8	A8	Plastic		Yes
Plastic cable ties	A9	A9	Plastic		
Plastic strapping band	A10	A10	Plastic		
Plastic crates and containers	A11	A11	Plastic	Yes	
Plastic diapers	B1	A12	Plastic	Yes	
Sanitary towel/tampon	B6	A13	Plastic	Yes	
Other plastic	A12	A14	Plastic		
Sanitary waste (unspecified)	B		Plastic	Yes	
Cotton buds	B2		Plastic	Yes	
Cigarette butts	B3		Plastic	Yes	
Condoms	B4		Plastic	Yes	
Syringes	B5		Plastic	Yes	
Other sanitary waste	B7		Plastic	Yes	
Metals	C	B	Metal		
Cans (food)	C1	B1	Metal		
Cans (beverage)	C2	B2	Metal		
Fishing related metal	C3	B3	Metal		
Metal drums	C4	B4	Metal		
Metal appliances	C5	B5	Metal		
Metal car parts	C6	B6	Metal		
Metal cables	C7	B7	Metal		
Other metal	C8	B8	Metal		
Rubber	D	C	Rubber		
Boots	D1	C1	Rubber		
Balloons	D2	C2	Rubber	Yes	
Rubber bobbins (fishing)	D3	C3	Rubber		Yes
Tyre	D4	C4	Rubber		
Glove	D5	C5	Rubber		
Other rubber	D6	C6	Rubber		
Glass/Ceramics	E	D	Glass		
Jar	E1	D1	Glass		
Glass bottle	E2	D2	Glass		
Glass/ceramic piece	E3	D3	Glass		
Other glass or ceramic	E4	D4	Glass		
Natural products	F	E	Natural		
Wood (processed)	F1	E1	Natural		
Rope	F2	E2	Natural		
Paper/cardboard	F3	E3	Natural		
Pallets	F4	E4	Natural		
Other natural products	F5	F5	Natural		
Miscellaneous	G	F	Other		
Clothing/rags	G1	F1	Other		
Shoes	G2	F2	Other		
Other	G3	F3	Other		

Swept area corrections

The area swept was defined as the distance trawled multiplied by the width of the trawl between the wings. Data on wingspan, doorspread and distance travelled were not consistently available. Given the low proportion of hauls containing the necessary information to estimate the swept area for each haul, it was decided to instead assume that all hauls of a specific gear type covered the median of the swept areas estimated for all hauls with TVL (large TV trawl) and TVS (small TV trawl), respectively (87163 m^2 and 68184 m^2, respectively).

Estimation of the indicator

Three metrics were investigated, the proportion of trawl hauls containing litter, the average catch of litter in number and the average catch of litter in weight, both per km^2.

The statistical properties of the data (large overdispersion and occasional very large catches) necessitated analysing the data in a statistical model (Stefánsson 1996, Berg *et al.* 2014). Survey indices were therefore calculated using the methodology described by Berg *et al.* (2014). Three models were fitted for each type of litter to estimate the amount of litter caught. Model 1 assumes that the amount of litter develops smoothly from year to year as a result of litter deteriorating slowly in the wild. Hence, the model utilises the knowledge we have of the lifetime of litter on the seafloor and is considered the most appropriate model. Model 2 allows the amount of litter to change freely between years, equivalent to the assumption that litter is removed from the surveyed area every year and replaced by new litter. This model is equivalent to estimating the annual amount independently of the previous year and is commonly used. Model 3 estimates a linear trend over the period and can be used to evaluate if there has been a significant steady increase from year to year within the sampling period. An alternative method to investigate the development in litter over time could be to compare the level in the period from 2016 to 2021 with that in the period from 2010 to 2015. However, this test is less statistically strong than model 3 as it does not utilise the information present in the development within assessment periods and further is complicated by the sampling only beginning midway in the first assessment period for most countries.

The spatial distribution of litter was assumed constant over time due to the sparsity of data. The following equations describe the models:

$$(1)\ g(\mu_i) = f_1(time_i) + f_1(lon_i, lat_i) + \log(effort_i)$$

$$(2)\ g(\mu_i) = Year_i + f_1(lon_i, lat_i) + \log(effort_i)$$

$$(3)\ g(\mu_i) = \alpha time_i + f_1(lon_i, lat_i) + \log(effort_i)$$

Effort is the swept area and amount caught is assumed to be directly proportional to this (i.e., if the area swept is doubled, the average amount caught is doubled). The swept area for a 30 min haul is assumed to be 68184 m^2 for the TVS gear and 87163 m^2 for the TVL (approx. 0.78 ratio, see above). All f-functions are Duchon splines with first derivative penalization. The models are fitted using both proportion of non-zero catches, numbers and mass as the response variable. For models using mass the Tweedie distribution (compound Poisson-Gamma) is used, because it is simple and easy to work with (see e.g., Thorson 2017). For models using numbers and to predict probability of catching litter the negative binomial distribution is used. Mass and number indices are standardized to a unit of kg / km^2 or numbers / km^2.

4.6. Follow up and needs for the future with regards to marine litter

At this moment in time, marine litter is perceived as an important problem. The historic agreement at the resumed Fifth Session of the United Nations Environment Assembly (UNEA 5-2) in March 2022 to develop an international legally binding agreement to end plastic pollution by 2024 is a clear example of such global commitment. HELCOM is committed to support the development of the global instrument, as stated in a voluntary commitment on the matter at the UN Ocean Conference held in Lisbon in June 2022. In alignment with such commitment, the updated Baltic Sea Action Plan contains, for the first time, a dedicated section on marine litter including both ecological and managerial objectives to achieve. The fulfilment of these objectives will count with the revised Regional Action Plan on Marine Litter, adopted in the 2021 Ministerial Meeting as HELCOM Recommendation 42-43/3, as its instrumental tool containing almost thirty regional actions addressing sea-based and land-based sources of marine litter (HELCOM, 2021). Moreover, in its preamble, the Action Plan states HELCOM ambitions towards development of additional core indicators and associated definition of GES and improved coordinated monitoring programmes. Such work is to be conducted considering outcomes of the related work under the EU MSFD and involving close coordination with the EU TG Litter, as well as with similar work of the Russian Federation.

In that sense, beach litter is adopted as an indicator to enable EU wide monitoring of litter in the marine environment according to the MSFD requirements in Article 8, 2008/56/EC (European Commission, 2022). It is also part of the OSPAR monitoring program since 2010 (OSPAR, 2010). UNEP/IOC (2009) agrees as well on the adequacy of this indicator. Future work needs to focus on the harmonisation of protocols, preferably by implementing the EU Joint List of Litter Categories for Marine Macrolitter Monitoring (Fleet *et al.* 2021) by all HELCOM Contracting Parties. Furthermore, there is a need for better coverage with continuous monitoring efforts on beaches in all sub-basins, representing different types of beaches including remote ones.

For seafloor litter, recommendations for sampling seafloor litter (specifying shallow and deeper waters) are derived from the MSFD GES Technical Group on Marine Litter (JRC, 2013) to contribute to the monitoring of litter in the marine environment according to the MSFD requirements. Seabed litter is also a common indicator of the OSPAR area, as detailed in the Second Regional Action Plan for Prevention and Management of Marine Litter in the North-East Atlantic (OSPAR, 2022). Further improvements to the analysis could include monitoring of the amount of litter in categories more closely related to ingestion, entanglement and contaminants. Furthermore, the issue of the source of litter items should be investigated in order to suggest appropriate management measures and likely impacts of these on the indicator.

5. Results for the underwater noise assessment

Assessment results in short

— The assessment of continuous noise evaluates the sound pressure levels in the Baltic Sea in 2018 which is a year considered to be representative for the conditions in the 6-year assessment period (2016-2021), being the year when more monitoring data were available. Continuous noise is evaluated on the basis of numerical modelling of the whole Baltic Sea. Modelled sound maps were validated with measurements from seven monitoring stations. Thus, good status is achieved when the indicator is below the spatial threshold, which expresses a proportion of area, for all months in 2018, for fish (125 Hz decidecade band) and marine mammals (500 Hz decidecade band). The recommendation from EU TG-Noise, the EU expert body working on establishing EU wide methodology and threshold values for the evaluation of underwater noise, is to use a spatial threshold of 20% or lower in the assessment. As there has not been an opportunity to discuss and agree on a regionally specific threshold value at this stage (i.e., a pre-core evaluation is carried out in this first iteration) for the Baltic Sea, the choice was made to use 20%, which is interpreted as the default value. Two variants of the indicator were evaluated. One variant uses the median total sound pressure level as metric to assess risk of behavioural disturbance. This indicator was below the 20% spatial threshold for all assessment units for both fish (125 Hz decidecade band) and marine mammals (500 Hz decidecade level). The other variant uses the median excess (elevation of ambient noise by anthropogenic sources) as metric to assess risk of masking. This indicator was below the 20% spatial threshold for all assessment units for marine mammals but exceeded the 20% spatial threshold for 9 out of 17 assessment units for masking of fish communication, although not for fish behavioural disturbance where it was below the threshold value. This pre-core indicator is still to be developed in a range of aspects. While spatial and temporal threshold values have just been adopted at EU level, formal discussions and agreements remain about their implementation, including the possibility of adopting stricter thresholds and decisions left to be made at the regional level. Most important, this relates to decisions on habitat designation and establishing species(group)-specific values for level of onset of biologically adverse negative effects (LOBE). The indicator will therefore be further discussed and developed towards HOLAS 4.

— Impulsive noise was evaluated on the basis of the occurrences of impulsive noise-producing maritime activities reported by Contracting Parties to the regional HELCOM/OSPAR noise registry hosted by ICES (ICES, 2015). The recommendation from EU TG-Noise is to evaluate the temporal and spatial proportion of habitats that are impacted and affected by underwater sound towards the establishment of a quantitative threshold value. In alignment with this approach, an interim assessment threshold value of a fraction over one year of exposed area of 10% of the Baltic Sea is used in this assessment. The distribution of sound was partially compared to the distribution of harbour porpoises in the Baltic Sea to get a first idea of overlap of sound and the occurrence of harbour porpoises. Across the assessment period the area/habitat exposed and disturbed with respect to displacement clearly remained below a fraction of 10% of the HELCOM area habitat per day, indicating that there should be enough habitat for harbour porpoises in the Baltic Sea to avoid regions impacted by low- and mid-frequency impulsive sounds.

— This pre-core indicator is still to be developed in a range of aspects. While spatial and temporal threshold values have just been adopted at EU level, formal discussions and agreements still remain about the use of these as well as e.g., subbasin and habitat size in the assessment, and sound level of onset of biologically adverse negative effects (LOBE). The indicator will therefore be further discussed and developed towards HOLAS 4.

5.1. Introduction to underwater noise

Concern about pollution by underwater noise and its effects on marine life was raised in the 1970's (e.g., Payne and Webb, 1971; reviewed by Richardson *et al.* 1995) and received renewed political attention when a link between navy sonars and whale strandings was established in the late 1990's (Frantzis, 1998; Evans and England, 2001). In parallel with this, the development of plans for an extensive expansion of renewable energy, in particular offshore wind, into coastal areas raised concerns about the possible impact of underwater noise (Madsen *et al.* 2006). These and other events were key factors in the gradual realisation that underwater noise was and is one of the significant human impacts on in particular marine mammals.

Fish species are able to detect sounds within the frequency range of the most widely occurring anthropogenic sounds (Popper, 2003). Some scientific papers suggest that fish species such as perch (Perca fluviatilis), carp (Cyprinus carpio), sea bass (Dicentrarchus labrax) and others, due to anthropogenic continuous or impulsive noise, experience elevated levels of cortisol hormone in blood, which is a primary indicator of stress response regardless their hearing sensitivities (Wysocki *et al.* 2006; Santully *et al.* 1999).

There are also studies providing indications on possible effects of underwater noise on invertebrates, although not quantified.

For low frequency continuous noise, the ability to mask acoustic communication and reception of other, biologically relevant sounds, is of particular importance, as is the disturbance of behaviour that high levels of noise may lead to. Direct injury for example to the inner ear, leading to partial hearing impairment, is considered less relevant for this indicator, but empirical evidence is lacking. Even less is known about possible physiological impact (cardiovascular and stress effects) of continuous noise exposure, preventing meaningful assessment of these effects. In this report we focused on continuous sound pressure component, which can cause auditory masking and disturbance of marine species. Effects of sound pressure are further discussed in section 5.6.1.

There is a large body of experimental evidence for behavioural reactions on marine mammals to loud impulsive noise, in particular for harbour porpoises (e.g., Madsen *et al.* 2006; Brandt *et al.* 2009; Tougaard *et al.* 2009; Tougaard *et al.* 2012; Dähne *et al.* 2013), but also harbour seals (e.g., Jacobs and Terhune, 2002; Gordon *et al.* 2015; Kastelein *et al.* 2015). Temporary and permanent damage to the auditory system (TTS and PTS, respectively) has also been well documented in these two species, as well as others (Lucke *et al.* 2009, Finneran, 2015). Impulsive noise input from unmitigated pile driving activities has been shown to induce avoidance reactions and thus disturbance to harbour porpoises at a distance of 25 km (Dähne *et al.* 2013). However, effective noise mitigation measures applied during pile driving activities reduce the effect radius for onset of measurable biological response to 12 km, while significant effects (disturbance of harbour porpoise associated with habitat avoidance) are reduced to 7,5 km from the source (Dähne *et al.* 2017, Brandt *et al.* 2018, Rose *et al.* 2019). Disturbance due to acoustic harassment devices, like seal scarers often used in aquaculture but also in pile driving activities have also the potential to disturb harbour porpoises and lead to habitat avoidance at distances of more than 7 km from the source (Brandt *et al.* 2013).

5.2. Details on the assessment results for underwater noise

5.2.1 Continuous noise

In figure 42, the modelling results of the median sound pressure level for the 125 Hz decidecade band in March 2018 is presented as illustration. In this period of the year the spatial effect of anthropogenic sound contribution is quite high because of favourable sound propagation conditions due to the generally well-mixed water column. In other months of the year, in particular during summer months, the sound propagation conditions are such that the ship noise is localized more around the shipping lanes. This effect is caused by downward refraction due to stratified waters (Klusek and Lisimenka 2016). However, sound channels could have effects which locally increase sound propagation (Sigray *et al.* 2016) which could not be accounted for by the model. The noise in the 125 Hz decidecade band used for assessment on fish is higher than in the 500 Hz decidecade band used for marine mammals. The map represents the monthly median noise level, indicating that noise levels in the Baltic Sea in March 2018 have been at the sound pressure levels indicated by the colour scale or higher, 50% of the time. Similar maps were created for the remaining months and the 500 Hz decidecade band.

The sound map in figure 43 shows the median excess level, also for March 2018 and the 125 Hz decidecade band level. The map thus indicates that the ship noise is expected to have elevated the ambient noise level with the amount given by the colour scale or more for 50% of the month. As this map is affected by sound propagation conditions in the same way as the map in figure 42, this map represents the situation at the time of the year where conditions facilitate noise transmission and therefore have the greatest potential for impacting marine life in the Baltic Sea.

The fraction of grid cells within each habitat (subbasins) were evaluated against the different LOBE values, as described above (see section 5.6.1 step 2 and Table 23), month by month in 2018 and results for three example habitats are plotted in figure 44 for the behavioural disturbance, and in figure 45 for masking. The three selected areas, Gulf of Finland, Northern Baltic Proper and Arkona Basin are all areas with heavy shipping traffic.

Horizontal red lines show the threshold of 20% of the estimated sub-basin area with LOBE exceeded. For all three basins there is a seasonal variation, with highest levels in the late winter and lowest levels in the late summer. These fluctuations relate to annual changes in the sound propagation properties, due to changes in the vertical stratification of the water column and it is not related to variations in the number of ships.

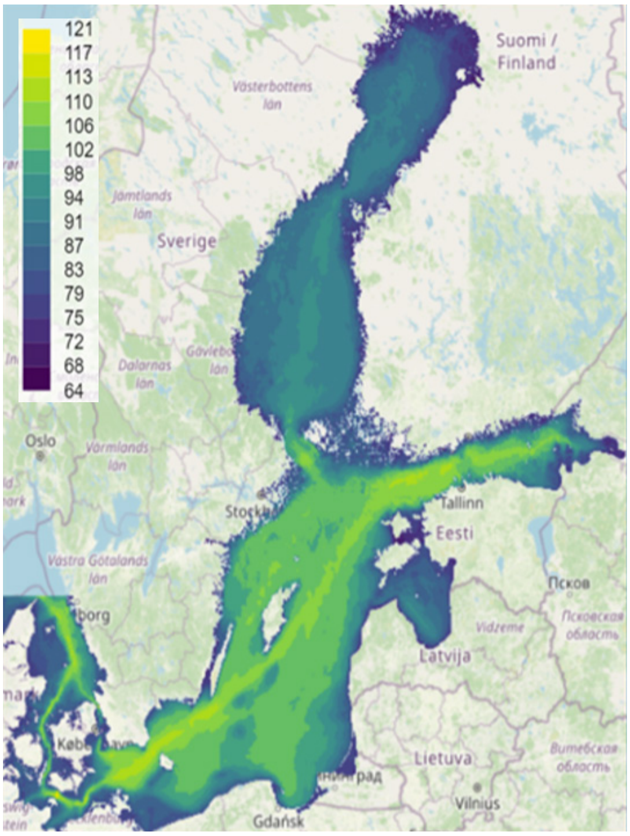


Figure 42. Median SPL for third octave band 125 Hz in March 2018. The map represents the time of the year with the most favourable conditions for the transmission of anthropogenic noise in the Baltic Sea.

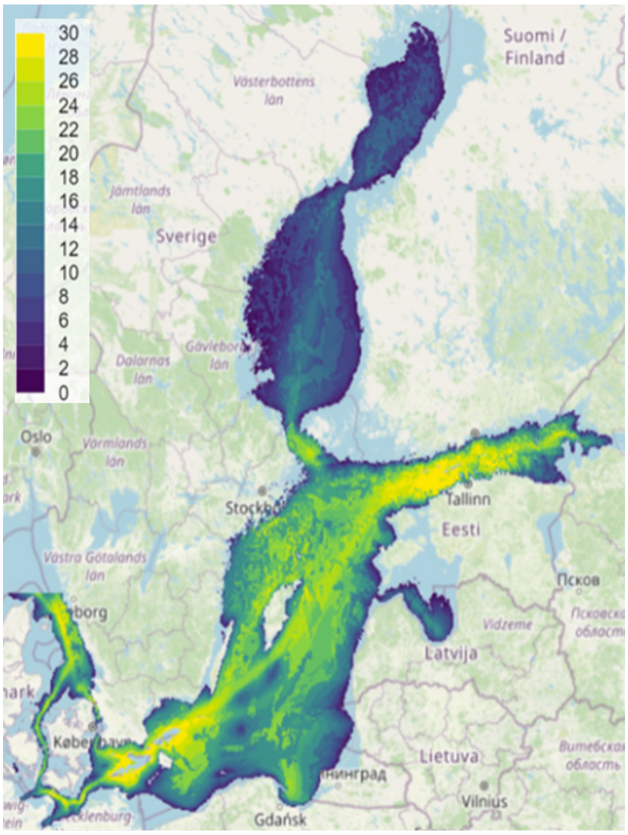


Figure 43. Median excess level for third octave band 125 Hz in March 2018. The map represents the time of the year with the most favourable conditions for the transmission of anthropogenic noise in the Baltic Sea.

It can be seen from figure 44 that for 125 Hz the median sound pressure level emerges in winter and spring but does not exceed the LOBE level of 110 dB re 1 µPa (from which disturbance/displacement can be assumed) on 20% of any assessment unit in any month. As for 500 Hz, the median sound pressure level corresponding to the LOBE level of 110 dB is practically absent for any assessment unit in the three examples in any month.

In figure 45 it can be seen that in terms of dominance 20% spatial threshold is exceeded for 125 Hz in all three subbasins indicating that in these subbasins fish can be affected. At the same time for 500 Hz exceedance of 20 dB is present, but never reaches spatial threshold of 20% set for marine mammals.

Assessment results of all subbasins are given in table 21. Three out of four variants of the indicator are in good environmental status (below the spatial threshold) in all subbasins, throughout the year, being the 125 Hz band, selected for masking of fish communication, the one that exceeds the spatial threshold in half of the subbasins (9 out of 17). Although the LOBE for disturbance was exceeded in an area below the 20% spatial threshold only, distinct known spawning grounds in Eastern Gotland, Bornholm and Arkona Basins as well as Kattegat may require management action.

The difference between the two assessment metrics relates primarily to the way the natural ambient noise is treated in the estimates of the metrics. For the first metric, the sound pressure level,

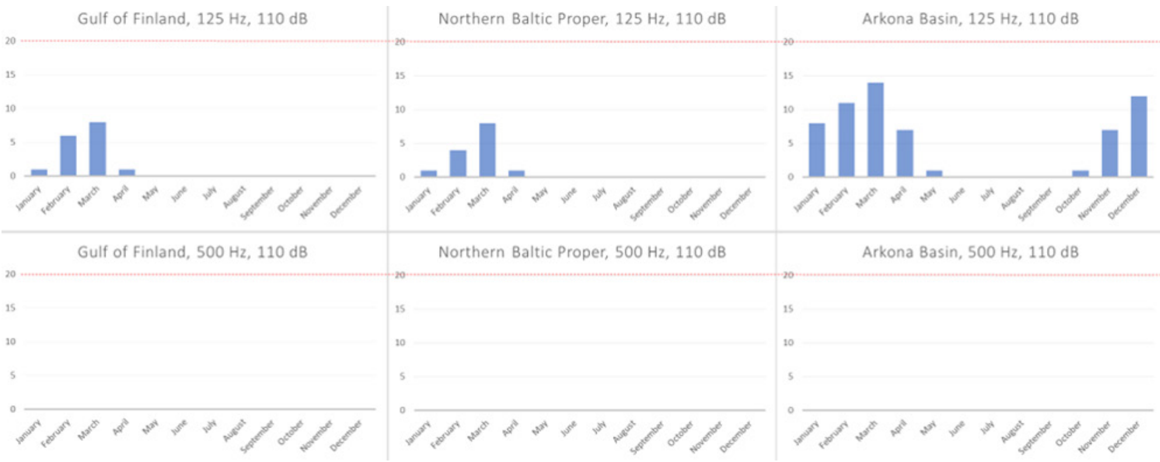


Figure 44. Disturbance level[1] LOBE occurrence in 3 subbasins by month. The red dotted lines indicate a spatial threshold of 20% of the estimated sub-basin area with a disturbance level above LOBE. For 125 Hz the spatial threshold has not been exceeded in any of the 3 subbasins. For 500 Hz, the LOBE value has not been reached..

1 Disturbance level is a total sound pressure level (SPL, sum of natural ambient noise and ship noise) that can trigger adverse behavioral reactions of the animal, such as avoidance of a habitat or startle reaction.

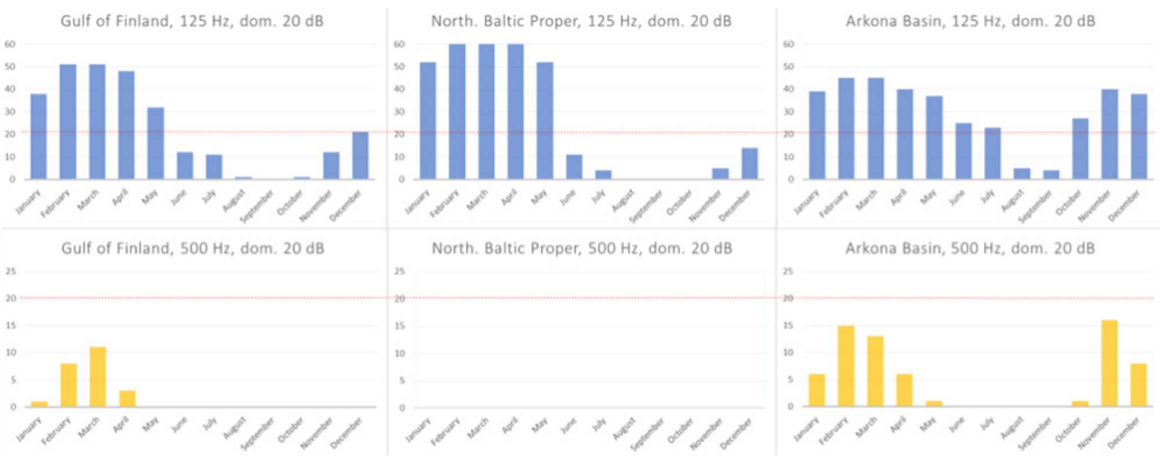


Figure 45. Masking excess in 3 subbasins by month. Results are given for two third octave bands 125 Hz (up) and 500 Hz (down) in 2018. The red dotted lines indicate a threshold of 20% of the estimated sub-basin area with an excess level above LOBE.

the natural ambient noise is ignored and only the total noise (natural ambient + ship noise) is evaluated against the LOBE (110 dB re 1 µPa). The second metric, the excess, is modelled relative to the natural ambient noise, i.e., expressing the difference between the current condition (natural ambient + ship noise) and the reference condition (natural ambient alone). The results show that: (i) as expected, shipping emits more noise in the low frequency bands where fish are more sensitive than marine mammals; (ii) low frequency noise propagates further and affects larger areas; and (iii) preliminary LOBE values have not yet received empirical confirmation and are subject to adjustment, which may change the results of these preliminary estimates.

When it comes to confidence on the results of the assessment, preliminary results from on-going projects and monitoring activities indicate that confidence of monthly averages, based on observational data are high enough to be used for assessing the statistical status of noise levels in the Baltic Sea. Regional standards for sensors, handling of data and signal processing have been established that will ensure that results will be trustable and comparable in the HELCOM region. Further, it has been demonstrated that annual and monthly soundscape maps can be drawn that cover the full area of the Baltic Sea, with exception of the shallow waters (less than 5-10 m), where the model is inappropriate. The benefit of the soundscape maps is that they extend the local measurement to the full Baltic Sea and thus they can be used to address impact in interest areas and/or specific periods. The combined use of soundscape maps and observations has not been fully investigated yet. The available results from observations and modelling shows that the prerequisites for managing anthropogenic sound is in place and can be used to establish statistical measures of the indicator. It must however be emphasised that the contribution of vessels not having AIS could not be taken into account and that sound propagation in coastal waters (e.g., shallow or in archipelagos) is complex and could also not be addressed in the model. Root mean square error between measurement and modelling were assessed at each measurement point (one station per Gulf of Finland, Bothnian Sea, Bornholm Basin, Eastern Gotland Basin, Arkona Basin and two stations in Kattegat were used for the validation of the model) and it changed from 0.4 to 3.4 dB depending on frequency band and measurement point position.

The main sources of uncertainty in the assessment lies in the biological input to the assessment. This relates to the spatio-temporal distribution of the indicator species, but also to the LOBE values, i.e., the levels of noise exposure expected to result in adverse effects. In the most recent guidance from TG Noise (2022), the responsibility for establishing values for LOBE is placed at the regional level, as LOBE is likely species dependent and thereby closely linked to the selection of indicator species.

Table 21. Assessment results. Fish: Baltic herring and cod, Marine mammals: all seals and harbour porpoise. Green indicates that the indicator is below the 20% spatial threshold for all months in 2018, red indicates that the indicator was above the 20% spatial threshold in at least one month of 2018.

Subbasins		125 Hz		500 Hz	
		Fish		Marine mammals	
		SPL 110 db	dom. 20 dB	SPL 110 dB	dom. 20 dB
1	Gulf of Finland	green	red	green	green
2	Gulf of Riga	green	green	green	green
3	Northern Baltic Proper	green	red	green	green
4	Aland Sea	green	green	green	green
5	Bothnian Sea	green	green	green	green
6	The Quark	green	green	green	green
7	Bothnian Bay	green	green	green	green
8	Western Gotland Basin	green	red	green	green
9	Eastern Gotland Basin	green	red	green	green
10	Gdansk Basin	green	red	green	green
11	Bornholm Basin	green	red	green	green
12	Arkona Basin	green	red	green	green
13	The Sound	green	green	green	green
14	Bay of Mecklenburg	green	red	green	green
15	Kiel Bay	green	green	green	green
16	Great Belt	green	green	green	green
17	Kattegat	green	red	green	green

5.2.2 Impulsive noise

Figure 46 depicts all locations (points and polygons) for which events were reported to the noise registry for the period 2016-2021, whereas figure 47 shows the number of days when events were reported for each year anywhere within the HELCOM area.

For a comprehensive analysis of the data available in the registry, two approaches were taken: an analysis regarding the properties of the events as reported to the registry, and an analysis of the daily exposure according to the amount and properties of events reported for each day. For the quantitative evaluation of the temporal and spatial exposure in the Baltic Sea, the exposed area was further calculated per day. The effect range for each reported source was evaluated based on standardized and source specific effect ranges (see table 25 in section 5.6.2).

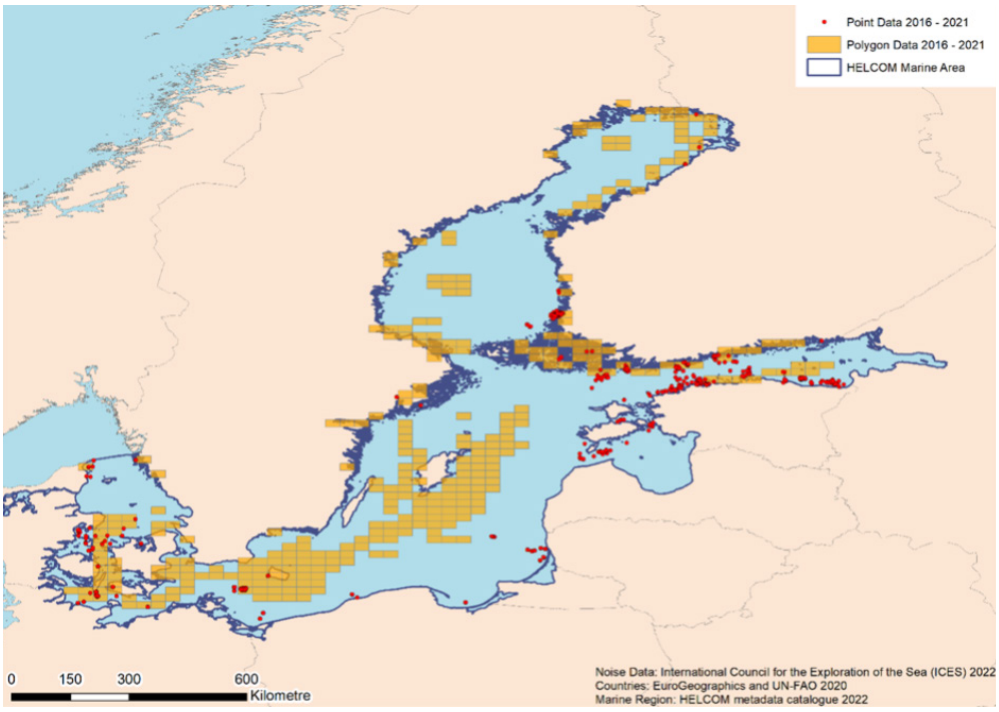


Figure 46. Overview of impulsive noise activities for the period 2016 – 2021 reported in the HELCOM area (data source: HELCOM noise registry hosted by ICES).

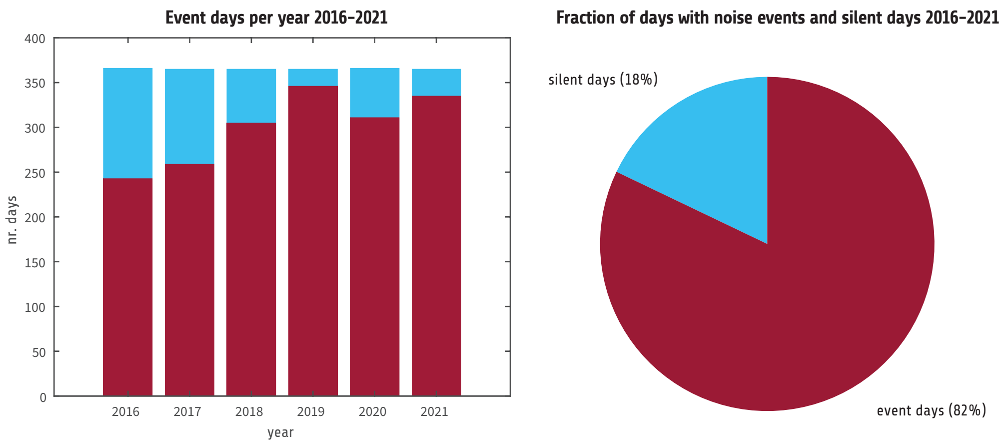
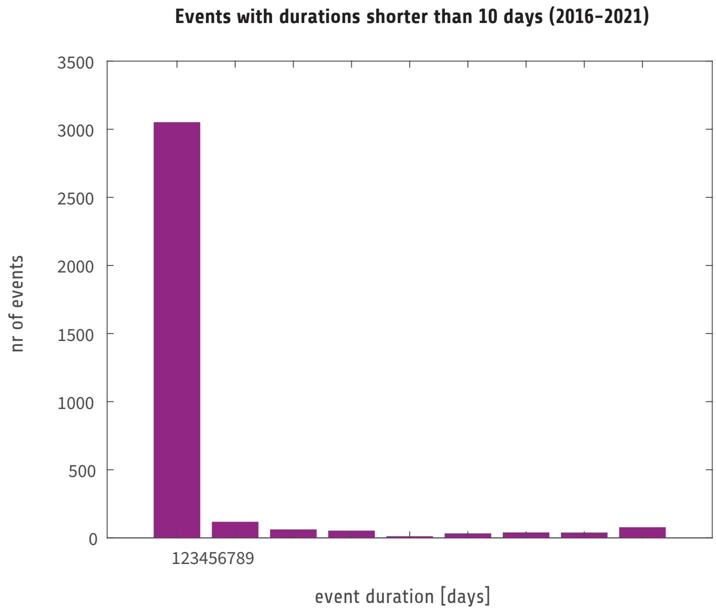


Figure 47. (a) Number of days for which one or more events were reported for each year anywhere within the entire HELCOM area (i.e., HELCOM Scale 1, whole Baltic Sea). (b) Proportion of days with (event days) and without (silent days) one or more events reported anywhere within the entire HELCOM area.

Characteristics of events with respect to the evaluation of long-term pressure

When it comes to long-term contributions to the regional pressure, the vast majority of events lasted only a few days (most only one day), but there is a considerable number of events with a very long duration, up to 250 days (Figure 48a). Events with a duration exceeding 10 days were reported for all source types in general (Figure 48b). Reported events of source type Sonar or Acoustic Deterrents are particularly frequently represented in this sub-group (89 events compared to 11-20 events for each of the other types of source events).



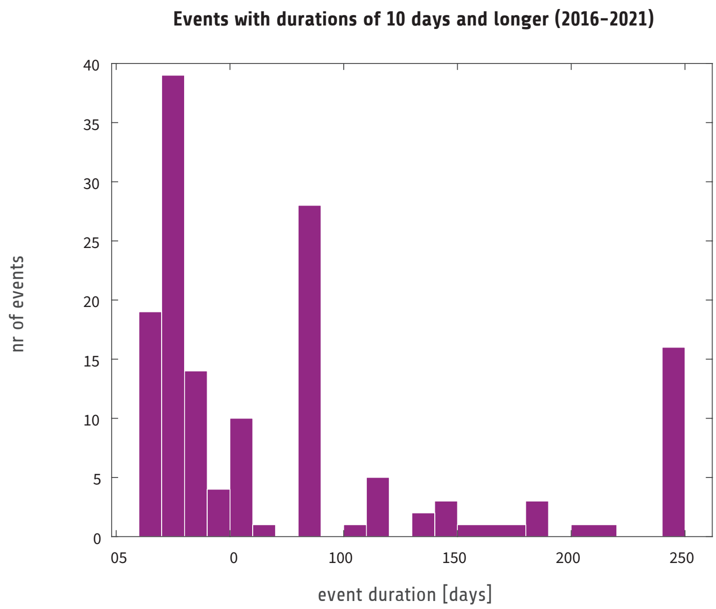


Figure 48. Overview of reported event duration (in days) and the number of such events; (a) shows events with a reported total duration shorter than 10 days, (b) shows events with a reported total duration of 10 days and longer. Note different y-axes.

Characteristics of events with respect to the evaluation of seasonal pressure

To consider seasonal effects, the number and properties of event days were evaluated per month for the assessment period. As depicted in figure 49 the majority of events occurred in the period May-November which partially coincides with the reproductive season of harbour porpoises and harbour seals in the Baltic Sea.

The Value Codes of the days in a month, averaged to calendar month values over the assessment period, are shown in figure 50. If for one day events with different Value Codes were reported, the highest reported Value Code was assigned to that day. However, it is to be noted that value codes are not comparable between source types.

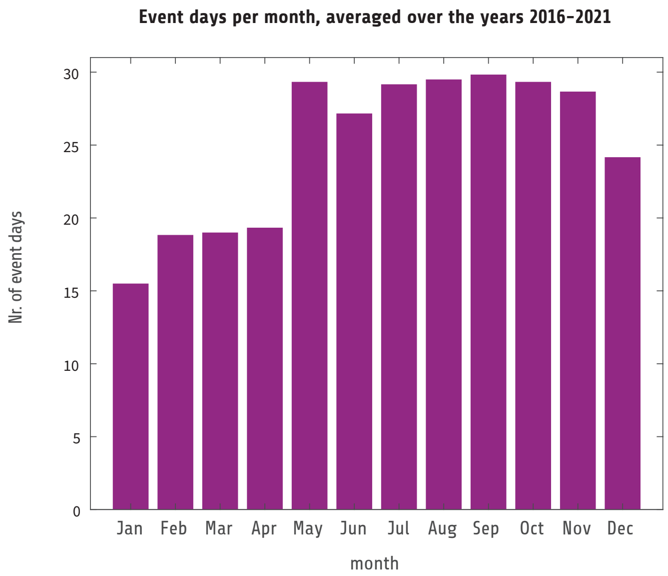


Figure 49. Distribution of event days per month within the entire HELCOM area (averaged over the years 2016–2021).

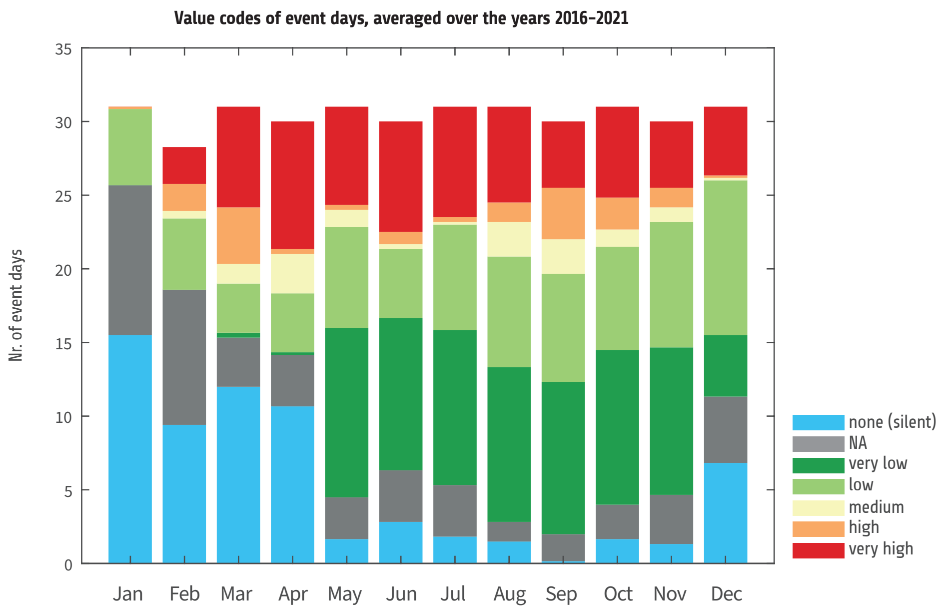


Figure 50. Event days of each value code for every month (averaged over the years 2016–2021), days for which events with different Value Codes were reported count into the highest category reported for that day. The category 'NA' (depicted in grey) indicates that the value code was not reported.

Activity type overview of spatial and temporal pressures distribution in the HELCOM area

The spatial distribution of reported events and their source types for the years 2016 – 2021 is shown in figure 51. Note that if events of different source types were reported for one polygon, only the most recent one is shown.

When considering the number of reported events and Event Days per source type (Figure 52), it is apparent that most Event Days fall into the category "multiple", i.e., for most days of the assessment period events of different source types occurred somewhere within the HELCOM-area.

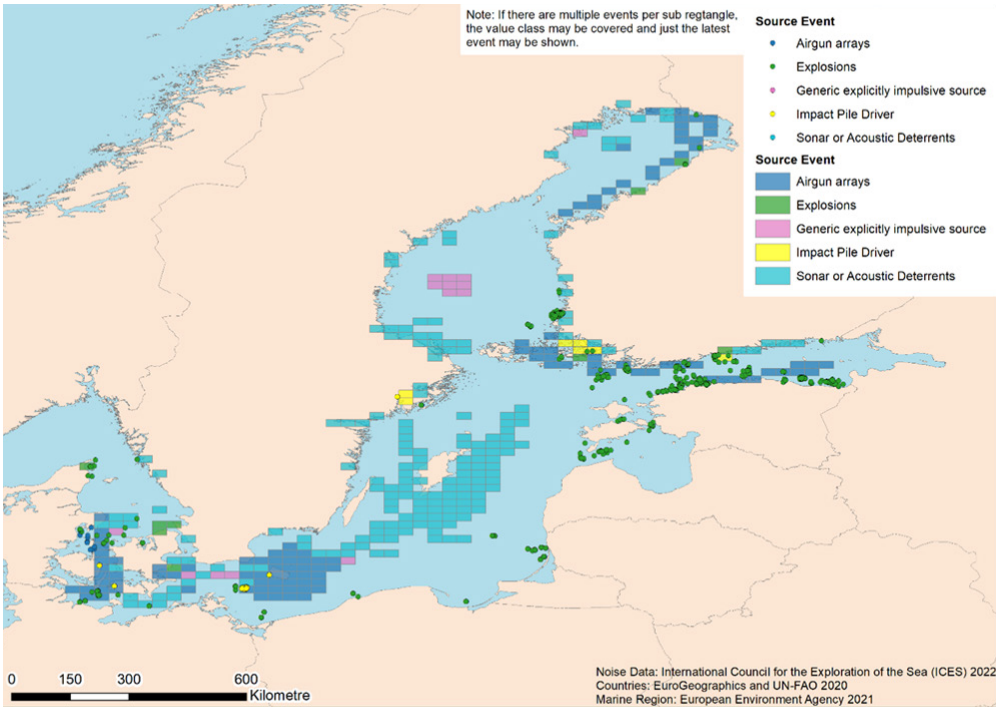


Figure 51. Overview of impulsive noise activities with respect to their source event type in 2016 – 2021 reported for the HELCOM area (data source: HELCOM Noise Registry).

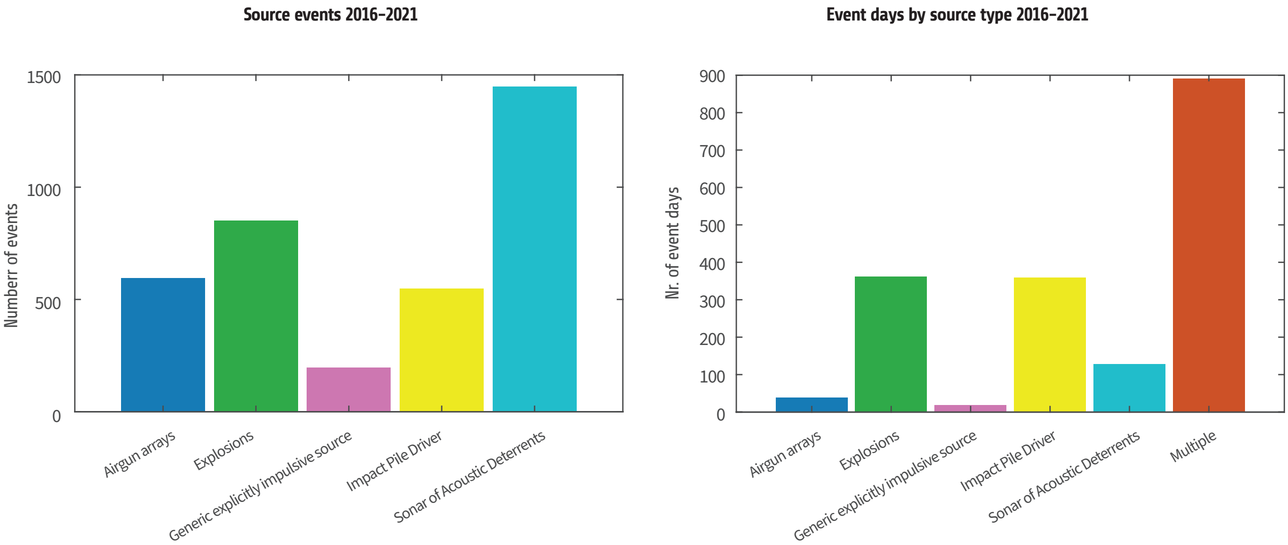


Figure 52. (a) Overview of source event types of reported events for the period 2016 – 2021. (b) Number of Event Days with reported source type, days for which events from different source types were reported count as 'multiple'.

Value code overview of spatial and temporal pressure distribution in the HELCOM area

An overview of the spatial distribution and respective value code is provided in figure 53. Where multiple occurrences take place in the same point or polygon, the latest event is depicted unless stated otherwise.

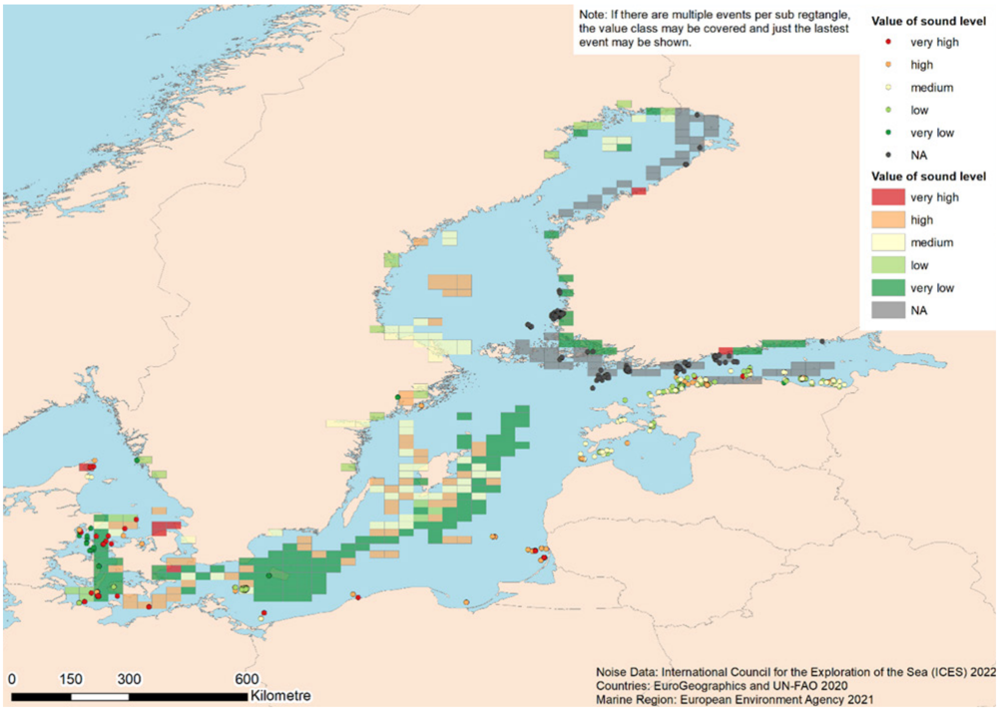


Figure 53. Overview of impulsive noise activities with respect to their value code in 2016 – 2021 reported for the HELCOM area (data source: HELCOM Noise Registry).

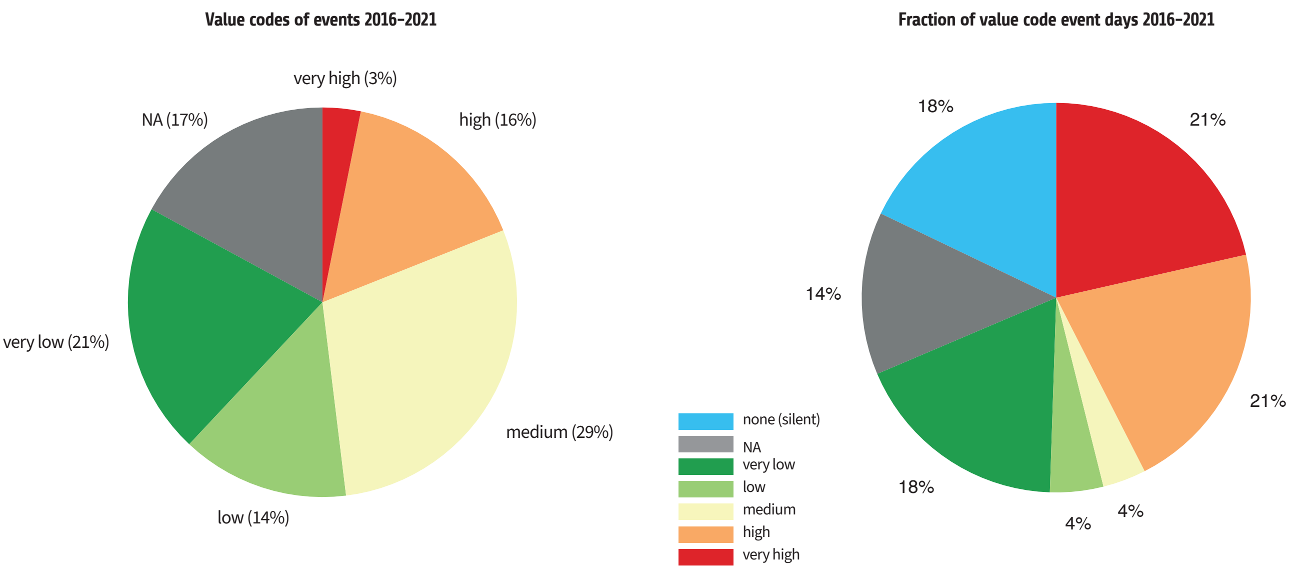
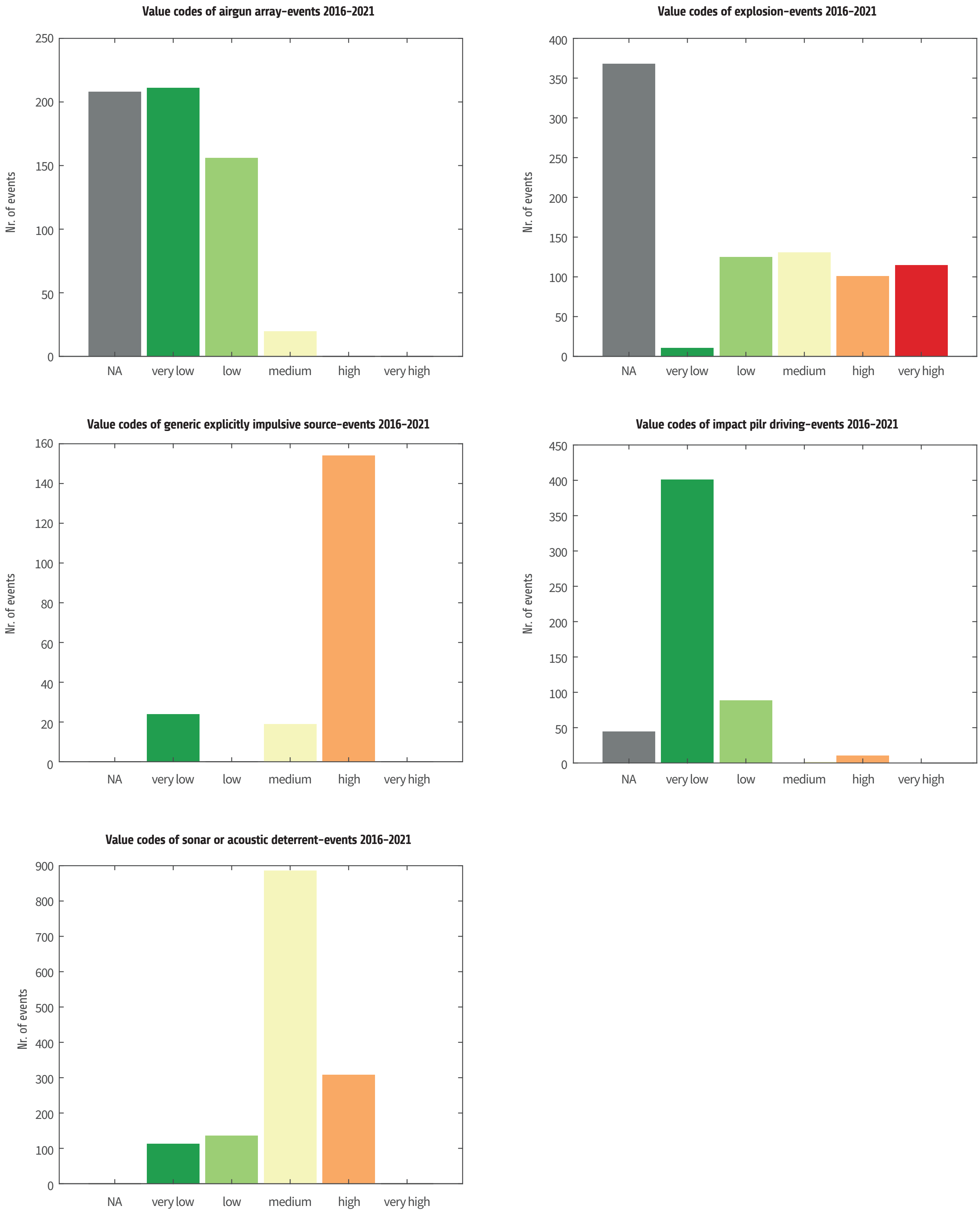


Figure 54. (a) Overview of the distribution of reported events in 2016 – 2021 according to their Value Codes. The total number of reported events is 3637. (b) Fraction of Event Days with reported Value Codes and silent days (on which no event was reported), days for which events with different Value Codes were reported count into the highest category reported for that day. The total number of Event Days is 1799, being 2191 the total number of days for the temporal period assessed.



Figures 55. (a) – (e): Value Codes of events reported for each Source Type. Note different y-axes.

The relative proportion of event Value Codes across the 2016-2021 period is shown in figure 54 (a) whereas figure 54 (b) shows the percentage of days, on which events of each Value Code occurred, and days, for which no event was reported (Silent Days). Since a number of events in the category very high occurred over several days, the temporal fraction of Event Days with events of value code very high is about 21% (470 days) compared to the relative proportion of events of value code very high, 3% (115 events). If events of different Value Codes were reported for a single day, the highest Value Code reported for that day was assigned. Unfortunately, for a considerable fraction of events (17 %) the Value Code was not reported to the registry. Approximately half of the events reported for 2016 – 2021 yield a value code of medium or higher.

The number of events per reported Value Code is shown in figure 55 for each source type. It is notable that for some source types a specific Value Code is predominant while others are more broadly distributed. Airgun array events and explosions have high numbers of events reported without Value Code (i.e., shown as NA), especially explosions. This is unfortunate since the reported explosion events span the whole range of Value Codes, with a considerable number of Value Codes 'high' and 'very high', and the difference in impact on marine life by events of different Value Code is probably the biggest for this type of event. Interestingly, most pile driving events had a Value Code of 'very low' even though only in very few cases noise mitigation measures were applied (figure 56).

A known caveat for the evaluation of reported value codes is that the comparison of value code categories between different source activity types is limited. However, the value code distribution within the impulsive noise type categories (single impulsive event, multiple impulsive event and non-pulse event) serves as proxy for the identification of severe risk of impact.

The assessment conducted shows that in the period 2016 to 2021 a broad range of impulsive sound events have taken place in the Baltic Sea region. Events of high intensity mostly referred to explosions, acoustic deterrents but also unmitigated pile driving events may have biological effects on species and their populations in the Baltic Sea.

Mitigated and unmitigated explosions and pile driving events 2016–2021

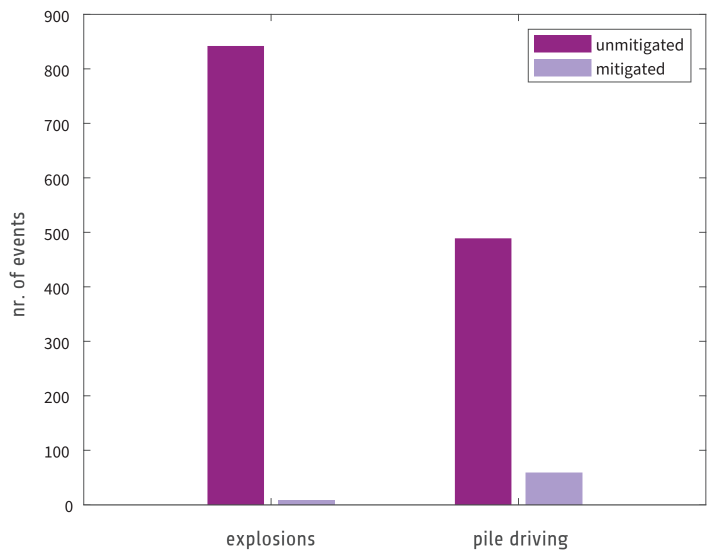


Figure 56. Reported explosions and pile driving events with and without noise mitigation measures.

Spatio-temporal assessment of exposure for harbour porpoise

The exposed areas for each year (i.e., the areas where impulsive noise is at levels that can impact on harbour porpoise), generated by considering the reported locations of events and their respective effect ranges to harbour porpoise (see table 25 in section 5.6.2) is illustrated in figure 57.

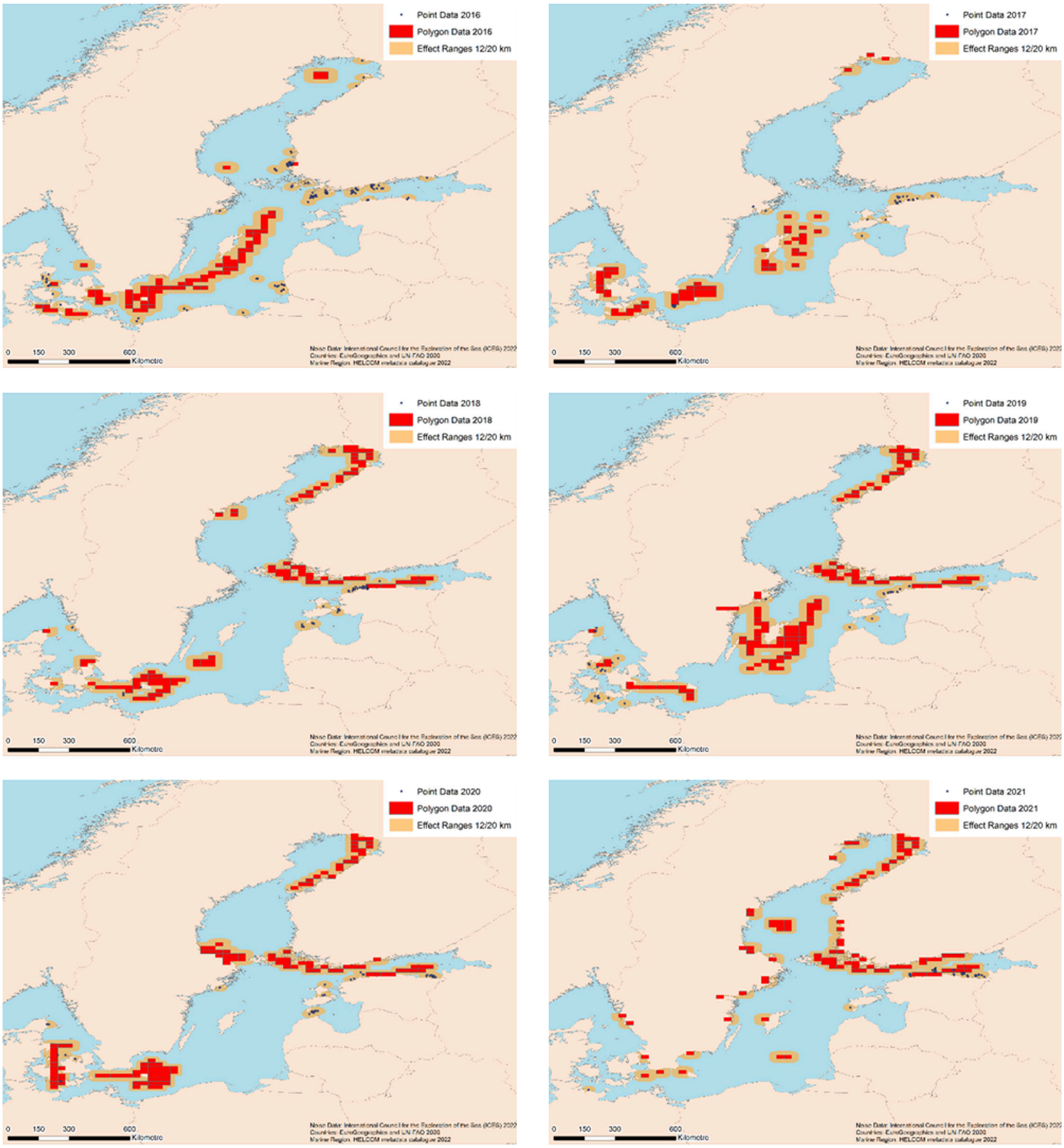


Figure 57. Annual overview of exposed areas/habitats due to impulsive noise activities in the period 2016 – 2021 reported for the HELCOM area (data source: HELCOM Noise Registry). The exposed area shown corresponds to the max. hold area (i.e., the maximum value of the unification of all areas). Please note that the harbour porpoise in the Baltic Sea at its current status and distribution does not cover large parts of the assessed area illustrated.

It should be noted that the harbour porpoise in the Baltic Sea at its current status and distribution does not cover the whole assessed area illustrated above. The current population that is divided into two management areas or populations. One is distributed in the Kattegat, Belt Sea and Western Baltic is mainly centred in the Belt Sea area ("Belt Sea" population) and in a smaller and critically endangered population occurs in the Baltic Proper. The prior distribution has however encompassed the whole Baltic Sea (see Abundance and Distribution of harbour porpoise indicators) thus the monitoring and evaluation of impulsive noise impacts are critical as these factors, especially when considered cumulatively with other pressures, are likely to impact on the recovery of the species at its former natural distribution and abundance. It should also be noted that in all years, except for 2021, there are significant records of noise events of a level that can impact on harbour porpoise within the core area or the Belt Sea population.

Figures 58-63 show the number of events with their effect ranges that overlap in the exposed areas, i.e., to how many events the area is exposed for each year. The blue line is the summer eastern management border for the Belt Sea harbour porpoise as considered in Carlén *et al.* (2018). Figure 61 is of particular interest, since the highest number of event days during the assessment period occurred in the year 2019.

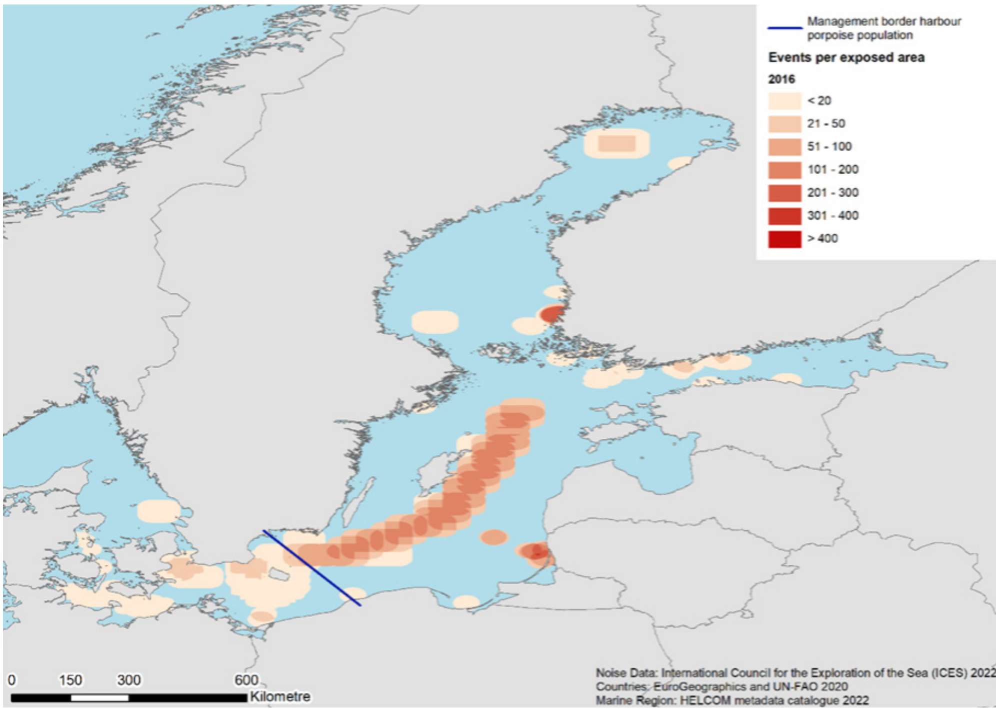


Figure 58. Events per exposed area for the year 2016. The blue line shows the summer eastern management border for the Belt Sea harbour porpoise population.

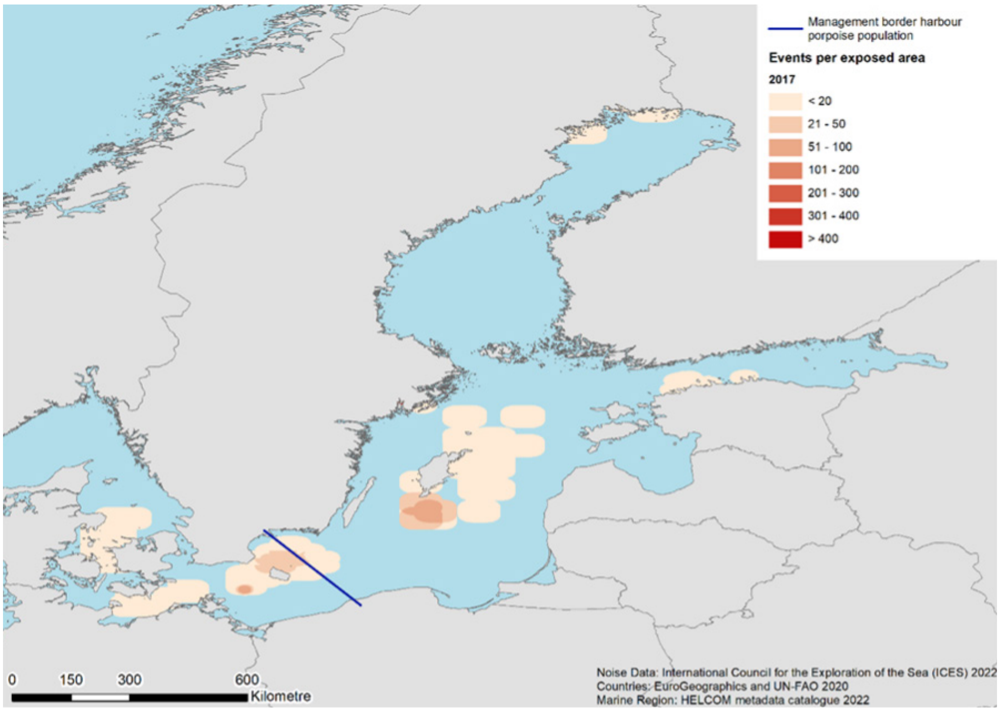


Figure 59. Events per exposed area for the year 2017. The blue line shows the summer eastern management border for the Belt Sea harbour porpoise population.

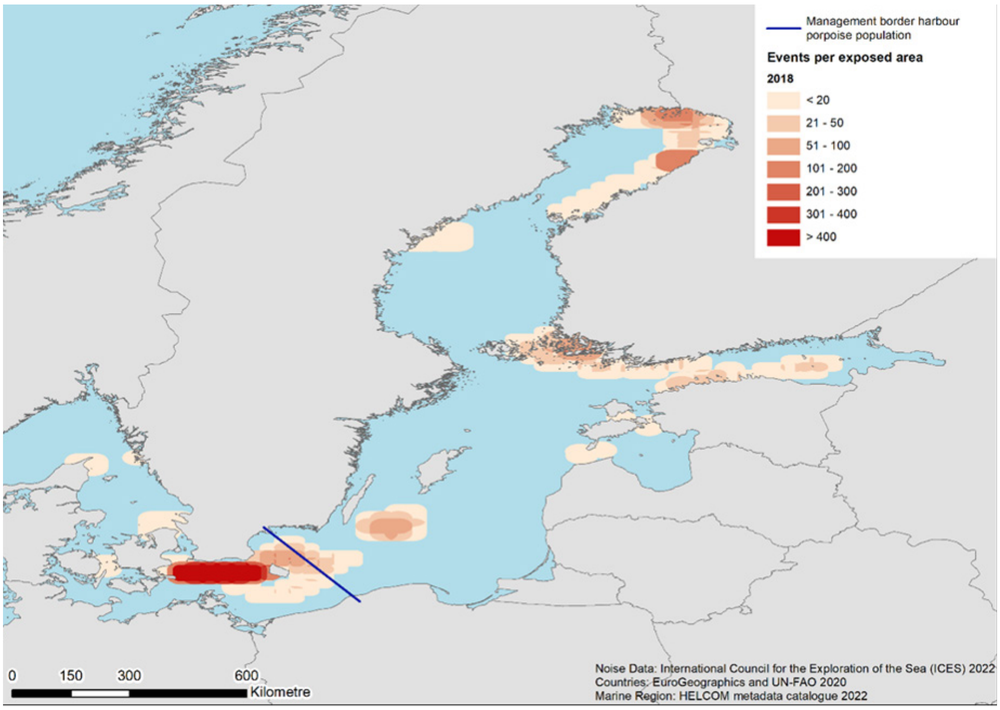


Figure 60. Events per exposed area for the year 2018. The blue line shows the summer eastern management border for the Belt Sea harbour porpoise population.

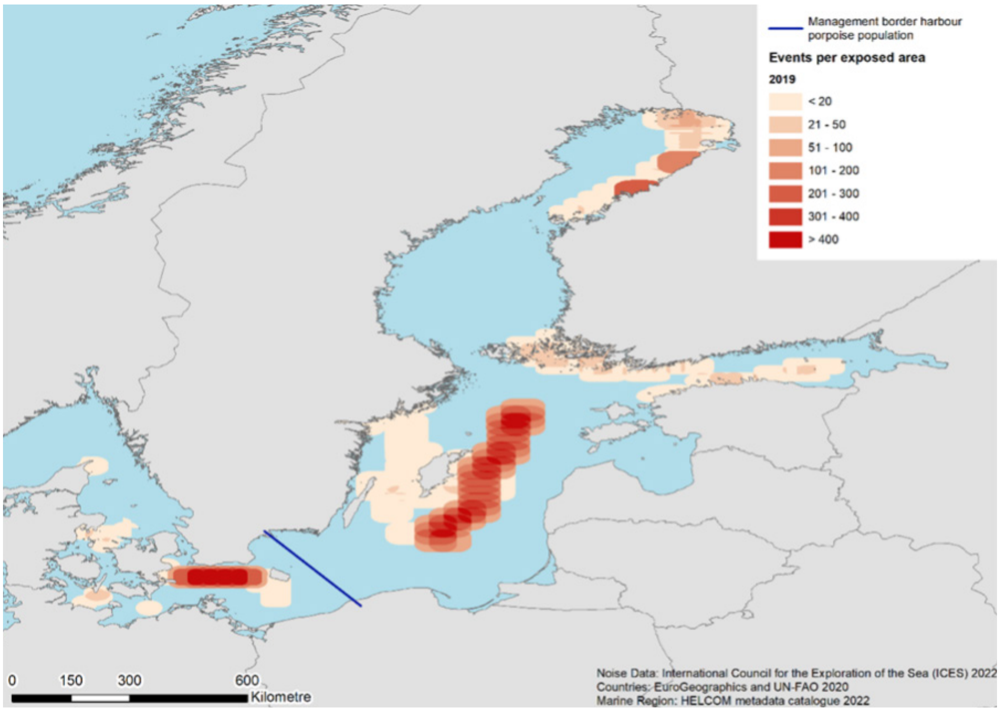


Figure 61. Events per exposed area for the year 2019. The blue line shows the summer eastern management border for the Belt Sea harbour porpoise population.

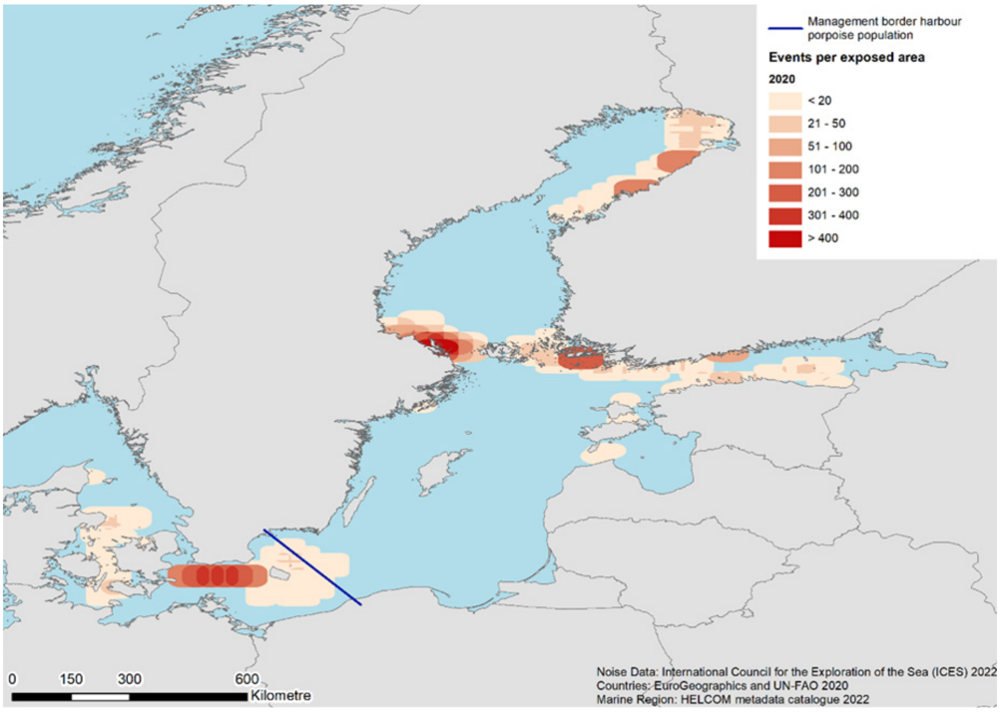


Figure 62. Events per exposed area for the year 2020. The blue line shows the summer eastern management border for the Belt Sea harbour porpoise population.

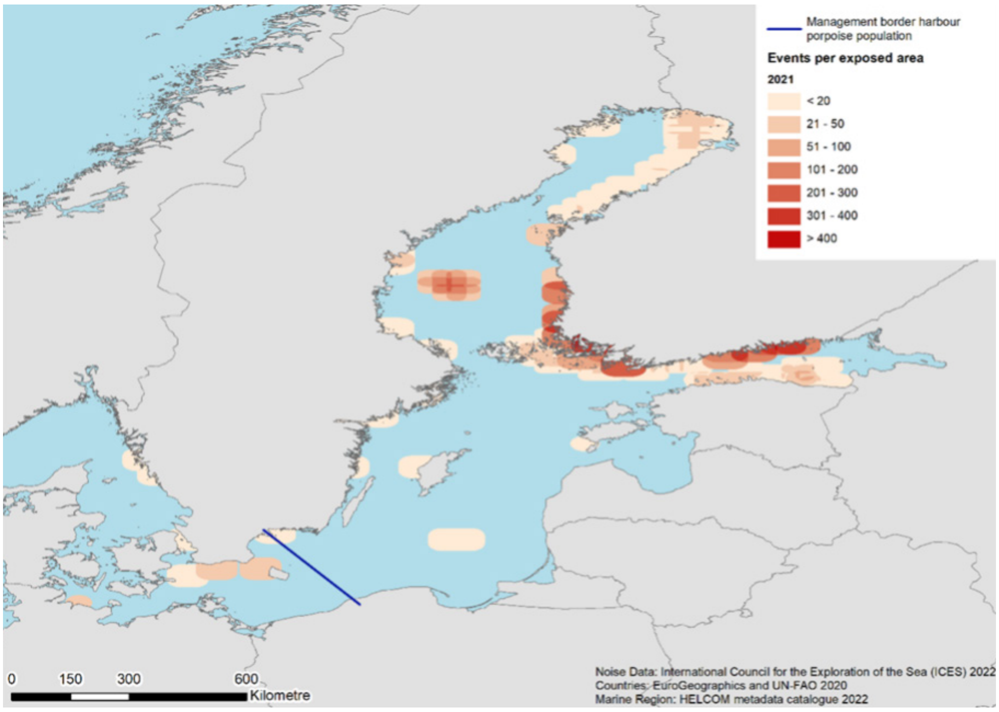


Figure 63. Events per exposed area for the year 2021. The blue line shows the summer eastern management border for the Belt Sea harbour porpoise population.

Figure 64 shows the daily percentage of the HELCOM area exposed to impulsive noise for each year, in total and per source type. Over most of the time, the area/habitat exposed and disturbed remained below a fraction of 10% of the HELCOM area habitat per day. There is, however, a period during the spring of 2016 where the percentage of total exposed area exceeded this proposed interim threshold value for several days (24 days). Within this period many events occurred simultaneously, a number of which were long-lasting events that overlapped. These were mainly sonar or acoustic deterrent events and explosions. Most of those events had the Value Code 'very low'; there were, however, several events of Value Codes 'high' and 'very high'. This coincidental accumulation and the occurrence of several unmitigated explosions at the same time seem to be the probable cause for the high exposure.

In the spring of 2019, there was another period of high exposure, when the percentage of total exposed area remained just below 10%. During this time there was also a very high number of long-lasting events (some of very long duration) present. Those were mostly sonar or acoustic deterrent events of Value Code 'very low', the high exposure seems to be caused by the large number of simultaneous events.

However, throughout the entire assessment period the daily exposed area remained below the daily (short term) threshold value developed on EU level of a habitat fraction of 20%.

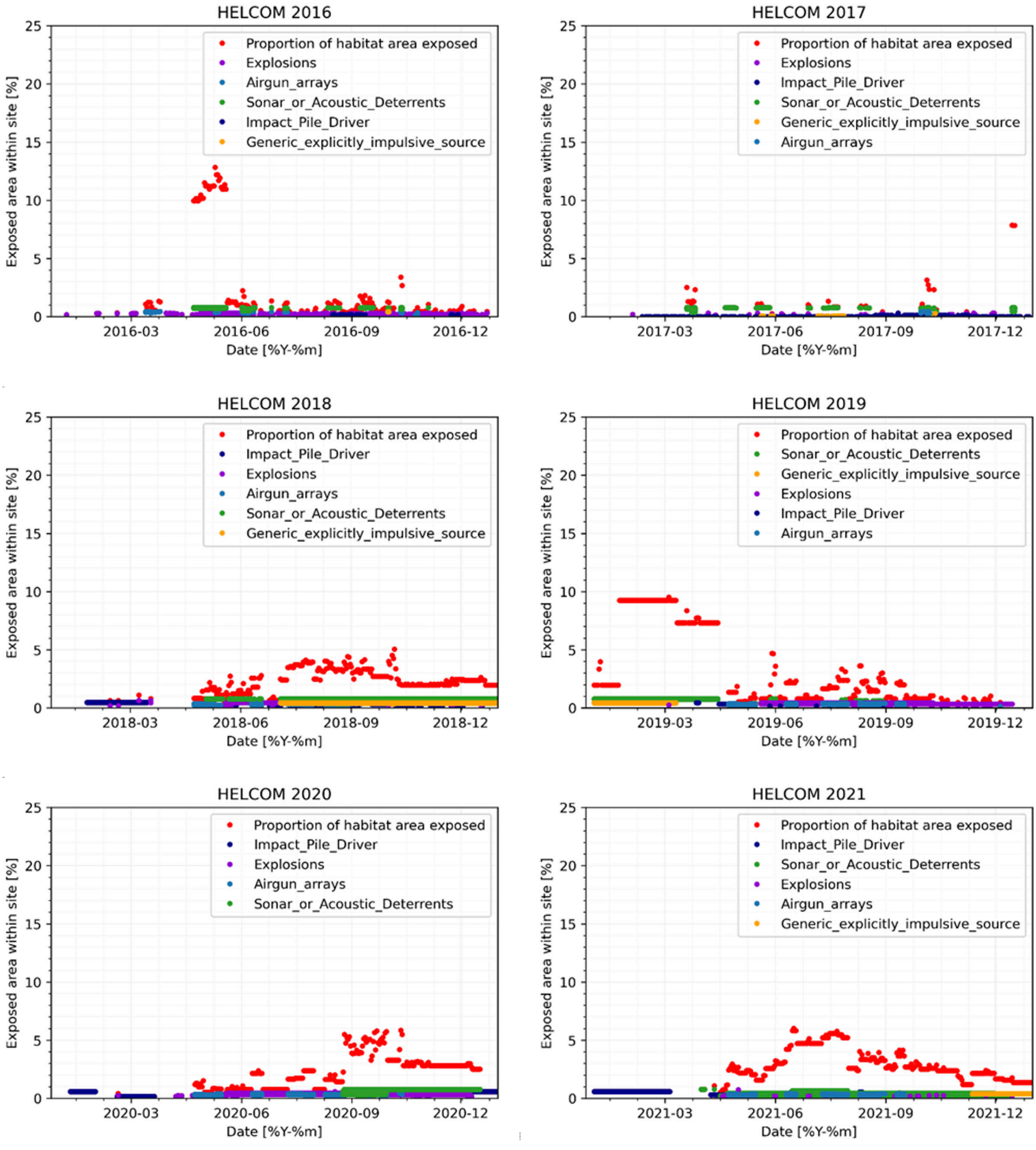


Figure 64. Annual overview of daily exposed area/habitat due to impulsive noise activities in 2016 – 2021 reported for the HELCOM area (data source: HELCOM Noise Registry).

Table 22 additionally presents the annual averages of the daily exposed habitat fractions for each year between 2016 and 2021. The annual average of each year was calculated as arithmetic means of the daily exposed habitat fractions in the respective year. Again, the habitat area considered for the evaluation refers to the entire HELCOM area. The annual averages of exposed habitat fraction remain well below a value of 3% throughout the entire assessment period and do therefore not exceed the annual (long term) threshold value developed at EU level of a yearly average habitat fraction of 10%. The largest annual averaged fraction of exposed habitat is obtained for 2019 with a value of 2.77%.

The impact of impulsive noise on harbour porpoises depends on the nature of the sound source and whether there have been mitigation and abatement technologies in place (where applicable). Furthermore, there may be times and areas during the year that are more sensitive than others (e.g., HELCOM 2019). Carlén *et al.* (2018) showed that between May – October there is a clear border between the critically endangered population in the Baltic Proper and the population in the Western Baltic. According to the study, calving and mating appear to take place during these months – the Baltic Proper population is concentrated in the area south of Gotland. During the winter months the populations disperse, which in turn means that animals belonging to the Baltic Proper population enter for example the Sothern Baltic Proper area (e.g., Arkona Basin). It is unclear however, how far individuals of this population migrate to the West and mix with the Belt Sea population.

To assess the exposure of those populations in more detail, a statistical analysis has been performed for the two areas depicted in figure 65. These areas are estimates of regions of high activity overlapping with the areas relevant to the mentioned populations.

Table 22. Annual averages of exposed habitat.

Year	Annual average of daily fraction of exposed habitat (i.e., of entire HELCOM area)
2016	1.18
2017	0.26
2018	1.70
2019	2.77
2020	1.59
2021	2.18

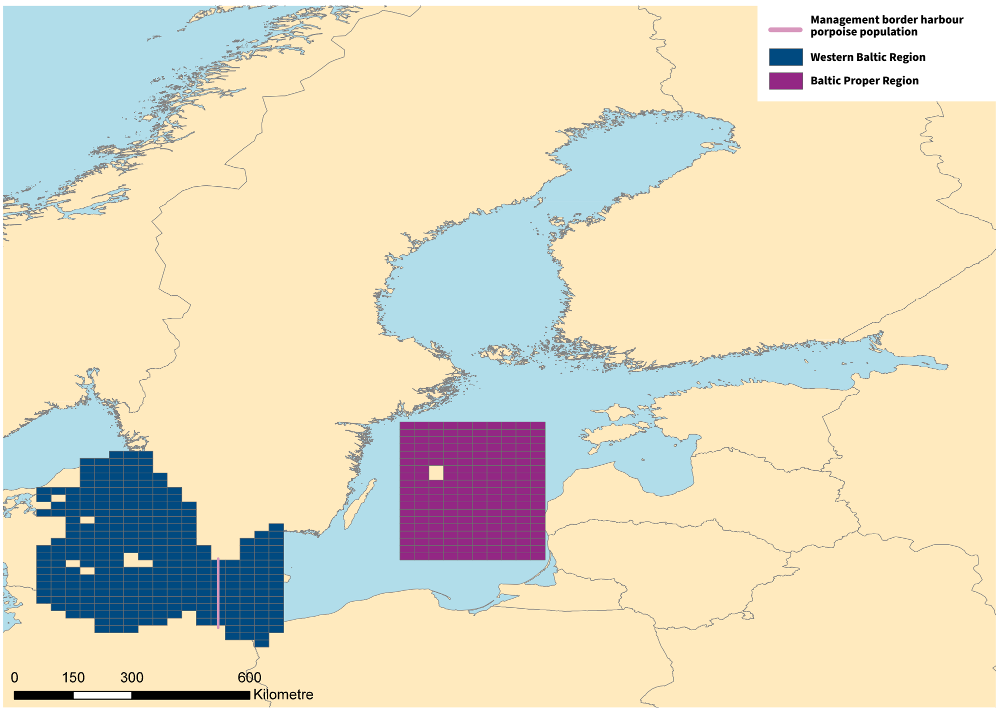


Figure 65. Areas considered in the statistical analysis regarding harbour porpoise populations. The light purple line represents the border between the Belt Sea population and the region shared with the Baltic Proper population.

These areas cover the region south and east of Gotland (Baltic Proper, blue in figure 65) and the region from Bornholm to the border between the Baltic and the North Sea (Western Baltic, green in figure 65). The latter contains the summer management border of the Baltic Proper and the Belt Sea population.

From the 3637 total events reported, only about 7.5 % (271 events) occurred in the area southeast of Gotland. These affect 203 Event Days, about 11.3 % of all Event Days (1799).

The exposure of the Western Baltic area is considerably higher. In this region, about 27.9 % (1013 events) of all reported events occurred on 35.63 % (741 days) of all event days. 39.9 % of those events occurred west of and 59.6 % east of the border mentioned above. Of the Event Days for that area, about 77.9 % (west) and about 80.3 % (east) were exposed, respectively.

As figure 66 shows, the fraction of Event Days and Silent Days varies strongly between the years. The highest number of Event Days in this area occurred in 2019.

The vast majority of events reported for the area southeast of Gotland were Sonar or Acoustic Deterrents (figure 67). In addition to Sonar or Acoustic Deterrent events, explosions occurred

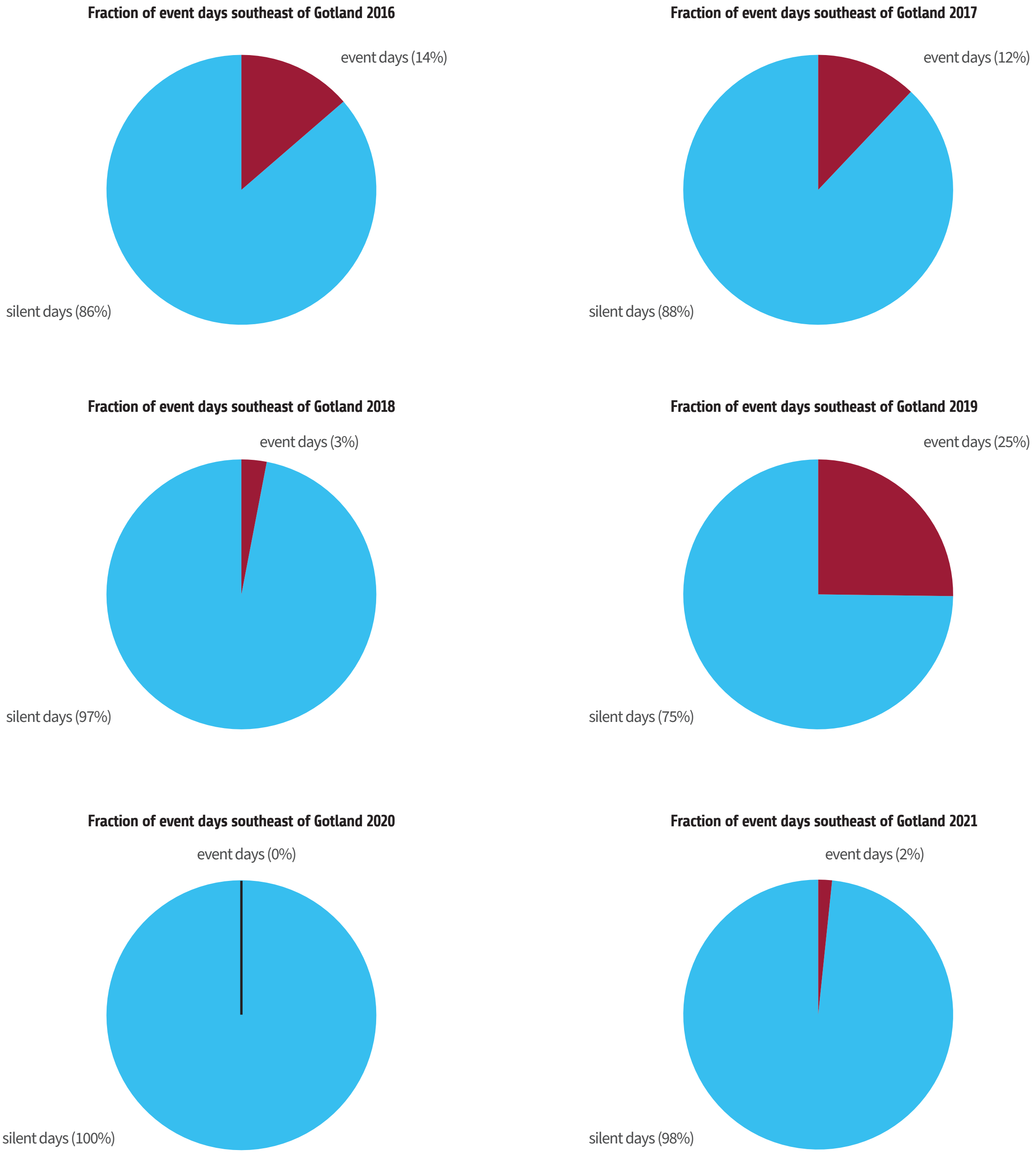


Figure 66. Number of Event Days and Silent Days in the area southeast of Gotland for each year.

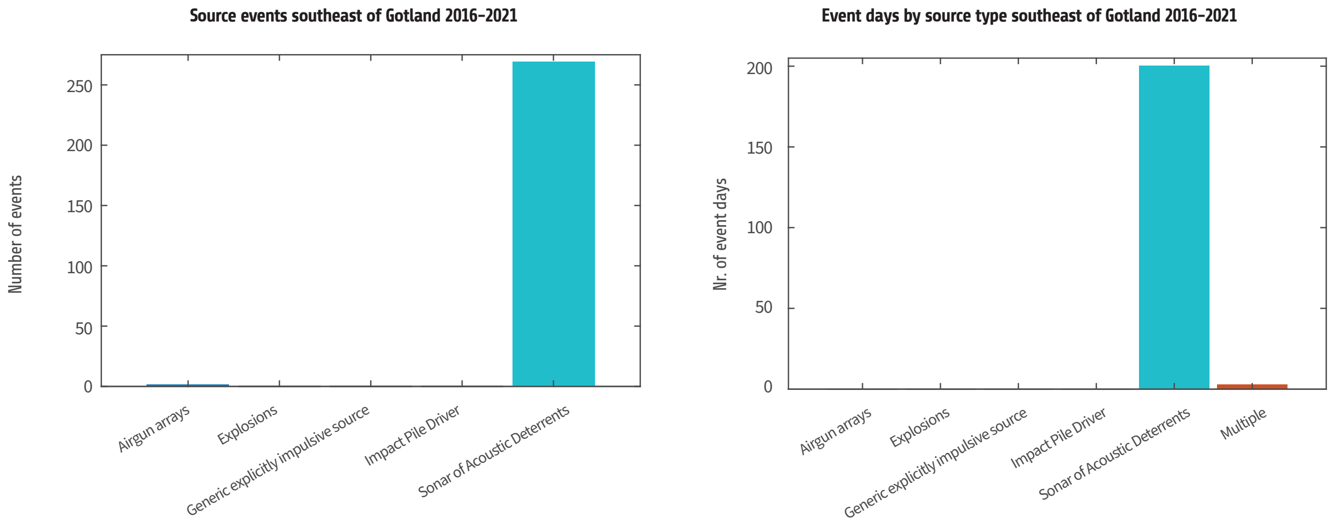


Figure 67. Source event types within the area southeast of Gotland. (a) Number of events reported for each source type. (b) Number of Event Days per source type. Days for which more than one source event type was reported count into category 'multiple'. Note different y-axes.

in three days. Since the considered area is the summer habitat of the endangered Baltic proper population it would be important to differentiate between the two types of events 'sonar' and 'acoustic deterrent' when reporting data to the registry, which is foreseen to be available in the near future.

Gillnets are by far the biggest threat to harbour porpoises, as bycatch occurring in gillnets is usually lethal. To account for this effect and for a general improvement of the depth of the analysis of different activities, an adjustment of the registry in this regard seems advisable.

In figure 68, which shows the value codes of events and Event Days within the area southeast of Gotland, there seems to be a discrepancy between the numbers of events and the numbers of Event Days for some categories: while there are several events reported with value codes 'low' and 'medium', their percentage of Event Days is zero and almost zero, respectively. This can be explained by the method of calculation of the Event Day value codes. If for a day, events of more than one value code have been reported, this day is counted into the category of the highest value code reported for that day. Thus, on each of the days on which events of value code 'low' occurred, at least one other event with a higher value code took place.

Figure 68 shows that about half of the Event Days in this area had value codes 'high' and 'medium' while also about half had the value code 'high'. No events with value code 'very high' were reported and no events were reported without value code ('NA'). Since the value code of the two reported airgun array events is 'very low', the events of source type Sonar or Acoustic Deterrent span the whole range of reported value codes, from 'very low' to 'high'.

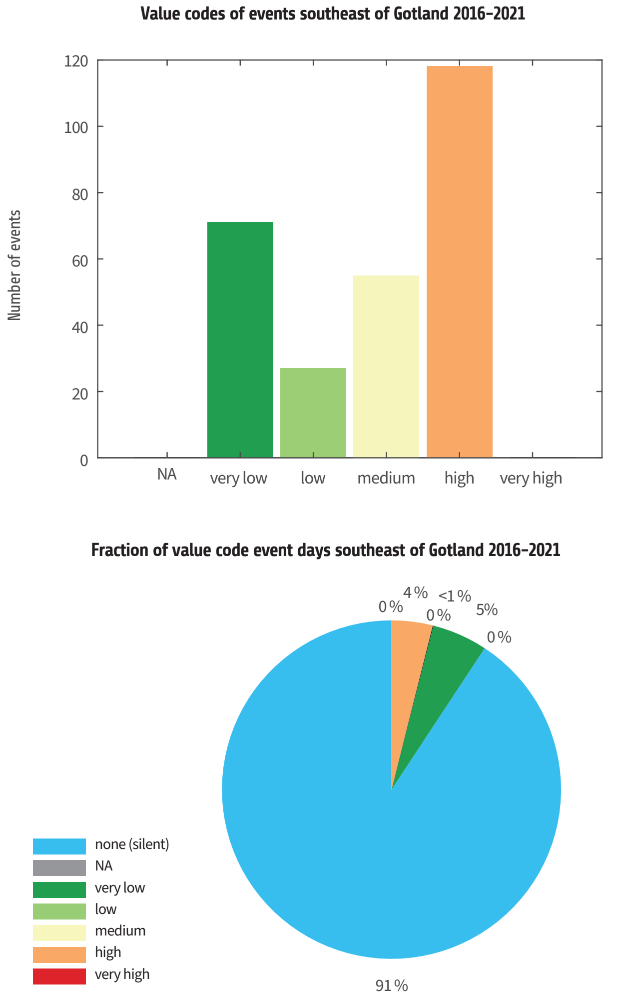


Figure 68. Value codes of events in the area southeast of Gotland. (a) Number of reported events per value code. (b) Fraction of Event Days with each value code, including Silent Days. Days for which events with different Value Codes were reported count into the highest category reported for that day.

The fraction of Event Days compared to Silent Days in the Western Baltic area for each year is shown in figure 69. As in the area south-east of Gotland, this fraction varies strongly over the years. The number of Event Days, however, is altogether higher in the Western Baltic area. The year with the highest fraction of Event Days is 2018, with a temporal exposure of about 56 % of the year. In none of the years, the fraction of Event Days is lower than 16 %.

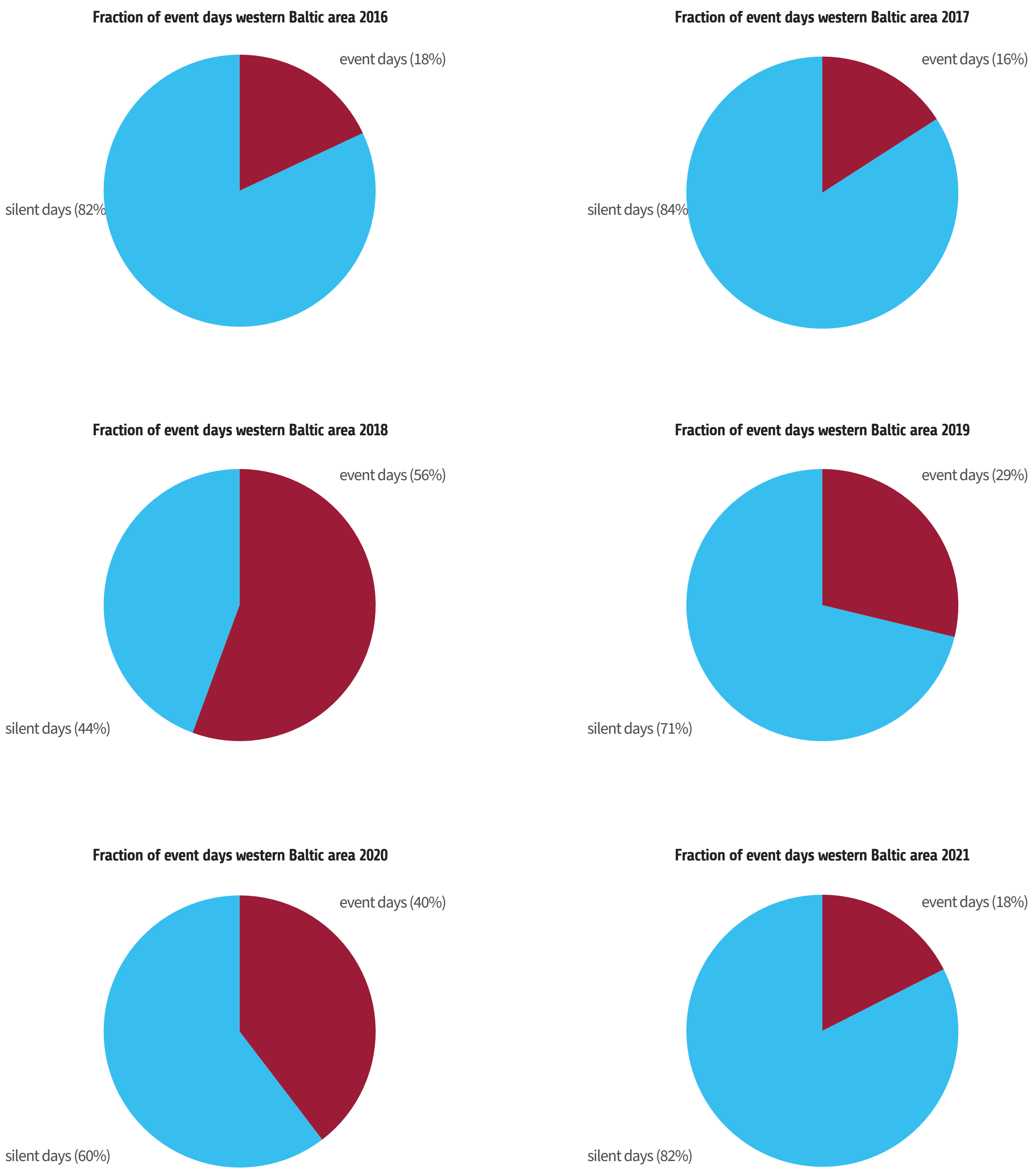


Figure 69. Number of Event Days and Silent Days in the Western Baltic area for each year.

Figure 70 shows the source event types of events and Event Days in the Western Baltic area. All source types were present, with most Event Days falling into the category 'multiple'. Similar to the area southeast of Gotland, a high number of Event Days contained Sonar or Acoustic Deterrent events.

The events in the Western Baltic area (Figure 71) span the whole range of value codes, with no events reported without value code ('NA'). Apparently, several events of value code 'high' lasted longer than one day, thus the fraction of Event Days with value code 'high' is the largest.

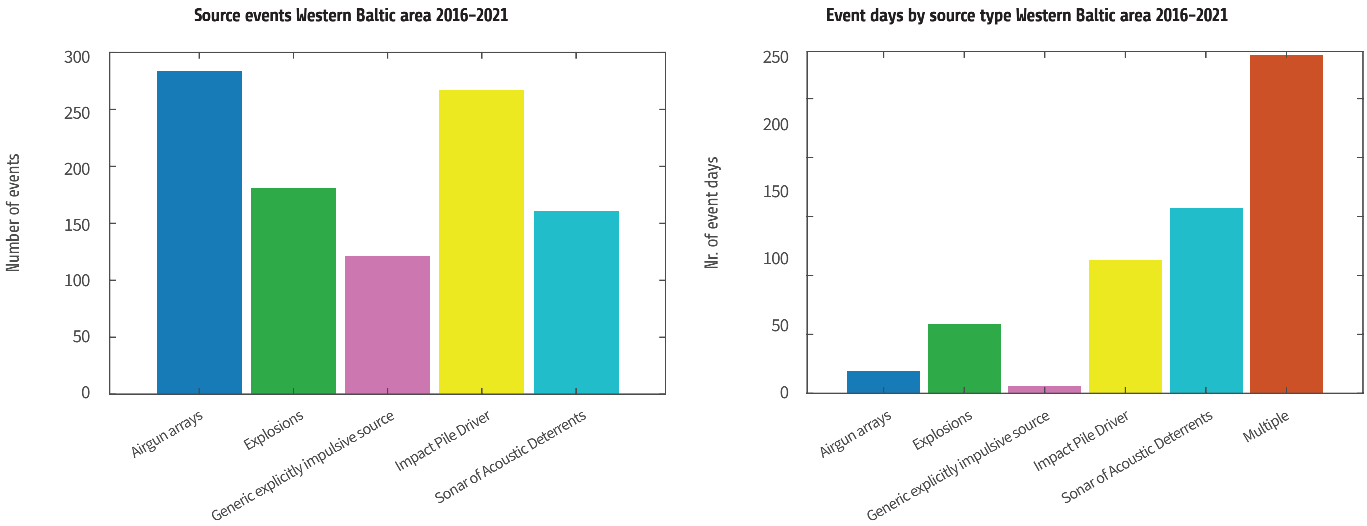


Figure 70. Source event types within the Western Baltic area. (a) Number of events reported for each source type. (b) Number of Event Days per source type. Days for which more than one source event type was reported count into category 'multiple'. Note different y-axes.

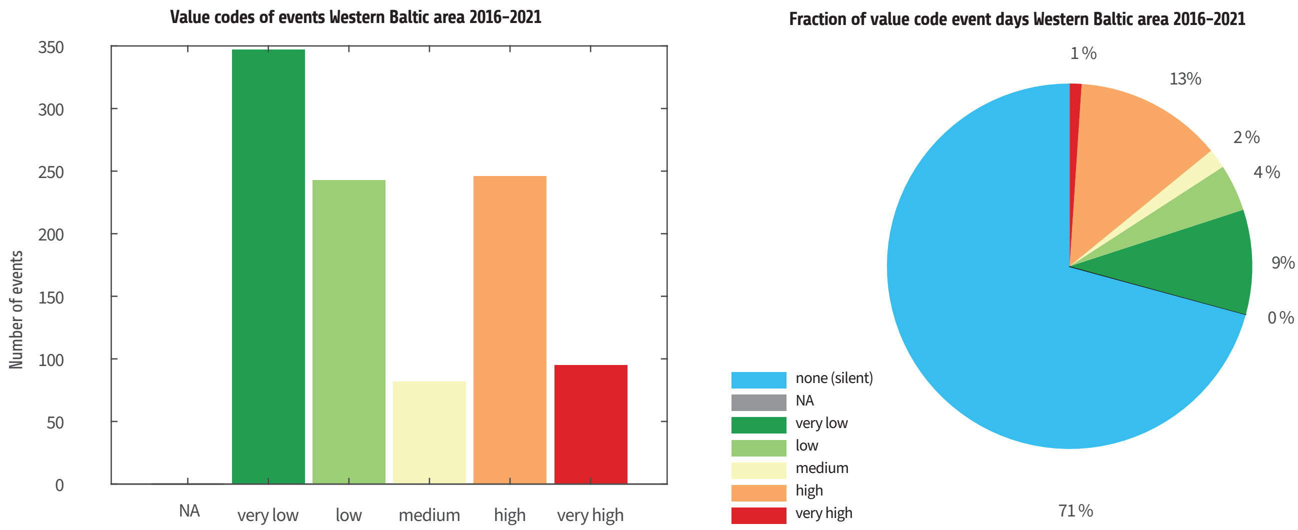


Figure 71. Value codes of events in the Western Baltic area. a) Number of reported events per value code. b) Fraction of Event Days with each value code, including Silent Days. Days for which events with different Value Codes were reported count into the highest category reported for that day.

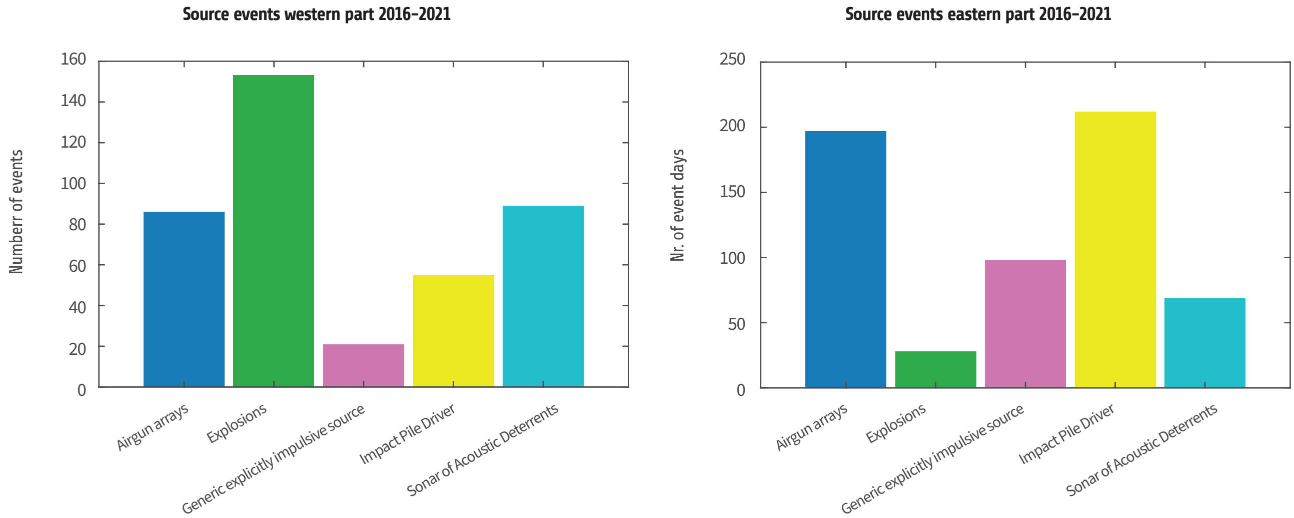


Figure 72. Events per source type in Western Baltic area. a) Western part. b) Eastern part. Note different y-axes.

As already mentioned, the Western Baltic area considered in this report contains the summer eastern management border for the Belt Sea harbour porpoise. To assess whether there is a difference in exposure between the region of the Belt Sea population and the region shared with the Baltic Proper population, a separate analysis of these parts was conducted. In both parts (see figure 72), all source event types were present; there is, however, a difference in the number of events for each source type. In the Western part, many explosions took place, while in the Eastern part the category for which the highest number of events was reported is impact pile driving. It is notable that high numbers of airgun array and generic explicitly impulsive sources events were reported for this area. This suggests that a lot of seismic exploration took place there, especially within the Eastern part.

Spatio-temporal qualitative assessment of exposure for seals

Ringed seals are known to inhabit the Bothnian Bay, the Archipelago Sea, Gulf of Finland and Western Estonia, with distribution and abundance data being evaluated from coastal sightings derived from national monitoring. The peak moulting season for ringed seals in the Baltic is Mid-April, while they give birth to their pups between February and March. The lactation period lasts between 3 and 6 weeks like for the other two seal species in the Baltic, the harbour seal and the grey seal.

Grey seals also give birth to their pups between February and March and have their peak in moulting in late May up to early June. Grey seals inhabit the entire Baltic Sea and can be found along the south coast of Sweden and on Bornholm in the described periods. The majority of grey seals are, however, located along the east coast of Sweden north of Gotland. Further habitats are Rødsand, the Kattegat, the islands north of the Gulf of Riga, the coast within the Gulf of Finland and the Gulf of Bothnia.

Harbour seals tend to have the most southern distribution of the Baltic Sea seal species. They occur mainly along the Swedish West coast, but also along the south coast of Sweden in addition to their distribution from southern islands of Denmark as well as the Kattegat and the Limfjord. Moulting occurs in mid-August, along the west coast of Sweden as well as spanning from islands of southern Denmark (e.g., Lolland, Falster) throughout the belts (e.g. Samsø, Saltholm) and Kattegat (e.g. Anholt, Læsø). A distinct subpopulation of harbour seals is known to inhabit the Swedish coast of Kalmarsund. Harbour seals give birth to their pups in June and have their peak moulting season during August.

For all three seal species mating starts after the lactation period. This period might be relevant to consider when assessing the impact of impulsive sound, since for all three species the males strongly vocalize in the range of a few hundred Hertz up to 5 kHz (ringed seals) in order to attract females.

It is difficult to assess the impact of impulsive noise on seal species, since there is sparse data concerning this topic. No data are found for ringed and grey seals, there is one study related to pile driving and the reaction of harbour seals by Russel *et al.* (2016). This study constitutes a significant reduction in harbour seal abundance in the radius of 25 km around the piling site. However, the study also describes this significant displacement to be restricted to the piling activity itself. The construction work around the piling is described to be non-significant in terms of displacement. Within two hours of cessation of pile driving, which was conducted without noise mitigation systems, seals were distributed again as during the non-piling scenario. Sensitive times for the respective seal species should be considered during mating (because of males using vocalization) and the lactation period. The latter being important because females and their pups could be impacted if displacement occurs. Females especially rely on food resources during this period in order to produce milk of high fat content.

Confidence

The monitoring strategy for impulsive noise requires active reporting of the occurrence of corresponding noise generating activities and does not include any passive monitoring of impulsive noise signals. Therefore, the status of reporting completeness of impulsive noise events in the HELCOM noise registry cannot be quantified and the reported numbers of events might in theory represent a fraction of actual occurrences of events in the Baltic Sea. To assure strong and harmonised future data sets on which to base such evaluations it may be necessary to review and strengthen monitoring and reporting guidelines in the light of the findings from this first evaluation of impulsive noise in the HELCOM region.

The reason for possible data gaps in the indicator may be manifold. Activities, which sole purpose is defence or national security are exempt from the obligation to report. Still, countries are encouraged to report on these activities on a voluntary basis. Some activities may be conducted without being subject to a licensing procedure, such as deterrents, limiting the possibilities of the responsible agencies to acquire information for reporting. A relevant source of gaps in reporting may be, that national procedures and reporting routines for impulsive noise events might not be fully implemented. Since submission regarding occurrences of impulsive noise events can be made for previous reporting periods, the data completeness for the indicator assessment can be improved at any time as soon as improved information becomes available.

A differentiation between the reason behind possible data gaps, and the transparent communication regarding the implications on uncertainty and the assessment results should be taken forward. Despite this caveat of incomplete reporting of event numbers, it could be demonstrated in this indicator evaluation that the exceedance of biologically relevant levels of disturbed habitat of population, but also regarding intensity, duration, seasonal and spatial relevance of impulsive events can be evaluated based on available data. Overall, the confidence in this indicator can be considered as moderate based on the current data availability.

5.3. Changes over time for underwater noise

As both the assessment for continuous noise and impulsive noise are the first assessments made with the current metrics, it is not possible to evaluate trends across years.

5.4. Relationship of underwater noise to drivers and pressures/biodiversity

5.4.1 Continuous noise

Human activities in the marine environment inevitably generates noise which may affects marine species. There are several anthropogenic sources that generate significant underwater noise. The two most widespread in open sea are commercial ships and fishing vessels but also energy installations, renewable energy sources and continuous dredging contribute to the total noise budget. A significant source especially in coastal areas and in the summer period is leisure boats (Hermannsen *et al.* 2019). The noise from these craft is largely missed by current monitoring and modelling methods, which means they are not included in the noise maps. The long-term trend is that overall, the gross tonnage transported by ship in the Baltic is increasing; this may mean that the commercial fleet will change in character in the future and that the resultant underwater noise will rise.

Climate change may affect the indicator by directly affecting the shipping activity and other activities. With warmer winter temperatures, the ice-covered season in the northern Baltic and Gulf of Finland becomes shorter, which may extend the open-water season, thereby extending the time when smaller ships and ships without sufficient ice classification can navigate these waters. This may lead to a redistribution of ships over the year and possibly also an increase in shipping.

Changes in the hydrography of the Baltic Sea is likely to follow due to climate change. This could have profound effects on the stratification of the water column, which, in turn, will affect the sound propagation properties significantly. In depth modelling of several scenarios is needed to understand associated effects on underwater noise.

5.4.2 Impulsive noise

There are a number of human activities that generate loud impulsive noise in the frequency range 10 Hz to 10 kHz. They can be divided into two types, those where the sound is a by-product of the main activity and those that deliberately use sound for their own purposes. Typical loud events that are recommended to be included in the registry are seismic airguns, underwater explosions, active sonars and pile driving (Dekeling *et al.* 2014). Sonars and seismic airguns are examples where sound is an essential part of the activity (although the high frequency part of the air gun signals is not used in the analysis of the data but may be the most significant source of impact for some species), while in pile driving and explosions sound is a by-product. Irrespectively of their purpose, these sources have the potential to induce large scale effects on the environment and, thus, should be monitored. The spatial and temporal characteristics of these sources can be very different and have to be considered when assessing their effects. The spatial extent varies primarily with the intensity of an activity but may also vary on average between different activities. Furthermore, the intensity of the impulsive noise sources largely determines the degree of adverse effects and the area associated with the noise input. This includes the potential for disturbance by impulsive noise events in general, and the additional potential for injury due to intense events such as explosions.

The focus of the indicator has been on open waters. The Baltic Sea has long broken coastlines and in some areas, rich archipelagos. The near-shore areas are important for many species and used for foraging, mating, nursery and growing ground for juvenile fish. Human activities taking place on land near to the sea will generate sound that propagates into the sea. The effect of land-based activities, such as piling in harbours, has not been investigated and as a result is not included in the impact assessment. The link between the land- based sources and the effect on the environment is weak. Further investigations on this matter are needed.

Echo sounders for boats and ships operate at higher frequencies (above 10 kHz) and thus fall outside the indicator's frequency range (Van der Graaf *et al.* 2012). The indicator, de facto, does not deal with echo sounders as a potential source.

The frequency range defined by the indicator was developed with the Atlantic and the Mediterranean in mind where absorption of sound starts to play an important role for frequencies higher than 10 kHz. The Baltic Sea differs to the Atlantic in that the salinity is lower, which results in a lower absorption. Thus, comparable absorption is obtained at higher frequencies. Extending the frequency interval would broaden the list of loud sources that will be included in the registry. An appropriate frequency interval for the Baltic Sea has not been studied but should be re-assessed in the future.

Underwater impulsive noise is a by-product of certain human activities and can also be limited to acceptable levels (or localised) by good planning/management and appropriate mitigation methods. These factors can result in sustainable use of the marine environment. Climate change and changes in management to respond or mitigate the impacts of it could have significant impact on noise levels in the marine environment. For example, coastal defence construction, changes in tourism or use of the marine environment and a move towards green technologies such as wind power may require construction and the by-product of such construction would be underwater noise. While no clear trends are possible to define here, other than an expected major increase in wind power development in the coming years, it is clear that such changes, especially if not carefully managed or mitigated, risk having a major impact on the marine environment.

5.5. How was the assessment of underwater noise carried out?

5.5.1 Continuous noise

Deliverable 3 (DL3) of TG-Noise (2021) describes a framework for assessment of continuous underwater noise. This assessment consists of nine steps, which are described below and details relevant for HOLAS3 added, aligned with the assessment methodology agreed upon in HELCOM (HOD, 2021).

Step 1. Define indicator species and their habitats

Principles for selection of indicator species for the HELCOM area were outlined by the BalticBoost workshop and subsequently included in the BSEP 167 (HELCOM, 2019). Indicator species should fulfil the following requirements:

- **hearing sensitivity:** for a species to be susceptible to impacts of noise, it must be able to detect sound;
- **impact of noise:** an indicator species must be sensitive to impact from noise. A species might be able to detect and produce sound within a range of frequencies, but it may not be very sensitive to noise disturbance, or it may react to noise even if the frequency spectrum is outside the frequency of best hearing or sound production of the species. Potential noise impact on the species is considered;
- **conservation status:** populations already affected by other sources, such as eutrophication or hazardous chemicals, may be more susceptible to detrimental effects from noise. Evaluated based on information from the HELCOM red list (HELCOM, 2013);
- **commercial value:** noise effects on species with high commercial value can potentially affect the economy of an industry such as the fishing industry or on a smaller scale recreational industry relying on the presence of marine mammals. Commercial value is therefore also included as a parameter; and
- **data availability:** sufficient knowledge must be available on hearing sensitivity, sensitivity to impact from noise and spatio-temporal distribution of the species. Indicator species excluded due to lack of information can be included in later assessments, as the needed information becomes available.

Based on these principles, two groups of indicator organisms were selected: fish and marine mammals. Fish is here understood as teleost fishes, i.e., excluding cartilaginous fish (sharks and rays) and sturgeons. Representative species for the Baltic Sea are cod (Gadus morrhua) and herring (Clupea harengus). Baltic herring and cod are both sensitive to low frequency sound and their threshold for disturbance has been assessed to be the same (see step 2, below). Both indicator fishes are sensitive for masking effects of anthropogenic sound which can trigger behavioural reactions in herring and masking effects in spawning cod.

Marine mammals of relevance for the Baltic Sea are harbour porpoise (Phocoena phocoena), harbour seal (Phoca vitulina), grey seal (Halichoerus gryphus) and ringed seal (Pusa hispida). As the hearing of the grey, harbour and ringed seals are comparable, they are treated under one in the following, bearing in mind that in each subbasin there is at least one species of seals is present. Consequently, each subbasin (see below) is considered as a habitat of seals for this assessment, although the actual habitats of the indicator species diverge and should be discussed for future assessments. Harbour porpoises are present in the southern subbasins of the Baltic Sea, and they are sensitive to higher frequencies than seals. However, for the sake of simplicity, it is possible to use the same frequency band for both seals and porpoises. LOBE (Level of Onset of Biologically adverse Effects, see step 2) for seals and porpoises in this case are very close.

The available information about distribution and sensitivity to noise does not yet allow a further differentiated assessment within each species group.

Assessment is subdivided into habitats. As knowledge about distribution and habitats for the indicator species in the Baltic is low or missing, the assessment was conducted at the level of HELCOM subbasins, as defined in the HELCOM Monitoring and Assessment Strategy (Annex 4), serving as proxies for habitats.

Step 2. Define the Level of Onset of Biologically adverse Effects (LOBE)

TG Noise deliverable 4 (DL4) defines the level of onset of biologically adverse effects (LOBE) as: "The noise level at which individual animals start to have adverse effects that could affect their fitness".

Fitness in this context is the ability of an individual to successfully reproduce, relative to other individuals in the population. If an animal experiences a loss in fitness, it means that its reproductive output is affected negatively, even if only slightly.

LOBE depends on the indicator species, as it depends on the hearing abilities of the animal and the sensitivity of the species. Furthermore, the type of impact caused by the noise has implications for the choice of metric to use in establishing LOBE. Thus, the first step in determining LOBE is to decide on which (negative) effect of noise should form the basis of the assessment. Examples of adverse effects of noise include disturbance of behaviour, temporary and permanent habitat loss due to displacement, reduced communication and listening space due to masking, and elevated stress hormone levels and other physiological effects.

TG-Noise does not provide guidance on which effect to select but provides examples for assessing both behavioural disturbance and masking. It was decided by HOD 2021 that assessment of continuous noise for HOLAS3 should pursue a double approach, where both masking and behavioural disturbance should be assessed.

LOBE values of two different kinds are used in the assessment. Disturbance level is a total sound pressure level (SPL, sum of natural ambient noise and ship noise) that can trigger adverse behavioural reactions of the animal, such as avoidance of a habitat or startle reaction. The LOBE values have been selected by the BLUES project after consultation in EG Noise and based on the scientific literature and they are given in table 23. However, there is substantial uncertainty around these values and the values are likely to be adjusted in

Table 23. Levels of Onset of Biologically adverse Effects (LOBE) for indicator species, as used in this assessment.

Marine species	Decidecade	Disturbance level	Auditory masking	References and comments
	Hz	dB re 1µPa		
		SPL	Dominance	
Seals	500	110	20	Kastelein *et al.* (2006), EG Noise recommendation
Porpoise	500	110	n/a	EG Noise recommendation
Herring	125	110	20	Engås *et al.* (1995), EG Noise recommendation
Cod	125	110	20	Engås *et al.* (1995), EG Noise recommendation

future assessments, following new research and guidance on methodology from TG Noise.

Excess level on the other hand, is a metric developed to describe the potential reduction in communication and listening space due to an elevation of the ambient noise level by the presence of ships. Dominance thus expresses the temporal aspect of the elevation of ambient noise by ships and gives the percent of time where the excess level (difference between the total noise (natural ambient + ships) and the natural ambient alone) exceeds the LOBE. Masking by ship noise can lead to interference with reception of vitally important signals thus compromising social behaviour, prey - predator interactions etc. There is comparatively little information available in the scientific literature to help setting LOBE for masking, but the choice of the EU Interreg project JOMOPANS, to use 20 dB excess as LOBE, has been followed (Kinneging and Tougaard, 2021). LOBE values for masking are given in table 23 as well. An excess level of 20 dB means that, under simplified assumptions (spherical transmission loss of communication signals), the maximum communication range is reduced by 90%, which translates into a reduction of active acoustic space (the maximum area in which communication can occur) by 99%. Within limits animals can compensate for this by e.g., the Lombard response (i.e., by "speaking louder" or vocalising in less affected frequency bands; Fournet *et al.* 2021, Kragh *et al.* 2019) which would reduce the loss of communication space. However, in future assessments it needs to be discussed where these limits are and how these relate to the onset of biological adverse effects.

Step 3. Determine time periods for the assessment

The assessment is done for the year 2018, which is used to represent conditions in the 6-year assessment period. The year 2018 was selected because it was the year where most monitoring data were available (see step 4). The resolution of the assessment is one month, to allow assessment of seasonal differences in conditions.

Step 4. Assess the acoustic status by monitoring

Monitoring of continuous underwater noise has been conducted by Contracting Parties in the assessment period, by measurement of continuous noise at fixed stations, in accordance with HELCOM guidelines (HELCOM, 2021). Validated measurements were uploaded by Contracting Parties to the HELCOM continuous noise database, hosted at ICES (ICES, 2022). Not all Contracting Parties have obtained measurements and uploaded data to the database. This has no impact on the spatial extent of the assessment, as the soundscape model (see step 5 and 6) extrapolates to the entire HELCOM area. Lack of measurements in certain areas will, however, lead to increased uncertainty on the assessment in those areas. Finally, a measure of correspondence between model and measurements is specified.

Step 5. Establish the reference condition

The reference condition was modelled by the company Quiet-Oceans (Brest, France). Based on meteorological data and knowledge of the relationship between wind speeds and noise levels (Mustonen *et al.* 2020), the noise in three frequency bands, each one decidecade[1] wide, centered at 63 Hz, 125 Hz and 500 Hz, was modelled throughout the Baltic Sea in steps of one hour throughout the assessment year. For technical reasons, the Baltic Sea was divided in three sub-areas of spatial resolution around 400m which were then merged into one single area (see Figure 73).

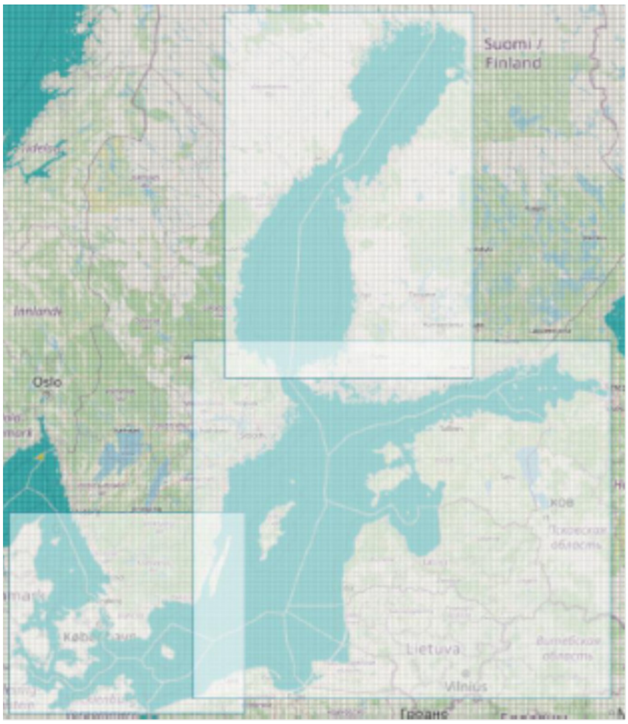


Figure 73. Division of the Baltic Sea in three areas for the purpose of the modelling of the soundscape maps: West (9.4° West, 17.6° East, 53.9° South, .57.8° North), Central (15.8° West, 30.3° East, 54.2° South, 60.8° North) and North (16.9° West, 25.5° East, 60.2° South, 65.9° North.

1 Please note that decidecade means third octave band (log to basis of 10).

Table 24. Evaluation of conditions conducted in each grid cell of the map for the two species groups (fish and marine mammals) and for the two types of effects considered (behavioural disturbance and masking).

Behaviour – fish The monthly median of the total noise level (natural ambient + ship noise) in the 125 Hz frequency band was compared to the LOBE of 110 dB re 1 µPa. Conditions in the grid cell acceptable, if monthly median <= LOBE.	**Behaviour – marine mammals** The monthly median of the total noise level (natural ambient + ship noise) in the 500 Hz frequency band was compared to the LOBE of 110 dB re 1 µPa. Conditions in the grid cell acceptable, if monthly median <= LOBE.
Masking – fish The monthly median excess level (total noise – natural ambient) in the 125 Hz frequency band was compared to the LOBE of 20 dB. Conditions in the grid cell acceptable, if monthly median <= LOBE.	**Masking – marine mammals** The monthly median excess level (total noise – natural ambient) in the 500 Hz frequency band was compared to the LOBE of 20 dB. Conditions in the grid cell acceptable, if monthly median <= LOBE.

Step 6. Establish the current condition
Based on information about the ships present at each hourly step in the modelling, the type, length and speed of the vessels, all obtained from AIS data, the noise from the individual ships were modelled with a source model (RANDI3). By means of input of bathymetry, sediment properties and hydrographical observations, the noise from individual ships were propagated into the surrounding waters around each ship, added together and added to the natural ambient noise modelled in step 5. The modelled output was compared against the measurements (from step 4) and model properties adjusted to obtain best possible correspondence with measurements. It is noted that this model approach does not consider all noise sources of continuous noise (e.g. operational Wind Farm noise or dredging noise), but corresponds to the state of the art.

Step 7. Evaluate the condition of the grid cells
Evaluation of conditions in each grid cell of the map was done for the two species groups (fish and marine mammals) and the two types of effects and hence metrics (behavioural disturbance and masking, respectively), meaning that in total four evaluations were performed for each grid cell (see table 24).

Step 8. Determine the status of the habitats
The status of each habitat (HELCOM subbasins) was evaluated against the spatial threshold proposed by TG-Noise (2022). The proposed threshold for continuous noise is 20%, which should be understood such that in any given month of the assessment year, no more than 20% of a habitat can be in non-acceptable conditions (c.f. the evaluation in step 7).

Step 9. Assess the status of the MRU (Marine Reporting Units) as being GES or not GES
This step is omitted, as it relates to EU Member States' own MSFD reporting.

5.5.2 Impulsive noise

The information set out in this report utilises the agreed methodologies discussed both in HELCOM (EG Noise) and within the EU for MSFD processes (i.e., adoption by the Marine Strategy Coordination Group, MSCG). However, since no threshold values are currently in place as no regionally agreed and approved threshold value has been adopted, the indicator results of this assessment are discussed in the light of a proposed interim threshold value of a daily fraction of exposed area of 10% of the Baltic Sea, in agreement with the EU threshold concept.

The basis of the proposed threshold values is the evaluation of the temporal and spatial proportion of habitats that are impacted and affected by underwater sound. A dual threshold is currently proposed to address short-term and long-term exposure to impulsive noise, where short-term exposure is set to 1 day and long-term exposure is set to 1 year. The specific proposal is as follows:

- a maximum fraction of 20% or lower over 1 day of the habitat of an indicator species to be exposed to impulsive noise levels higher than a species-specific level of biological relevance (LOBE: Level of Onset of Biological adverse Effects);
- a maximum of 10% or lower over 1 year on average of the habitat of an indicator species to be exposed to impulsive noise levels higher than a species-specific level of biological relevance.

Regional or local specificities and indicator species shall be taken into account when determining the exact threshold value by Regional Sea Conventions. The relevant habitats for the marine unit under consideration are to be defined in conjunction with the selection of associated indicator species at regional level.

The approach for this indicator assessment is to exploit the highest spatial and temporal resolution of the reported impulsive noise events, while ensuring that all available data is included in the assessment in a coherent manner.

The reporting format to be used to upload data to the registry is available to download in the data portal.

The registry includes well-defined metadata of impulsive sound events on a mandatory basis and offers the possibility to optionally include processed data on the events, like measured sound exposure levels and type of technical mitigation measures applied. Information to be provided is either mandatory (i.e. date and location of the event) or optional (i.e. types of mitigation measures). Information on the type of mitigation measures was reported only for a minority of events, therefore these parameters could not be evaluated.

For each source type, a range of five Value Codes ranging from very low to very high can be associated to the reported events based on the sound pressure or energy of the source. The start and end dates of the events must be reported, including the year in which they occurred. Some of the reported events are single events (e.g., a single explosion), others contain multiple sound pulses (e.g., pile driving or seismic surveys).

Event locations can be reported as geographic point source locations (i.e., latitude, longitude and geometry type) or as polygon-IDs. When reported as point location, the exact coordinates of the event are available. The polygon-IDs of events reported as such refer to specific ICES-polygons, pre-defined map rectangles with individual IDs. Polygon source data can be reported in two ways: by entering the Latitude and Longitude of the centroid of the polygon and selecting the appropriate polygon type from 'Geometry_type', or alternatively, an identifier for the polygon can be reported in the 'Polygon_ID' column. Additionally, events reported by the German military on a voluntary basis are reported in the specific polygon format of German Naval Tiles. To avoid strongly overestimating the exposed area due to these events, the geometric centroid of the intersection of the respective naval tile with the German EEZ was assigned as location of the explosions that were reported for that tile. Since the number of explosions for each naval tile was reported, that number was included in the statistical analysis of the numbers of reported events. To avoid overestimating the exposed time, in the statistical analysis considering Event Days, the days within the time period of 08/28/2019 to 08/31/2019 were assigned as Event Days to the aforementioned locations. This time period was inferred solely from publicly available information.

Due to this possibility of reporting events as point source or polygon information, the reported spatial extend of the source was used for the analysis of exposed area. The table below contains the activities annually reported to the registry (Table 25).

The effect range of the disturbance of the harbour porpoise according to each reported source was evaluated based on standardized and source specific effect ranges (Table 26). These effect ranges to the reported events were applied to obtain both yearly and daily percentages of exposed area.

A standardized temporal resolution of 24 hours (one pulse block day) was used for the assessment. Events for which the duration extends over several days are considered as pressure contribution on each of the affected days. Events with a duration of less than a day are considered as pressure contribution on the affected day.

Table 25. Activities as reported to the regional noise registry and corresponding minimum level category that triggers the entry into the noise registry.

Source type	Minimum level category of events to trigger an entry into the noise registry
Explosions	mTNTeq > 8g
Airgun arrays	SLz-p > 209 dB re 1 µPa m
Impact pile driver	hammer energy > 0 kJ
Sonar or acoustic deterrents	SL > 176-200 dB re 1 µPa m
Generic explicitly impulsive source	ESL > 186 dB re 1 µPa² m² s

Table 26. Effect ranges for the assessment of harbour porpoise disturbance according to different sources.

Source Event	Effect Range (km)
Airgun Arrays	12
Generic explicitly impulsive source	12
Impact Pile Driver mitigated	12
Impact Pile Driver non mitigated	20
Explosions	20
Sonar or Acoustic Deterrents	20

5.6. Follow up and needs for the future with regards to underwater noise

At international level, marine biodiversity is to be protected and prevented from any kind of pollution (UNCLOS, 1982). Underwater noise is a type of pollution, although it is an emission of energy rather than a polluting substance. The International Maritime Organization (IMO) added "Noise from commercial shipping and its adverse impact on marine life" as a high priority item to the work programme of its Marine Environment Protection Committee (MEPC). In 2014, the MEPC approved Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life (IMO, 2014), which are being currently reviewed by a dedicated Correspondence Group, aiming at their consideration by the next meeting of the Sub-Committee on Ship Design and Construction (SDC 9) to be held in January 2023.

In 2009, ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic and the North Sea) adopted a Resolution on Adverse Effects of Underwater Noise on Marine Mammals during Offshore Construction Activities for Renewable Energy Production. Impulsive noise is in focus when within this Agreement guidelines from the perspective of marine mammal protection in connection with underwater noise were developed. A couple of years later (2011) a Resolution at UNEP level was adopted to protect cetaceans together with other migratory species. Moreover, the Jastarnia Plan for the protection of harbour porpoise in the Baltic Proper was adopted by ASCOBANS in 2010 and revised in 2016. In 2012, the Conservation Plan for the population in the Kattegat, the Belt Seas, the Sound and the Western Baltic (WBBK) was adopted.

The harbour porpoise population of the Baltic Proper is considered critically endangered according to the IUCN Red list.

In the HELCOM framework, the updated Baltic Sea Action Plan (HELCOM, 2021) contains a dedicated section on underwater noise including both ecological and managerial objectives to achieve. The fulfilment of these objectives will count with the Regional Action Plan on Underwater Noise, adopted in the 2021 Ministerial Meeting as HELCOM Recommendation 42-43/1, as its instrumental tool containing thirty-five regional actions and seventeen national actions focused on reduction of pressures and impacts from underwater noise sources of different type (HELCOM, 2021).

At EU level, the non-binding European Commission Guidelines for the establishment of the Natura 2000 network in the marine environment consider noise as a source of pollution that affects the marine environment and biodiversity (European Commission, 2007). The guidelines identify several sources of underwater noise pollution, including the propeller and machinery noise of ships. Moreover, the indicator provides information that covers the requirements of EU MSFD purposes. This is aligned with the 2018 HELCOM Brussels Ministerial Declaration where Contracting Parties agreed to continuing regional work in developing scientifically sound threshold values for underwater noise that are consistent with GES for species identified as sensitive to noise in the Baltic Sea, in close coordination with work undertaken by Contracting Parties in other relevant fora including UNEP Regional Seas Programme.

Also at EU level, the Fauna Flora Habitat (FFH)-Directive (art. 12) does not allow to induce injury or death to strictly protected species of Annex IV, to which all whale species belong to. Moreover, the European Commission Guidance Document on Wind Energy Developments and Natura 2000 refers to potential impacts of wind farms on marine animals due to marine noise pollution (EU, 2011).

When it comes to assessment methodological approaches, for continuous noise, TG Noise document DL4 provides a spatial threshold of 20% with the option to set it lower, based on regional specificities. Such regional specificities could be indicator species or populations considered particularly vulnerable and/or endangered, uncertainty in the noise model, for example related to effects of strong sound speed gradients, or influence from sources such as recreational boats not included in the current models, both of which requires a precautionary approach. Such regional specificities are to be considered towards HOLAS 4.

Knowledge about the Levels of Onset of Biologically adverse Effects (LOBE) for indicator species will be improved in coming years, as many research groups are working on this topic. In particular, fish is known to be sensitive to the water particle motions. Future assessments are likely to include effects of particle motion generated by the sources of continuous noise. The habitat sizes of indicator species and the following sizes of assessment subbasins need attention and broader discussions involving also biodiversity expert groups. Many wind parks will be constructed in the Baltic Sea in the near future. Continuous low-frequency noise from these installations should be taken into account in the future models.

Actual ship underwater noise model considers only commercial ships. However, fishing and leisure boats are known to contribute to the underwater noise in the coastal waters during some seasons and their contribution should be included as far as corresponding ship traffic data will be collected.

For impulsive noise, future work is needed to further develop threshold values and attain regional agreement on their application. Other issues to consider include a review and evaluation of data reporting (i.e., if complete and if all required parameters are included), further detailed reporting on mitigation methods employed, more differentiation between sources, stronger scientific understanding of the link between noise and marine mammals or key sensitive species (especially seals), studies and evaluations across sensitive periods (e.g., breeding), and a more detailed confidence evaluation of the data and evaluation carried out. Consideration could also be given to the assessment scale used for the indicator (e.g., link to 17 sub-basin or marine mammal management units) and even the value in carrying out an integrated assessment of underwater noise in which the overall pressure of impulsive and continuous noise can be presented overall.

6. Results for the non-indigenous species assessment

Assessment results in short

- Thirteen new non-indigenous species (NIS) or cryptogenic species (CS) have appeared for the first time in the Baltic Sea during the assessment period 2016-2021. Since the threshold value between Good Environmental Status (GES) and sub-GES conditions is no new introductions of NIS (and the indictor is evaluated at the whole Baltic Sea scale) through human activities during a six year assessment period, the HELCOM core indicator for trends in arrival of new non-indigenous species does not reach GES (sub-GES).
- The Baltic Sea assessment units in which these new NIS/CS have been recorded are the Kattegat, Great Belt, Kiel Bay, Bay of Mecklenburg, Bornholm Basin, Gulf of Gdansk, Archipelago Sea and Gulf of Finland. The new species have been detected both during regular environmental monitoring activities, as well as research surveys and citizens science observations. The data have been verified by national experts. The indicator is only considering new human-mediated introductions and thus the secondary spread by natural means (migration, water currents etc.) within the Baltic Sea is not specifically part of this indicator.
- The trend in arrival of new NIS/CS has been increasing since the beginning of the 1900s, generally indicating a clear anthropogenic impact on the Baltic Sea environment. This marked increase may also be due in part to more intense and directed monitoring activities. Moreover, there has been an increase in the number of new NIS/CS detected during the current assessment period (thirteen) as compared to the previous one (2011-2016, twelve). This trend comparison is however complicated by retrospective reporting of NIS/CS records and a large number of reporting for the previous assessment period that occurred after the previous indicator evaluation occurred, actually suggest that the current period reflects a decrease in new introductions (though future retrospective reporting may also alter this). The main human induced pathway associated with NIS/CS is maritime transport.
- Routine monitoring does not cover all invasion hotspots, habitats and taxonomic groups in many of the countries surrounding the Baltic Sea. The confidence in the assessment for areas where detections of new NIS/CS have been made is high. In assessment units where no observations were recorded, the confidence may be low if no regular monitoring is conducted. This however varies between assessment units. However, the overall confidence is considered moderate for the evaluation made since the available records clearly show that the threshold value has not been achieved. This variation across the region with regards to dedicated monitoring programmes and significant variation in monitoring effort mean that a high confidence evaluation can not be carried out in all areas or at a higher spatial scale (e.g., sub-basin level).
  - At the Baltic Sea scale non-indigenous species do not achieve Good Environmental Status (sub-GES) as new introductions of NIS/CS due to human activities are detected in the current assessment period.
  - An apparent increase in introductions between this and the previous assessment period is complicated by retrospective reporting of introductions from the previous assessment period. Including these a decrease of introductions is recorded.
  - In sub-regions (e.g., sub-basins) where detections occur the evaluation has high confidence, however no detection does not with certainty reflect no introductions unless paired with operational monitoring programmes. Such uncertainties also prevent application of the indicator at the sub-basing scale.

6.1. Introduction to non-indigenous species

Non-indigenous species may spread in the Baltic Sea and cause harm to the marine environment. For example, the round goby (Neogobius melanostomus), a bottom-dwelling invasive fish originating in the Black Sea and Caspian Sea, was observed for the first time in the Baltic Sea in 1990. After a few years with low abundance, the species increased dramatically and it is now a dominant species in many areas of the Baltic Sea, with a capacity to change interactions in the benthic food web (Kotta *et al.* 2016). This pattern of establishment, and consecutive spread, is characteristic of invasive species. However, not all non-indigenous species are invasive, and may not spread widely nor become abundant. Established non-indigenous species may influence biodiversity and the ecosystem in different ways, and their effects are often difficult to foresee. Risk assessments are important to guide the management of non-indigenous species and help to implicate measures at an early stage (Katsanevakis *et al.* 2014).

Overall, NIS have caused ecological, economic and public health impacts globally (Ruiz *et al.* 1997; Mack *et al.* 2000; Lockwood *et al.* 2007; Ojaveer & Kotta, 2014). NIS can induce considerable changes in the structure and dynamics of marine ecosystems and may also hamper the economic use of the sea or even represent a risk for human health. Ecological impacts include changes in habitats and communities and alterations in food web functioning, in extreme cases even loss of native species can occur (Galil, 2007). Economic impacts range from financial losses in fisheries to expenses for industries for cleaning intake or outflow pipes and structures from fouling (Black, 2001; Williams *et al.* 2010). Public health impacts may arise from the introduction of pathogens or toxic algae. The impacts, especially when taken cumulatively with other pressures, on marine ecosystems can be unpredictable and may be large. NIS may also have positive effects e.g., increase fisheries, make water clearer by effective filtering or improve oxygen conditions on the seabed (Reise *et al.* 2021).

Our knowledge is very limited for the majority (60%) of widespread NIS of the Baltic Sea (Ojaveer *et al.* 2021). According to the biopollution index (Zaiko *et al.* 2011), the highest biopollution (BPL = 3, strong impact) occurs in coastal lagoons, inlets and gulfs, and the moderate biopollution (BPL = 2) in the open sea areas. None of the Baltic sub-regions is classified as 'low impact' (BPL = 0 or 1) indicating that invasive species with recognized impacts are established in all areas.

Eradication of already established NIS is always time consuming and cost intensive and has generally proven not to be feasible in aquatic environments (Sambrook *et al.* 2014). No knowledge of eradication of already established NIS has been recorded in the Baltic Sea. Thus, reaching a pristine status cannot be used as a relevant threshold value. Full recovery in the sense of returning back to a previous state is not possible. Hence, management should primarily aim to prevent further introductions, along with minimizing the negative effects of the already introduced non-indigenous species.

6.2. Details on the assessment results for non-indigenous species

Thirteen new human-mediated introductions to the Baltic Sea were observed from 2016 to 2021, thus, since evaluated at the whole Baltic Sea level, the indicator fails its threshold value. These species are: *Haminoea solitaria, Laonome xeprovala sp. nov., Caprella mutica, Fenestrulina malusii, Hemigrapsus sanguineus, Polydora aggregata, Chelicorophium robustum, Moerisia inkermanica, Mytilicola orientalis, Nippoleucon hinumensis, Echinogammarus ischnus, Proterorhinus nasalis* and *Babka gymnotrachelus*. These include a mollusc, a crab, a hydrozoan, a crustacean, a parasitic copepod (on bivalves), a bryozoan, three amphipods, two polychaetes and two gobiid fish. *Laonome xeprovala sp. nov*. was observed during the same year (2016) the first time in German and Finnish waters.

To provide additional context to the evaluation the spatial distribution of new records across the whole Baltic Sea area are also provided based on records from each of the 17 sub-basins of the Baltic Sea. In four sub-basins two new NIS were observed (Kattegat, Great Belt, Kiel Bay and Bay of Mecklenburg), in one area three new NIS were observed (Bornholm Basin) and in three areas (Gulf of Gdansk, Archipelago Sea, Gulf of Finland) only one new NIS was observed for the first time in the Baltic Sea (14 sub-basins are listed here as one of the species, Laonome xeprovala sp. nov., was recorded in two sub-basins in the same year as a first introduction). These sub-basins are considered to fail the established threshold value, thus the overall assessment at the whole Baltic Sea level (HELCOM Scale 1 assessment units) also fails to achieve GES. As the uncertainty related to vectors and pathways concerning many new introductions inside the Baltic Sea is high we cannot conclude that the other sub-basins are in good status although there are no known new Baltic Sea-first observations recorded in them.

In the current assessment period we see an increase from newly introduced NIS into the Baltic Sea in comparison to the previous HOLAS II assessment (now, 13 instead of 12 new introductions). This might be either explained by a general increase in arrival of NIS in the Baltic Sea or by increased monitoring efforts.

Indicator	Quantitative evaluation	Result	Assessment scale	Source
Non-indigenous species	Threshold value: no new introduction of NIS in the assessment period	Fail	Level 1	https://indicators.helcom.fi

The indicator considers only new introductions into the Baltic Sea as a whole (where we have a better level of confidence for the vector/pathway) and not the spread inside the Baltic, even though part of this within-Baltic Sea spread is likely due to human actions (certainly for some bivalve species e.g. *Mytilopsis leucophaeata* and *Rangia cuneata*).

To enable an evaluation of status, the indicator requires a baseline in the form of a list that specifies which NIS/CS were already present in each assessment unit, and ultimately the entire Baltic Sea, at a certain point in time. The baseline list for this assessment has been made for the year 2015, i.e. the year prior to the current assessment period, showing altogether 205 NIS and cryptogenic species in the Baltic Sea (based AquaNIS 2015) (see Metadata for details). The number of species present in 2015 varies between assessment units but for the evaluation for the whole Baltic Sea level at which this indicator is evaluated this overall value a as baseline is relevant. It should also be noted that some flexibility in the indicator evaluation against the baseline should be allowed if a NIS/CS is later found to have invaded an area during a previous assessment period.

The confidence for areas where detections of new NIS have been made is high. The detections have been verified by experts, and the observations are considered to be correct. In sub-basins where no detections have been made, the confidence may be low if no regular monitoring is conducted. This however varies between sub-basins. The confidence in the applicability of the threshold value is moderate as the concept is broadly considered to be valid. As monitoring data is not readily available across the entire region and the indicator has not been evaluated with national monitoring data alone, the success and suitability of monitoring data remains to been sufficiently tested. It is however a critical tool in improving the understanding of NIS in the Baltic Sea. The six-year evaluation period has been selected based on management cycles (e.g. BSAP and MSFD) and may not be the most ecologically relevant assessment period. However, a study conducted by ICES on the temporal adequacy of a three year period assessment states that this is likely to be a too short a period and considers a six-year assessment period to be more appropriate (ICES, 2013). Routine monitoring does not cover all invasion hotspots, habitats and taxonomic groups in many of the countries surrounding the Baltic Sea. However, the overall confidence is considered moderate for the evaluation made since the available records clearly show that the threshold value has not been achieved.

6.3. Changes over time for non-indigenous species

The number of new NIS/CS introductions has been fairly low until the mid-20th century but generally much higher afterwards (Figure 74). The lack of knowledge about the intensity in monitoring activities as well as on species identification make it difficult to estimate the accuracy of the values registered at the early years in figure 1.

The trends in arrival of new NIS to the Baltic Sea increased sharply in the second half of the 20th Century and has not shown signs of decline in 2000s. However, the number of new NIS records in the present assessment period (Table 27) was similar to that reported in the previous 6-y period (Table 28). The discrepancy in the new NIS introductions in results figure 74 and Table 28 for the HOLAS II period (2011-2016) is due to retrospective reporting of many new NIS after publishing the HOLAS II report. Thus, there is an apparent large decrease in reported NIS for this current assessment period (HOLAS 3, 2016-2021) as compared to the latest available information related to the preceding 5-year period (Figure 74).

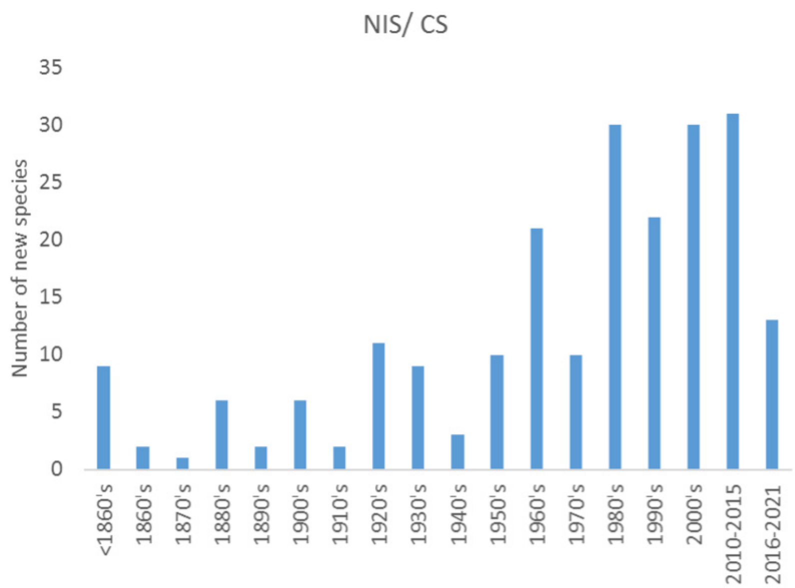


Figure 74. Number of new NIS in Baltic Sea until 2021 (data source AquaNIS). The bars indicate the number of new introduced species per time-period. Note that the latter period on the figure is not representative of equal time periods. The threshold value is 0 new introductins.

Table 27. New NIS/CS records in the present assessment period, by country, sub-basin and year of first introduction.

New NIS/CS	Country	Sub-basin	Year of first introduction
Haminoea solitaria	Germany	Bay of Mecklenburg	2016
Laonome xeprovala sp. nov.	Germany Finland	Kiel Bight Archipelago Sea	2016 2016
Caprella mutica	Denmark	Belt sea	2017
Fenestrulina malusii	Denmark	Kattegat	2017
Hemigrapsus sanguineus	Denmark	Kattegat	2017
Polydora aggregata	Denmark	Belt sea	2017
Chelicorophium robustum	Poland	Bornholm Basin	2018
Moerisia inkermanica	Germany	Bornholm Basin	2018
Mytilicola orientalis	Germany	Kiel Bight	2018
Nippoleucon hinumensis	Germany	Bay of Mecklenburg	2019
Echinogammarus ischnus	Germany	Bornholm Basin	2020
Proterorhinus nasalis	Estonia	Gulf of Finland	2020
Babka gymnotrachelus	Poland	Gulf of Gdansk	2021

Table 28. Status summary and comparison to prior evaluation. *Note that 2016 is included in both periods.

HELCOM Assessment unit name (and ID)	Threshold value achieved/failed – HOLAS II	Threshold value achieved/failed – HOLAS 3	Distinct trend between current and previous assessment.	Description of outcomes, if pertinent.
Baltic Sea	12 new NIS/CS - failed	13 new NIS/CS - failed	Stable - no trend or obvious change between the two assessment periods* is observed.	13 new NIS/CS were observed in the Baltic Sea. As the threshold for GES is 0 new introductions, the indicator results show that the assessment has failed the established threshold value.

6.4. Relationship of non-indigenous species to drivers and pressures/ biodiversity

The indicator evaluates the status of the marine environment affected by anthropogenic pressures. It is important to distinguish between naturally spreading and anthropogenically introduced species. If it is not possible to distinguish between a human mediated introduction and natural spread the species is called cryptogenic. For the indicator all new observed species are therefore first to be treated as NIS or cryptogenic and only species which can be shown to have spread naturally will be removed from the indicator.

According to Minchin *et al.* (2008), nine main categories of pathways through which species may spread for all aquatic environments can be defined. These are: shipping, canals, wild fisheries, culture activities, ornamental and live food trade, leisure activities, research and education, biological control and alteration to natural waterflow. In the Baltic Sea, the increasing shipping activities and development of new navigable waterways during the last 60 years has dominantly resulted in the increasing number of unintentional introduction of NIS/CS, transported in ballast tanks or on ship hulls (Olenin *et al.* 2009). Besides shipping, especially aquaculture has been identified as a very important vector in some parts of the Baltic Sea (Wolff and Reise 2002). Finally, the introduction of infrastructure associated with renewable and non-renewable energy to the marine environment (e.g., offshore wind turbines, oil and gas platforms) provides hard substrate which may be colonised by marine organisms, and subsequently serve to spread NIS. This is however a weaker link than maritime traffic for the influence of new introductions of non-indigenous species (Table 29).

Changes in abiotic conditions and increased stress of native species (Stachowicz at al. 2002, Occhipinti-Ambrogi, 2007; Hellmann *et al.* 2008) can be favourable for some invasive species and their ecological impacts can be expanded by climate change

Table 29. Brief summary of relevant pressures and activities with relevance to NIS.

	General	MSFD Annex III, Table 2a
Strong link	Maritime traffic, especially ballast water management and biofouling, aquaculture.	Biological - Input or spread of non-indigenous species
Weak link	Offshore wind turbines, oil and gas platforms; leisure activities	Biological - Input or spread of non-indigenous species

(low confidence: Pyke *et al.* 2008; Rahel *et al.* 2008). Such issues may support new NIS/CS to establish or spread in and to the Baltic Sea in the future, though significant further research is required on this topic for the region.

Climate change has generally shifted species boundaries towards the poles so immigration of new species can be expected. If the salinity of the Baltic Sea is reduced at the same time this can prevent successful invasions of marine species, but facilitate invasion of freshwater species (Holopainen *et al.* 2016).

Several parameters are highly inter-correlated, and also high impact of other direct and indirect anthropogenic disturbances like eutrophication and habitat degradation may interact with biological invasions.

Within the 2021 Climate Change in the Baltic Sea Fact Sheet a number of parameters were linked to NIS, indicating that changes in these could support the occurrence or establishment of NIS. These include direct parameters: water temperature, salinity, carbonate chemistry, and via indirect parameters (i.e. subsequent changes as a consequence of direct parameters): oxygen, benthic habitats, marine protected areas, and ecosystem function (HELCOM and Baltic Earth 2021).

6.5. How was the assessment of non-indigenous species carried out?

The majority of the relevant data is in point format. The processing required for making an evaluation against the baseline species list for an assessment unit only requires summing the number of new species introduced to the Baltic Sea per assessment unit. The 17 sub-basin assessment units (HELCOM Scale 2) are used for the assessment but due to differing monitoring efforts the indicator evaluation (against the threshold) is done on the whole Baltic scale, I.e. scale 1 (more details about the assessment scale are provided at the end of this subchapter).

The borders of the sub-basins reflect the large scale environmental gradients typical of the Baltic Sea, with salinity often being the most relevant gradient in relation to the introduction and potential large-scale spreading of NIS. The relevance of evaluating the number of new introductions on the scale of sub-basins is also due to the relatively low current detection rate of new arrivals. Monitoring programmes do not currently cover coastal areas adequately, however some monitoring activities are carried out in the coastal areas. Also, future wider implementation of port surveys and other monitoring programmes may warrant evaluations based on the coastal assessment units. Thus, existing programmes should be used for the indicator and be adapted, if possible. A further opportunity is the implementation of a cost-efficient rapid-assessment program on NIS, which already exists in some countries and outlined in the HELCOM Guidelines for non-indigenous species monitoring by extended Rapid Assessment Survey (eRAS).

The main parameters used to evaluate whether the threshold value is achieved in this core indicator are the new species introduced by human actions to the Baltic Sea per assessment unit after the year used to determine the baseline. However, in order to increase regional coherence and comparability between the HELCOM and OSPAR environmental assessments, the same indicator parameter processing is proposed. Therefore, the parameters 'inventory' and 'dispersal' are also considered in this core indicator. These two parameters are to be considered as supporting parameters that provide important information and their use in providing information of the spread of NIS might become more strongly incorporated in the indicator concept at a later stage of development.

Indicators evaluating the negative effects of NIS are not currently being developed in HELCOM. Advantages with the approach of the current indicator is considered to be that the indicator:

— is based on quantitative and qualitative data, not on expert judgement,
— works on a short time scale (in contrast to assessing environmental impact),
— can reflect the effectiveness of measures,
— evaluation is not dependent on earlier evaluations
— can be applied to a range of monitoring types and efforts,
— pragmatic, simple and considered to be effective,
— takes into account the current levels of uncertainty in relation to requirements for monitoring for NIS in the marine environment, and
— incorporates the same parameters as the comparable OSPAR indicator promoting regional coherence.

1. Species-Parameter

This main parameter describes how many new NIS/CS have been recorded in the Baltic Sea per assessment unit due to human actions during the assessment period. Only this parameter is used in the trend evaluation at this point in time.

SP (assessment period) = number of new introduced non-indigenous and cryptogenic species in the Baltic Sea per assessment unit.

Regular monitoring of species has to be conducted to identify new human-mediated arrivals. The parameter depends on the 2010 baseline list of NIS, and only documents new species detected after 2010 per assessment unit. This parameter can be used to measure the effectiveness of measures aimed at stopping or reducing the human-mediated introductions of NIS.

The parameter can also be used to evaluate the provisional threshold value, i.e. the rate of introduction. This could provide the most accurate indication of the effectiveness of implemented management measures. For example the species parameter could be used to show the trend in the annual numbers of introductions after the implementation of ballast water management measures to enable conclusions on the ballast water management effectiveness as a management option.

2. Inventory-Parameter

The calculation of the Inventory-Parameter is not applied to the trend assessment, but contains additional information for the state of the NIS community:

IP (assessment period) = number of NIS and CS in the assessment unit - number of NIS in the same assessment unit from the previous assessment period.

The parameter focuses on changes in the number of NIS detected in a specific assessment unit irrespective of regional species-baseline lists. The 'inventory' parameter quantifies whether the NIS species composition changes over time and focuses on changes in the total number of NIS individuals independent of the species list.

This supporting parameter enables an evaluation of whether recently introduced species persist over a longer period of time or vanishes after, for example, the following winter. The inventory parameter concentrates on the community of NIS and changes therein.

The inventory is negative if the number of disappearing NIS is higher than the number of newly introduced NIS, i.e. reflecting a good status. Should there be measures to eradicate unwanted species or NIS in general (e.g. cleaning pontoons in marinas); the Inventory Parameter can monitor the effectiveness of these measures and can provide additional information on management effectiveness at the regional and/or local level.

The indicator status (i.e. achievement of the threshold value) is currently evaluated at HELCOM Assessment Scale 1 – the whole Baltic Sea as a single assessment unit. The indicator results are also provided at HELCOM Scale 2 assessment units, these being the 17 sub-basins in the HELCOM area, to provide a spatial component to the evaluation. The assessment units are defined in the HELCOM Monitoring and Assessment Strategy Attachment 4. The indicator covers the entire Baltic Sea: national coastal and offshore waters divided to sub-basins. There are however wide gaps in the spatial coverage of the current biodiversity monitoring especially in the coastal areas. Currently, the monitoring of coastal and estuarine biodiversity is not conducted to reliably show the distribution and abundance of several NIS.

The time series data may overemphasize the recent decades and show too steep increase in the rate of introductions due to improved monitoring of NIS.

The large uncertainty related to new introductions, especially concerning their vectors/pathways, as well as unequal monitoring effort, prevents the use any more detailed scale in the assessment with this current indicator. At present the indicator only considers new introduction to the Baltic Sea as a whole but the indicator results show these introductions per sub-basin in addition. This approach however underestimates the NIS introductions in many areas as we cannot obtain reliable data for intra-Baltic spread (for vectors/pathways) and thus we cannot assess the status of new arrivals per sub-basin, which would give a better view of the status.

6.6. Follow up and needs for the future with regards to non-indigenous species

Since the early 1990s when the Marine Environmental Protection Committee (MEPC) of the International Maritime Organisation (IMO) put so-called Harmful Aquatic Organisms and Pathogens (HAOP) on the agenda, the issue has gathered an ever- increasing weight in marine environmental protection. In 2004, the International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM Convention) was adopted by the IMO. The Convention requires ships in international traffic to manage their ballast water and sediments (Regulation B-3) to certain standards specified in the Convention (Regulation D-2), as well as keeping a ballast water record books and an international ballast water management certificate. There is a phase-in period for ships to implement their ballast water and sediment management plan, during which they are allowed to exchange ballast water (Regulation B-1) in the open sea under certain premises of depth and distance from the shore (Regulation D-1). The Convention entered into force 8 September 2017. Futhermore, the Guidelines for the control and management of ships´ biofouling to minimize the transfer of invasive aquatic species (Resolution MEPC.207 (62)) are in the review process.

In the Baltic Sea Action Plan (BSAP 2007) Contracting Parties agreed to adjust/extend by 2010 the HELCOM monitoring programmes to obtain reliable data on non-indigenous species in the Baltic Sea, including port areas, in order to gather the necessary data to conduct and/or evaluate and consult risk assessments according to the relevant IMO guidelines. As a first step, species that pose major ecological harm and those that can be easily identified and monitored should be covered. The evaluation of any adverse ecological impacts caused by NIS should form an inherent and mandatory part of the HELCOM monitoring system.

Good Environmental Status (GES) according to the EU MSFD is to be determined on the basis of eleven qualitative descriptors. One of the descriptors concerns NIS and describes the Good Environmental Status (GES) for this descriptor as 'Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem' and sets the ambition level as achieved where the number of non-indigenous species introduced is minimised and where possible reduced to zero (Commission Decision (EU) 2017/848).

In order to minimize adverse effects of introductions and transfers of marine organisms for aquaculture ICES published the 'ICES Code of Practice on the Introductions and Transfers of Marine Organisms' (ICES, 2005). The Code of Practice summarizes measures and procedures to be taken into account when planning the introduction of NIS for aquaculture purposes. On the European level, the EC Council Regulation No 708/2007 concerning the use of NIS and locally absent species in aquaculture (EC, 2007) is based on the ICES Code of Practice. With a wider scope the recently adopted EU Regulation on the prevention and management of the introduction and spread of invasive alien species, entering into force on 1 January 2015, aims to protect native biodiversity and ecosystem services, as well as to minimize and mitigate the human health or economic impacts that these species can have (EU, 2014).

The new Baltic Sea Action Plan (BSAP 2021) addresses NIS with the fundamental link to sea-based activities, reinforcing the goal to achieve "Environmentally sustainable sea-based activities" with the ecological objective being "No or minimal disturbance to biodiversity and the ecosystem", and the management objective stated as "No introductions of non-indigenous species". Furthermore, the BSAP 2021 provides a complementary link to the biodiversity segment with the goal to achieve that the "Baltic Sea ecosystem is healthy and resilient". The ecological objective is stated here as "Viable populations of all native species"; "Natural distribution, occurrence and quality of habitats and associated communities" and "Functional, healthy and resilient food webs". The management objective is to "Minimize disturbance of species, their habitats and migration routes from human activities"; "Effective and coordinated conservation plans and measures for threatened species, habitats, biotopes, and biotope complexes", and "Reduce or prevent human pressures that lead to imbalance in the food web". Furthermore, links to other legislation such as IMO Ballast Water Management Convention, 2004 are provided. The BSAP 2021 addresses NIS via several actions, specifically for the topic of NIS (action S7-S12). These six actions aim at e.g. strengthening harmonisation of IMO biofouling guidelines, collaboration and harmonisation between HELCOM and OSPAR on ballast water management (BWM) convention; early warning systems for new introduction of NIS at ports; and improved development and use of biofouling management, techniques and research (HELCOM 2021).

General needs for future work are improvement of NIS monitoring, which should be the priority of the Baltic Sea countries if the objective is to improve the confidence of the indicator and perform an evaluation that has higher confidence and can be carried out at a more appropriate assessment unit scale (e.g. HELCOM Scale 2 assessment units, 17 sub-basins). New and emerging technologies and methods (incl. molecular and semi-automated tools) should be implemented in monitoring programs. Such issues require concerted effort and resourcing. Beyond HOLAS 3, and interlinked to other issues addressed under future work here, it may also be relevant to explore harmonisation of threshold value approaches with other regions (e.g., threshold values that incorporate a reduction of new introductions or may differ sub-regionally where suitable monitoring and data collection is available). In addition, further work on the topic of NIS though not directly related to this specific indicator is also needed, for example to better understand and evaluate issues, where relevant, such as spread, establishment and impact. These additional factors are also of relevance for policy, such as factors required under the Marine Strategy Framework Directive (MSFD) Descriptor 2. A trend analysis of not only the new NIS introductions but also the total number of NIS present may be of interest, in particular, from the managerial perspective.

7. Conclusions of the thematic assessment on hazardous substances, marine litter, underwater noise and non-indigenous species

Pollution is a broad topic and in this report a focus is provided on hazardous substances (chemical concentrations, and to an extent their effects), marine litter, underwater noise and non-indigenous species. All of these components of pollution are significant in the Baltic Sea region, to a great extent they originate directly from human activities, and they represent pressures that require effective management to prevent (or reverse) the failure of Good Environmental Status. Another commonality is that for all of these pollution pressures it appears that measures are most effectively placed at, or as close as possible to, source. It is thus critical that these issues are evaluated (e.g., the status evaluations provided in this report) to comprehend the levels of pressure exerted on the Baltic Sea ecosystem (species and habitats) so that the human activities that generate them can be reviewed and, where required, measures can be implemented to prevent harm. To effectively achieve this it is also vital to understand the complex interlinkages that result in the pressures and furthermore how these pressures effect status (e.g., through conceptual management, chemical lifecycles, or causal frameworks). This allows pressures and responses (measures) to be managed in optimal ways. Some pressures related to pollution also have a direct impact on humans as human are simply a component of the ecosystem. For example, excessive beach litter may deter visitors to beaches or hazardous substance concertations in fish used as a foodstuff may prevent healthy consumption. The linkage to humans can also be conceptualised in financial terms or in terms of direct effects (e.g., Economic and Social Analyses). However, the impacts on humans and the impacts on the ecosystem as a whole (its habitats and species) are in essence inseparable and irrespective of the route through which impacts are determined the response in terms of measures, and for these types of pressure ideally precautionary or pre-emptive measures, is critical in achieving GES.

The four topics addressed under pollution differ widely and are thus presented briefly under separate conclusion sections. No assessment that formerly incorporated all the components is applied.

Hazardous substances

Hazardous substances represent a vast group of chemicals that are generally man-made and enter the Baltic Sea marine environment through a complex web of inputs (e.g., riverine, point source, atmospheric, etc.). Certain commonalities may be possible define, allowing certain groups of substances (e.g., based on their chemical behaviours) to be treated together when setting measures or evaluating status, however the sheer number of substances that are known to be harmful or may be harmful needs to be considered. In the marine environment these substances can have direct (e.g., toxicity and even poisoning) and indirect (e.g., health, breading success, or food web) harmful effects on species or habitats and dependant on factors like concentration or persistence these effects may present risk from the individual animal, through to species and population effects.

Hazardous substances monitoring and evaluation has classically focused on single substance and focused on lists of defined priority substances for which a wealth of data and toxicity information is available. Such evaluations provide for example the major basis of the work on HELCOM indicators and the integrated assessment of contamination status presented in this report. These contribute a clear understanding of key priority substances that are often persistent, bioaccumulatory and toxic and when integrated offer an insight into the overall pressure of hazardous substances (based on current best available knowledge) across the Baltic Sea. The key finding indicate that the pressure from hazardous substances remains high in most areas (assessment units) across the region, with concentrations of Polybrominated diphenyl ethers (PBDEs), Tributyltin (TBT), Mercury(Hg) and Copper (Cu), predominantly in the sampling matrix biota (i.e., fish and mussels), driving the failure to achieve Good Environmental Status (sub-GES). It is also vital to note that where good (or better) status is detected in the current integrated assessment it is in the majority of cases paired with low confidence in the evaluation, reflecting a poorer data quality or the lack of sufficient substances being assessed in the specific assessment unit.

Despite the general overview of sub-GES conditions across the region there are however indications of some improvement. A larger number or stations, larger also then were detected in the previous assessment period (HOLAS II), showed downward trends than those showing increasing trends. This was particularly so for biota (though biota generally also provided more stations with longer-term time series on which the analysis could be applied) and suggests that concentrations of some of these priority substances are decreasing. Some of the priority substances evaluated are, by nature of their categorisation, persistent legacy substances and have been identified to have extensive degradation times. For example, TBT has been suggested to persist in the marine environment for up to 40 years under certain conditions. It is thus clear that recovery from historic contamination can take a significant time, despite measures that prevent or reduce new introductions of the substance. There are also other promising signs in relation to status improvement, for example a small number of open sea sub-basins appear to have shifted slightly towards better status (integrated contamination status, though changes in the methodology may contribute to a certain level) and studied of dated sediment cores provide an understanding in reduction of inputs for certain substances.

It is becoming more widely accepted that single substance evaluations or a focus on a few priority substances alone is insufficient when determining GES. This report also provides initial steps to address this, reflecting the initial results of the first regional screening of hazardous substances and the a pilot study addressing the integrated biological effects of contaminants. Target and non-target screening, as applied here across harmonised sampling matrices, can provide clues to new and emerging substances beyond the focus on priority substances. Identifying these substances, not just in the marine environment but also beyond this and across pathways of inputs, can provide a clear risk evaluation and even act as a trigger for management action, or requirement of further study (e.g., to identify sources, pathway or toxicity and threshold values). The initial study suggests some 40-130 substances, some of which are already considered under the existing evaluations, that may warrant further evaluation. Moreover, knowing the status of the environment and the impacts on the ecosystem is key and this step is explored using biological effects of contaminants. The initial pilot study shows that in general effect-based approaches are a valid way to identify status as they generally show marked effects on the resident biota from exposure to elevated contaminant concentration.

Future work is still needed to better address knowledge gaps related to hazardous substances. These gaps range from further development of effect-based approaches and appropriate use of the outputs of initial screening studies to more detailed factors such as appropriate conversion factors between tissues and across trophic levels. Furthermore, the work in relation to Baltic Sea Action Plan (BSAP) action HL1 to 'develop a regional strategic approach and, on the basis of that approach, an action plan for HELCOM work on hazardous substances by 2024', in association with other key associated actions (e.g., evaluating priority substances) will be vital in creating a systematic approach that can limit inputs or improve status. Another important aspect requiring study is how climate change interacts with the flows and loads of hazardous substances and the existing link between these hazardous substances and biota.

Marine Litter

Beach litter is probably the indicator most used worldwide to monitor the input of marine litter to aquatic ecosystems. Surveys of litter on the beach allow for a detailed evaluation of litter in terms of amounts and composition. Its strength lies on the provision of information on potential harm to marine biota and ecosystems as well as social harm (aesthetic value, economic costs, hazard to human health) and, to some extent, on sources of litter and the potential effectiveness of management measures applied.

Litter present on beaches comes both from land- and sea-based sources. Land-based sources are often linked to consumer behaviour, such as recreational/tourism activities. Other land-based sources are riverine inputs and inputs from storm water overflows. Important sea-based sources are professional and recreational ships as well as fishing related activities. Thus, beach litter monitoring can reflect trends of littering of the coast/beaches including coastal waters and possibly also litter transported over long distances. Beach litter can, to a certain extent, be linked to sources and pathways, which is a fundamental step for a subsequent definition of measures aimed at acting on those sources and pathways to minimize the presence of marine litter in the aquatic environment.

The status evaluation of marine beach litter in the Baltic Sea for 2016-2021 shows that 11 out of 16 sub-basins are above the HELCOM threshold value of 20 litter items per 100 m beach. The most commonly found category of litter is various plastic items and fragments above 2.5 cm. Several of the items on the top-ten list are related to single use plastics and other types of plastic used. Single use plastics is a common litter item and is a driving force for the trends of marine litter. Marine litter from sea-based sources are only contributing slightly to littering on Baltic Sea beaches.

There is a need to assess the presence of litter in other ecosystem compartments than beaches, to obtain an overview of this pollution problem and provide the most holistic overview possible. Thus, litter on the seafloor is considered due its ecological relevance and data availability. For example, seafloor litter can cause anoxia to the underlying sediments, which alters biogeochemistry and benthic community structure, may provide substrata for the attachment of sessile biota in sedimentary environments and alter faunal community composition, and so on. Data of marine litter collected in trawls during fish stock surveys is thus used as an indication of the true amount of litter on the seafloor.

In relation to the seafloor litter status evaluation, when litter density was measured in weight, the categories "other", plastic and fisheries related litter increased significantly in the period from 2015 to 2021 whereas when density was measured in numbers, only "other" and plastic litter increased significantly and thereby failed the preliminary threshold value of 'no significant increase' from 2015 to 2021 in both weight, numbers and probability of catching litter. Fisheries related litter passed the threshold (trend not significantly >0) when measured in numbers per km^2 but not when measured in weight per km^2. The categories glass, metal, natural, rubber and single use plastics (SUP) showed no significant increase in weight and numbers per km^2 and hence passed the preliminary threshold of no significant increase on the seafloor.

Looking into the future and considering that after a stagnation in 2020 due to the Covid-19 pandemic, the global plastics production increased to 390.7 million tonnes in 2021, it may be envisaged that part of this plastic production is mismanaged after use and ends up in the marine ecosystems. Lau *et al.* published in 2020 an estimate of the effectiveness of interventions to reduce plastic pollution. They modelled stocks and flows of municipal solid waste and four sources of microplastics through the global plastic system for five scenarios between 2016 and 2040. They found that implementing all feasible interventions would reduce plastic pollution by 40% from 2016 rates and 78% relative to "business as usual" in 2040.

At the regional level, the implementation of the 2021 HELCOM Regional Action Plan on Marine Litter is expected to enable the achievement of the marine litter ecological ("no harm to marine life from litter") and managerial objectives ("prevent generation of waste and its input to the sea, including microplastics" and "significantly reduce amounts of litter on shorelines and in the sea") of the 2021 Baltic Sea Action Plan to be achieved by 2030. There are also further relevant developments related to indicators and assessments that are also important to consider, for example the evaluation of microlitter (in sediments and water) as well as the impact of litter on biota.

Underwater Noise

Continuous anthropogenic noise represents a significant pressure on the marine environment due to its constant presence and extensive spatial coverage over the entire water column in open sea areas. The noise from ships, when sailing at service speed, is caused primarily by their propulsion (engine noise and propeller cavitation), with secondary components being machinery and the movement of the hull through the water. Sound has the capacity to impact marine organisms in several ways; for low frequency continuous noise, the ability to mask acoustic communication and reception of other, biologically relevant sounds, is of particular importance, as is the disturbance of behaviour that high levels of noise may lead to.

This first-time quantitative assessment of continuous underwater noise shows substantial contributions of ship noise to the Baltic Sea environment, with considerable variations in space (shipping lanes much more affected than elsewhere) and in time (ship noise being more wide-spread in winter than summer). This indicator evaluation was below the 20% spatial threshold for all assessment units for marine mammals, but exceeded the preliminary 20% spatial threshold for 9 out of 17 assessment units for masking of fish communication, although not for fish behavioural disturbance where it was below the threshold value. It is to be noted that the assessment itself comes with significant uncertainties, relating to the selection of input parameters (most notably the Levels of Onset of Biologically adverse Effects - LOBE levels) and the distribution of the indicator species.

The most significant man-made sources of loud impulsive noise are explosions, pile driving, seismic explorations and low frequency sonars. Sound waves propagate efficiently in water, which means that loud sources without noise mitigation measures may have far-reaching effects, up to tens of kilometres from the source. Thus, even though noise does not persist in the environment, it may harm marine species if no measures are taken in order to mitigate adverse effects. Effects of loud impulsive sound ranges from behavioural effects (deterrence, disturbance) over impact on auditory systems (temporary and permanent hearing loss) to physiological injury and in extreme cases death.

The indicator is based on the occurrences of impulsive noise-producing maritime activities reported by Contracting Parties to the regional HELCOM/OSPAR noise registry. Based on the available data, a broad range of impulsive sound events occurred in the Baltic Sea region during 2016-2021; however, no clear trends were observed for the prevalence of events related to any of the different types of source activity. Across the assessment period, the area exposed and disturbed with respect to displacement for harbour porpoise clearly remained below a fraction of 10% of the HELCOM area habitat per day. Several aspects are to be improved from this preliminary assessment (e.g., impact of mitigation measures and the identification of areas of high temporary impact).

Future work is needed to further develop the threshold values for both indicators and attain regional agreement on their application. Thus, further work is envisaged on, for instance, the Levels of Onset of Biologically adverse Effects (LOBE) for indicator species, the habitat sizes of indicator species and the following sizes of assessment subbasins.

Bearing in mind, that the aim is to achieve a long-term reduction of anthropogenic noise in marine ecosystems, the implementation of international, regional and national commitments is key. To list a few: the envisaged revised IMO Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life, the 2021 Baltic Sea Action Plan, and the HELCOM Regional Action Plan on Underwater Noise.

Non-indigenous species

Non-indigenous and cryptogenic species have the potential to cause harm in the environments to which they enter. They can for example displace native species or alter food web structures and energy flows. Introductions of new non-indigenous species occur are as a direct result of human activities, for example related to shipping. The trends in arrival of new NIS to the Baltic Sea increased sharply in the second half of the 20th Century and has not shown signs of decline in 2000s. In the current evaluation there is an apparent decrease in the number of new introductions as compared to the previous assessment period, however, there remain some uncertainties in this as a large amount of reportings for the HOLAS II period (2011-2016) also took place after the previous indicator evaluation was completed.

Once established non-indigenous species are in general difficult to remove (if not impossible, at least impractical), thus preventative measures are key. Future work on the topic includes improving the overall resolution of the evaluation, a task that requires more and more detailed monitoring, improving the understanding of natural spread and establishment of species, and determining the role or impact if such species in the environment. Such improvement would provide a stronger and more ecologically relevant understanding of non-indigenous species in the Baltic Sea ecosystem.

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Annex 1. Methodology for the CHASE integrated assessment of hazardous substances

The integrated assessment was done using the HELCOM CHASE tool (Chemical Status Assessment Tool), which integrates individual results for indicator substance (or substances group) evaluations into a quantitative estimate of overall contamination status. The CHASE tool is only applied on regionally agreed HELCOM core indicators and only for those parameters that directly evaluate substance concentrations.

In the integrated assessment, the threshold value for each individual substance (or substance group sum) and for each matrix is used to calculate the contamination ratio (CR). The contamination ratio forms the starting data point for the integration and is expressed as the measured concentration divided by the threshold value. Thus, the contamination ratio can indicate the distance from threshold value of monitored substances. The use of contamination ratios prior to entry into the integrated assessment ensures an equal weighting of the different data types.

The current version of the CHASE integrated assessment tool is developed for use in R (https://www.r-project.org/), a free statistical software. The CHASE code is freely available at GitHUB (https://github.com/ helcomsecretariat/CHASE-integration-toolE), and online open-source repository and version-control system for software codes. Previous application and development of the tool are set out in HELCOM (2018): HELCOM Thematic assessment of hazardous substances 2011-2016. Baltic Sea Environment Proceedings n°157, the Thematic assessment of hazardous substances from HOLAS II (2011-2016 period).

A.1. Structure and assessment approach of CHASE

The CHASE tool produces an assessment of contamination status by nesting evaluation results for indicators (or substances and substance groups) sampled within three matrix categories: water, biota, sediment. The categories relate to matrices in which

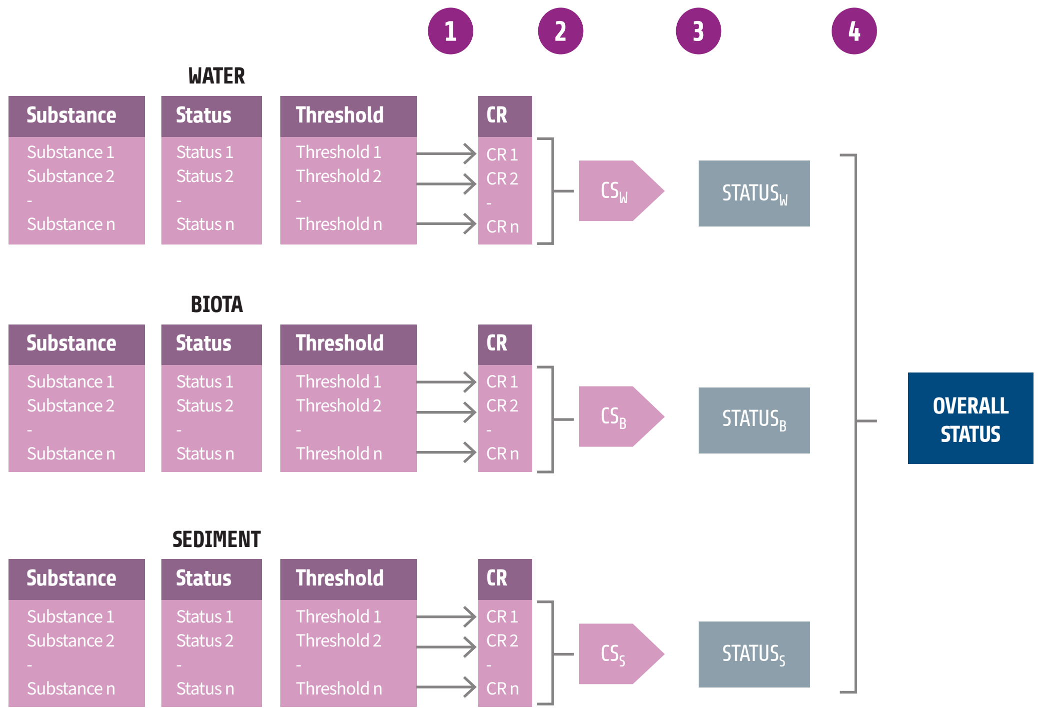

Figure A1.1. Structure of the CHASE tool, describing the flow of information within the tool. The numbers in the blue circles correspond to the steps which are described in detail below: 1) Status values (=observed values) for each substance (substance group) and the associated threshold values are used to calculate a Contamination Ratios (CR). 2) The contamination ratios within each matrix category (water, biota or sediment) are calculated to give a 'matrix' Contamination Score (CS). 3) The Contamination score is used to determine the Category Status. 4) The overall status for the assessment unit is defined as the status of the category showing the highest score, corresponding to the worst status.

hazardous substances are typically measured and the indicator evaluation results are carried out at designated HELCOM assessment scales. Hence, the CHASE tool integrates the regionally agreed HELCOM core indicator evaluation results, based on the matrix used for the respective threshold values in each indicator. The assessment structure of the CHASE tool and the calculation steps involved is shown in Figure A1.1.

Step 1. For each indicator substance (or substance group), a contamination ratio (CR) is calculated as the ratio of the observed value (monitored value; Cmon) to the specific threshold value (Cthreshold). Note that the indicator calculation script (MIME) generates this CR value and the CHASE integrated assessment tool can also be provided with the CR values as direct input data.

$$\mathrm{CR} = \frac{C_{mon}}{C_{threshold}}$$

When the observed value exceeds the threshold value, the resulting contamination ratio will be greater than 1.0, and if it is below the threshold value, the contamination ratio will be 1.0 or less. For all hazardous substances (indicators), an increase in concentration is associated with worsening status, hence the indicator fails the threshold value when the observed value exceeds it.

Step 2. An aggregated contamination score (CS) is calculated separately for each matrix category (CI= water, CII = biota, CIII = sediment):

$$\mathrm{CS} = \frac{1}{\sqrt{n}} \sum_{i=0}^{n} \mathrm{CR}_i$$

The CHASE tool is robust against the so called 'dilution effect' - which describes a situation when several low-scoring indicators can mask the effect of one or a few indicators having a high contamination ratio.

Step 3. If the aggregated contamination score (CS) from step 2 (the matrix CS) is less than 1.0 within one matrix (water, biota or sediment), the status for that individual matrix is determined to be good (matrix status). If above 1.0 that matrix is classified as not good. This is reflected as a 'low' or 'high' respective contamination status. The low contamination status class is further subdivided into two categories, and the high contamination status class is subdivided into three categories, based on the value of the aggregated contamination score (Table 3). The five categories give a coarse estimate of how far the obtained result is from the 'target', and can help distinguish an area with a very high contamination score from an area with a score closer to 1.

Step 4. The overall status assessment result is determined by the “One-out-all-out” approach, so that the matrix category with the worst status of the three categories (water, biota, sediment) determines the overall status for an individual assessment unit. The score of the category with the worst status is retained to indicate how far from 1 the overall assessment result is (Table A1.1).

Table A1.1. Result categories of the contamination status assessment.

	Contamination score (CS)	Contamination Status category
Contamination score less than 1.0	≤0.5	Low contamination score
	0.5<CS ≤1.0	Low contamination score
Contamination score less than 1.0	1.0<CS ≤5.0	High contamination score
	5.0<CS ≤10.0	High contamination score
	>10.0	High contamination score

A.2. Confidence assessment methodology

The hazardous substances and substance groups which are used in the integrated assessment are known to enter the Baltic Sea ecosystem due to human activity, generally meeting the requirements for core indicators of having wide ranging spatial and temporal monitoring, and threshold values agreed by all HELCOM Contracting Parties. There are, however, significant regional differences in how much monitoring data is available for each assessment unit. HELCOM assessment units at scale 3 are used in the CHASE integrated assessment. Since the underlying indicator evaluation, based on the MIME script, applies defined calculation rules (and normalisation procedures in certain cases), only data meeting these conditions are processed to the result evaluation point and forms the output that enters the CHASE tool. The approach applied in the integrated assessment allows a wide range of spatial and temporal data to be incorporated, despite regional differences, and it should be noted that the confidence setting approach (described below) provides a balance to the conclusions to be drawn from the integrated assessment outcomes. The confidence assessment is carried out in parallel to the status assessment in the CHASE tool, and gives an overall confidence rating based on the type or quality of underlying monitoring data and the reliability of the threshold value and methodology applied.

An overall confidence value is calculated per assessment unit based on five components that are evaluated within each indicator. These include a temporal confidence, spatial confidence, methodological confidence, accuracy confidence and a threshold value confidence component (as set out within each indicator report). These components have been weighted at 10, 25, 25, 25, 25 and 15% of the overall confidence, respectively for HOLAS 3 and further details on the categorisation is presented within the specific indicator reports (indicator website). When calculating the overall confidence score in the CHASE tool, the confidence rating is first translated to a numerical format so that rating ‘High’ is given value 1.0, rating ‘Moderate’ is given value 0.5 and rating ‘Low’ is given value 0:

$$ {}_i = \begin{cases} 1.0, & "High" \\ 0.5, & "Moderate" \\ 0.0, & "Low" \end{cases} $$

The confidence score for the category (water, biota or sediment) is the average of the indicator confidence scores:

$$ c_{cat} = \frac{1}{n} \sum_{i=1}^{n} c_i t $$

The overall confidence score is the average of the category confidence scores:

$$ CR = \frac{C_{mon}}{C_{threshold}} $$

Finally, the overall Confidence Score is provided in the output additionally as a Confidence Class, which is converted to an Overall Confidence Status, according to Table A1.2. As a final step, the overall confidence is evaluated based on which substances were includ-

Table A1.2. Confidence classes applied in the integrated hazardous substances assessment using the CHASE tool.

Confidence Score	Confidence Status	Overall Confidence Status
≥0.75	**Class I**	**High**
between 0.5 and 0.75	**Class II**	**Moderate**
<0.50	**Class III**	**Low**

Table A2.3. Criteria that need to be fulfilled at the level of assessment unit in the integrated assessment of hazardous substances. If the minimum requirement criteria are not met, a penalty is applied to the overall confidence.

Minimum requirement criteria	Penalty applied to the confidence score if the criteria is not met
At least two heavy metal substances are included in the assessment (two individual metals irrespective of monitoring matrix)	50% reduced confidence
At least three organic substances are included in the assessment (all categories)	50% reduced confidence

ed, and a penalty is applied to the overall confidence if minimum requirements are not met. The minimum requirements consider substances (or substance groups), and not indicators, and the requirements are detailed in Table A1.3.

This overall confidence rating system is applied at the level of each individual assessment unit (HELCOM assessment unit scale 3), providing an overview map though which the data-based status assessment can be moderated. It is, for example, an important way in which to address areas for which a contamination status is provided but for which the underlying data or threshold values appear less certain.

Additional details can be found in HELCOM (2018): HELCOM Thematic assessment of hazardous substances 2011-2016. Baltic Sea Environment Proceedings n°157, the Thematic assessment of hazardous substances from HOLAS II (2011-2016 period). An overview of the CHASE outputs is provide in Annex 2 and also the results are summarised in the main report.

References

HELCOM (2018). HELCOM Thematic assessment of hazardous substances 2011-2016. Baltic Sea Environment Proceedings n°157. http://stateofthebalticsea.helcom.fi/pressures-and-their-status/hazardous-substances/

Annex 2.
Overview of outputs for the CHASE integrated assessment of hazardous substances (at Level 3 Assessment Units)

Table A2.1. Overview of CHASE integrated assessment outputs (Level 3 assessment units). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.

Assessment unit	'Worst' monitoring matrix	ConSum value	Status outcome	Confidence Score	Confidence class	Number of metals	Number of organic contaminants	Penalty applied
1	biota	22.428	Bad	0.838	Class I	3	5	0%
2	biota	12.336	Bad	0.843	Class I	3	5	0%
3	biota	39.816	Bad	0.536	Class II	2	4	0%
4	biota	10.791	Bad	0.881	Class I	3	5	0%
5	biota	40.91	Bad	0.797	Class I	3	5	0%
6	biota	16.029	Bad	0.892	Class I	3	5	0%
7	biota	0.15	High	0.25	Class III	0	0	75%
8	biota	14.912	Bad	0.672	Class II	3	5	0%
9	biota	22.082	Bad	0.658	Class II	3	5	0%
10	biota	7.559	Poor	0.616	Class II	3	6	0%
11	biota	11.963	Bad	0.792	Class I	4	8	0%
12	biota	12.551	Bad	0.808	Class I	4	8	0%
13	water	0.364	High	0.219	Class III	0	0	75%
14	biota	10.64	Bad	0.618	Class II	4	8	0%
15	biota	16.251	Bad	0.679	Class II	3	3	0%

Table A2.1. (Continued). Overview of CHASE integrated assessment outputs (Level 3 assessment units). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.

Assessment unit	'Worst' monitoring matrix	ConSum value	Status outcome	Confidence Score	Confidence class	Number of metals	Number of organic contaminants	Penalty applied
16	biota	11.512	Bad	0.723	Class II	3	7	0%
17	water	2.826	Moderate	0.673	Class II	3	5	0%
18	biota	14.254	Bad	0.859	Class I	3	3	0%
19	water	3.709	Moderate	0.45	Class III	3	2	50%
20	water	0.422	High	0.219	Class III	0	0	75%
21	water	0.422	High	0.219	Class III	0	0	75%
22	water	0.74	Good	0.372	Class III	2	1	50%
23	water	0.444	High	0.234	Class III	0	0	75%
24	biota	5.151	Poor	0.796	Class I	4	8	0%
25	water	0.479	High	0.234	Class III	0	0	75%
26	sediment	16.778	Bad	0.846	Class I	4	7	0%
27	water	0.479	High	0.234	Class III	0	0	75%
28	biota	10.36	Bad	0.807	Class I	3	6	0%
29	water	0.503	Good	0.238	Class III	0	0	75%
30	biota	25.692	Bad	0.93	Class I	3	7	0%
31	biota	42.167	Bad	0.825	Class I	3	8	0%
32	biota	18.859	Bad	0.89	Class I	3	8	0%
33	biota	1.943	Moderate	0.46	Class III	3	2	50%
34	water	0.43	High	0.222	Class III	0	0	75%
35	sediment	45.444	Bad	0.826	Class I	3	5	0%
36	sediment	13.792	Bad	0.786	Class I	4	9	0%
37	water	0.427	High	0.219	Class III	0	0	75%
38	biota	69.527	Bad	0.889	Class I	3	7	0%
39	biota	0.629	Good	0.407	Class III	3	2	50%
40	biota	7.131	Poor	0.887	Class I	4	9	0%

Table A2.1. (Continued). Overview of CHASE integrated assessment outputs (Level 3 assessment units). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.

Assessment unit	'Worst' monitoring matrix	ConSum value	Status outcome	Confidence Score	Confidence class	Number of metals	Number of organic contaminants	Penalty applied
SEA-001	biota	8.806	Poor	0.805	Class I	4	8	0%
SEA-002	biota	1.411	Moderate	0.424	Class III	3	2	50%
SEA-003	biota	13.43	Bad	0.808	Class I	3	5	0%
SEA-004	biota	3.287	Moderate	0.814	Class I	3	3	0%
SEA-005	sediment	3.748	Moderate	0.83	Class I	3	4	0%
SEA-006	biota	13.789	Bad	0.873	Class I	4	9	0%
SEA-007	biota	8.774	Poor	0.84	Class I	4	9	0%
SEA-008	biota	12.911	Bad	0.794	Class I	4	7	0%
SEA-009	biota	15.379	Bad	0.787	Class I	4	7	0%
SEA-010	biota	13.722	Bad	0.76	Class I	4	8	0%
SEA-011	biota	10.103	Bad	0.639	Class II	3	4	0%
SEA-012	biota	6.345	Poor	0.646	Class II	4	8	0%
SEA-013	biota	6.896	Poor	0.865	Class I	4	8	0%
SEA-014	sediment	0.89	Good	0.894	Class I	3	5	0%
SEA-015	biota	12.919	Bad	0.855	Class I	4	8	0%
SEA-016	biota	10.705	Bad	0.637	Class II	3	4	0%
SEA-017	biota	55.82	Bad	0.708	Class II	4	8	0%

Table A2.2. Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	1	5548.1492	CD	HM	biota	1.80451789	H	M	H	M	H	Metals	0.75	22.428	Bad	0.8	Class I
3	1	5548.1492	HBCD	Org	biota	0.0033418	M	M	H	M	H	HBCD	0.7	22.428	Bad	0.8	Class I
3	1	5548.1492	HG	HM	biota	5.38652275	H	M	H	M	H	Metals	0.75	22.428	Bad	0.8	Class I
3	1	5548.1492	PB	HM	biota	0.11539813	H	H	H	M	M	Metals	0.8	22.428	Bad	0.8	Class I
3	1	5548.1492	SBDE6	Org	biota	59.3201028	H	M	H	M	H	PBDEs	0.75	22.428	Bad	0.8	Class I
3	1	5548.1492	TEQDFP	Org	biota	0.20993207	M	M	H	H	H	Dioxins	0.825	22.428	Bad	0.8	Class I
3	1	5548.1492	SCB6	Org	biota	0.10447444	H	H	H	M	H	PCBs	0.875	22.428	Bad	0.8	Class I
3	1	5548.1492	PFOS	Org	biota	0.15055945	H	M	H	H	H	PFOS	0.875	22.428	Bad	0.8	Class I
3	1		CS137	Radioactive	biota	0.18987579	H	M	H	H	H	Radioactive	0.875	22.428	Bad	0.8	Class I
3	1		CS137	Radioactive	water	0.3605625	H	M	H	H	H	Radioactive	0.875	0.361	H	0.875	Class I
3	2	5047.84029	CD	HM	biota	1.90548566	H	M	H	M	H	Metals	0.75	12.336	Bad	0.81111111	Class I
3	2	5047.84029	HBCD	Org	biota	0.00103457	H	M	H	M	H	HBCD	0.75	12.336	Bad	0.81111111	Class I
3	2	5047.84029	HG	HM	biota	1.62025443	H	M	H	M	H	Metals	0.75	12.336	Bad	0.81111111	Class I
3	2	5047.84029	PB	HM	biota	0.15946215	H	H	H	M	M	Metals	0.8	12.336	Bad	0.81111111	Class I
3	2	5047.84029	SBDE6	Org	biota	32.8420046	H	M	H	M	H	PBDEs	0.75	12.336	Bad	0.81111111	Class I
3	2	5047.84029	TEQDFP	Org	biota	0.18410626	H	M	H	H	H	Dioxins	0.875	12.336	Bad	0.81111111	Class I
3	2	5047.84029	SCB6	Org	biota	0.05876384	H	H	H	M	H	PCBs	0.875	12.336	Bad	0.81111111	Class I
3	2	5047.84029	PFOS	Org	biota	0.04605228	H	M	H	H	H	PFOS	0.875	12.336	Bad	0.81111111	Class I
3	2		CS137	Radioactive	biota	0.18987579	H	M	H	H	H	Radioactive	0.875	12.336	Bad	0.81111111	Class I
3	2		CS137	Radioactive	water	0.3605625	H	M	H	H	H	Radioactive	0.875	0.361	H	0.875	Class I
3	3	3404.89947	CD	HM	biota	0.8125	L	L	H	L	H	Metals	0.4	39.816	Bad	0.53571429	Class II
3	3	3404.89947	PB	HM	biota	0.38461538	L	M	H	L	M	Metals	0.45	39.816	Bad	0.53571429	Class II
3	3	3404.89947	SBDE6	Org	biota	102.614379	L	L	H	L	H	PBDEs	0.4	39.816	Bad	0.53571429	Class II
3	3	3404.89947	TEQDFP	Org	biota	0.41570662	L	M	H	L	H	Dioxins	0.525	39.816	Bad	0.53571429	Class II
3	3	3404.89947	SCB6	Org	biota	0.50918519	M	L	H	L	H	PCBs	0.45	39.816	Bad	0.53571429	Class II
3	3	3404.89947	PFOS	Org	biota	0.44615385	L	M	H	L	H	PFOS	0.525	39.816	Bad	0.53571429	Class II
3	3		CS137	Radioactive	biota	0.16132378	H	H	H	H	H	Radioactive	1	39.816	Bad	0.53571429	Class II
3	4	1788.49803	CD	HM	biota	0.86437968	H	H	H	M	H	Metals	0.875	10.791	Bad	0.88055556	Class I
3	4	1788.49803	HBCD	Org	biota	0.00103249	H	H	H	M	H	HBCD	0.875	10.791	Bad	0.88055556	Class I
3	4	1788.49803	HG	HM	biota	2.34308827	H	M	H	M	H	Metals	0.75	10.791	Bad	0.88055556	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	4	1788.49803	PB	HM	biota	0.18007717	H	H	H	M	M	Metals	0.8	10.791	Bad	0.88055556	Class I
3	4	1788.49803	SBDE6	Org	biota	28.3999801	H	H	H	M	H	PBDEs	0.875	10.791	Bad	0.88055556	Class I
3	4	1788.49803	TEQDFP	Org	biota	0.26829431	H	H	H	H	H	Dioxins	1	10.791	Bad	0.88055556	Class I
3	4	1788.49803	SCB6	Org	biota	0.07580531	H	H	H	M	H	PCBs	0.875	10.791	Bad	0.88055556	Class I
3	4	1788.49803	PFOS	Org	biota	0.0787282	H	H	H	M	H	PFOS	0.875	10.791	Bad	0.88055556	Class I
3	4		CS137	Radioactive	biota	0.16132378	H	H	H	H	H	Radioactive	1	10.791	Bad	0.88055556	Class I
3	5	3518.64607	CD	HM	biota	1.38386042	M	L	H	L	H	Metals	0.45	40.91	Bad	0.59444444	Class II
3	5	3518.64607	HBCD	Org	biota	0.00155456	M	M	H	L	H	HBCD	0.575	40.91	Bad	0.59444444	Class II
3	5	3518.64607	HG	HM	biota	7.66476133	H	M	H	M	H	Metals	0.75	40.91	Bad	0.59444444	Class II
3	5	3518.64607	PB	HM	biota	0.15201398	L	M	H	L	M	Metals	0.45	40.91	Bad	0.59444444	Class II
3	5	3518.64607	SBDE6	Org	biota	112.431335	M	L	H	L	H	PBDEs	0.45	40.91	Bad	0.59444444	Class II
3	5	3518.64607	TEQDFP	Org	biota	0.38605252	L	M	H	M	H	Dioxins	0.65	40.91	Bad	0.59444444	Class II
3	5	3518.64607	SCB6	Org	biota	0.27005653	M	L	H	L	H	PCBs	0.45	40.91	Bad	0.59444444	Class II
3	5	3518.64607	PFOS	Org	biota	0.25782716	M	M	H	M	H	PFOS	0.7	40.91	Bad	0.59444444	Class II
3	5		CS137	Radioactive	biota	0.18107361	H	M	H	H	H	Radioactive	0.875	40.91	Bad	0.59444444	Class II
3	5		CS137	Radioactive	water	0.51846528	H	H	H	H	H	Radioactive	1	0.518	Good	1	Class I
3	6	6386.74258	CD	HM	biota	1.92001984	H	M	H	M	H	Metals	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	HBCD	Org	biota	0.00069224	H	M	H	M	H	HBCD	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	HG	HM	biota	1.2859348	H	M	H	M	H	Metals	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	PB	HM	biota	0.46887416	H	M	H	M	M	Metals	0.675	16.029	Bad	0.78333333	Class I
3	6	6386.74258	SBDE6	Org	biota	43.8197092	H	M	H	M	H	PBDEs	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	TEQDFP	Org	biota	0.25699878	H	M	H	H	H	Dioxins	0.875	16.029	Bad	0.78333333	Class I
3	6	6386.74258	SCB6	Org	biota	0.11892794	H	M	H	M	H	PCBs	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	PFOS	Org	biota	0.0349903	H	M	H	H	H	PFOS	0.875	16.029	Bad	0.78333333	Class I
3	6		CS137	Radioactive	biota	0.18107361	H	M	H	H	H	Radioactive	0.875	16.029	Bad	0.78333333	Class I
3	6		CS137	Radioactive	water	0.51846528	H	H	H	H	H	Radioactive	1	0.518	Good	1	Class I
3	7		CS137	Radioactive	biota	0.14994904	H	H	H	H	H	Radioactive	1	0.15	H	1	Class I
3	8	14341.166	CD	HM	biota	1.39104229	H	L	H	M	H	Metals	0.625	14.912	Bad	0.67222222	Class II
3	8	14341.166	HBCD	Org	biota	0.00116815	H	L	H	M	H	HBCD	0.625	14.912	Bad	0.67222222	Class II
3	8	14341.166	HG	HM	biota	1.51473951	H	L	H	M	H	Metals	0.625	14.912	Bad	0.67222222	Class II

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	4	1788.49803	PB	HM	biota	0.18007717	H	H	H	M	M	Metals	0.8	10.791	Bad	0.88055556	Class I
3	4	1788.49803	SBDE6	Org	biota	28.3999801	H	H	H	M	H	PBDEs	0.875	10.791	Bad	0.88055556	Class I
3	4	1788.49803	TEQDFP	Org	biota	0.26829431	H	H	H	H	H	Dioxins	1	10.791	Bad	0.88055556	Class I
3	4	1788.49803	SCB6	Org	biota	0.07580531	H	H	H	M	H	PCBs	0.875	10.791	Bad	0.88055556	Class I
3	4	1788.49803	PFOS	Org	biota	0.0787282	H	H	H	M	H	PFOS	0.875	10.791	Bad	0.88055556	Class I
3	4		CS137	Radioactive	biota	0.16132378	H	H	H	H	H	Radioactive	1	10.791	Bad	0.88055556	Class I
3	5	3518.64607	CD	HM	biota	1.38386042	M	L	H	L	H	Metals	0.45	40.91	Bad	0.59444444	Class II
3	5	3518.64607	HBCD	Org	biota	0.00155456	M	M	H	L	H	HBCD	0.575	40.91	Bad	0.59444444	Class II
3	5	3518.64607	HG	HM	biota	7.66476133	H	M	H	M	H	Metals	0.75	40.91	Bad	0.59444444	Class II
3	5	3518.64607	PB	HM	biota	0.15201398	L	M	H	L	M	Metals	0.45	40.91	Bad	0.59444444	Class II
3	5	3518.64607	SBDE6	Org	biota	112.431335	M	L	H	L	H	PBDEs	0.45	40.91	Bad	0.59444444	Class II
3	5	3518.64607	TEQDFP	Org	biota	0.38605252	L	M	H	M	H	Dioxins	0.65	40.91	Bad	0.59444444	Class II
3	5	3518.64607	SCB6	Org	biota	0.27005653	M	L	H	L	H	PCBs	0.45	40.91	Bad	0.59444444	Class II
3	5	3518.64607	PFOS	Org	biota	0.25782716	M	M	H	M	H	PFOS	0.7	40.91	Bad	0.59444444	Class II
3	5		CS137	Radioactive	biota	0.18107361	H	M	H	H	H	Radioactive	0.875	40.91	Bad	0.59444444	Class II
3	5		CS137	Radioactive	water	0.51846528	H	H	H	H	H	Radioactive	1	0.518	Good	1	Class I
3	6	6386.74258	CD	HM	biota	1.92001984	H	M	H	M	H	Metals	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	HBCD	Org	biota	0.00069224	H	M	H	M	H	HBCD	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	HG	HM	biota	1.2859348	H	M	H	M	H	Metals	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	PB	HM	biota	0.46887416	H	M	H	M	M	Metals	0.675	16.029	Bad	0.78333333	Class I
3	6	6386.74258	SBDE6	Org	biota	43.8197092	H	M	H	M	H	PBDEs	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	TEQDFP	Org	biota	0.25699878	H	M	H	H	H	Dioxins	0.875	16.029	Bad	0.78333333	Class I
3	6	6386.74258	SCB6	Org	biota	0.11892794	H	M	H	M	H	PCBs	0.75	16.029	Bad	0.78333333	Class I
3	6	6386.74258	PFOS	Org	biota	0.0349903	H	M	H	H	H	PFOS	0.875	16.029	Bad	0.78333333	Class I
3	6		CS137	Radioactive	biota	0.18107361	H	M	H	H	H	Radioactive	0.875	16.029	Bad	0.78333333	Class I
3	6		CS137	Radioactive	water	0.51846528	H	H	H	H	H	Radioactive	1	0.518	Good	1	Class I
3	7		CS137	Radioactive	biota	0.14994904	H	H	H	H	H	Radioactive	1	0.15	H	1	Class I
3	8	14341.166	CD	HM	biota	1.39104229	H	L	H	M	H	Metals	0.625	14.912	Bad	0.67222222	Class II
3	8	14341.166	HBCD	Org	biota	0.00116815	H	L	H	M	H	HBCD	0.625	14.912	Bad	0.67222222	Class II
3	8	14341.166	HG	HM	biota	1.51473951	H	L	H	M	H	Metals	0.625	14.912	Bad	0.67222222	Class II

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	8	14341.166	PB	HM	biota	0.20569662	H	L	H	M	M	Metals	0.55	14.912	Bad	0.67222222	Class II
3	8	14341.166	SBDE6	Org	biota	41.0007953	H	L	H	M	H	PBDEs	0.625	14.912	Bad	0.67222222	Class II
3	8	14341.166	TEQDFP	Org	biota	0.23816199	H	M	H	M	H	Dioxins	0.75	14.912	Bad	0.67222222	Class II
3	8	14341.166	SCB6	Org	biota	0.10948524	H	L	H	M	H	PCBs	0.625	14.912	Bad	0.67222222	Class II
3	8	14341.166	PFOS	Org	biota	0.12520569	H	L	H	M	H	PFOS	0.625	14.912	Bad	0.67222222	Class II
3	8		CS137	Radioactive	biota	0.14994904	H	H	H	H	H	Radioactive	1	14.912	Bad	0.67222222	Class II
3	9	3461.17674	CD	HM	biota	1.6319963	M	L	H	L	H	Metals	0.45	22.082	Bad	0.565625	Class II
3	9	3461.17674	HBCD	Org	biota	0.00061992	M	M	H	L	H	HBCD	0.575	22.082	Bad	0.565625	Class II
3	9	3461.17674	HG	HM	biota	1.97384677	M	M	H	L	H	Metals	0.575	22.082	Bad	0.565625	Class II
3	9	3461.17674	PB	HM	biota	0.39392488	M	M	H	L	M	Metals	0.5	22.082	Bad	0.565625	Class II
3	9	3461.17674	SBDE6	Org	biota	58.0434619	M	L	H	L	H	PBDEs	0.45	22.082	Bad	0.565625	Class II
3	9	3461.17674	TEQDFP	Org	biota	0.17323617	M	M	H	M	H	Dioxins	0.7	22.082	Bad	0.565625	Class II
3	9	3461.17674	SCB6	Org	biota	0.16529836	M	L	H	M	H	PCBs	0.575	22.082	Bad	0.565625	Class II
3	9	3461.17674	PFOS	Org	biota	0.07594815	M	M	H	M	H	PFOS	0.7	22.082	Bad	0.565625	Class II
3	9		CS137	Radioactive	water	0.47804167	H	L	H	H	H	Radioactive	0.75	0.478	H	0.75	Class I
3	10	1863.24516	CD	HM	water	0.08660254	M	H	H	M	H	Metals	0.825	2.62	M	0.7	Class II
3	10	1863.24516	CD	HM	biota	0.1875	L	M	H	L	H	Metals	0.525	7.559	Poor	0.53125	Class II
3	10	1863.24516	HBCD	Org	biota	0.00049728	L	M	H	L	H	HBCD	0.525	7.559	Poor	0.53125	Class II
3	10	1863.24516	HG	HM	biota	5.5	L	M	H	L	H	Metals	0.525	7.559	Poor	0.53125	Class II
3	10	1863.24516	PB	HM	biota	2.69230769	L	H	H	L	M	Metals	0.575	7.559	Poor	0.53125	Class II
3	10	1863.24516	PB	HM	water	0.05958436	M	H	H	L	H	Metals	0.7	2.62	M	0.7	Class II
3	10	1863.24516	SBDE6	Org	biota	12.5080214	L	M	H	L	H	PBDEs	0.525	7.559	Poor	0.53125	Class II
3	10	1863.24516	TEQDFP	Org	biota	0.33524245	L	M	H	L	H	Dioxins	0.525	7.559	Poor	0.53125	Class II
3	10	1863.24516	SCB6	Org	biota	0.10545455	L	M	H	L	H	PCBs	0.525	7.559	Poor	0.53125	Class II
3	10	1863.24516	PFOS	Org	biota	0.05164835	L	M	H	L	H	PFOS	0.525	7.559	Poor	0.53125	Class II
3	10	1863.24516	PFOS	Org	water	0.23458386	M	M	H	L	H	PFOS	0.575	2.62	M	0.7	Class II
3	10	1863.24516	TBSN+	Org	water	5	L	M	H	M	H	TBSN+	0.65	2.62	M	0.7	Class II
3	10		CS137	Radioactive	water	0.47804167	H	L	H	H	H	Radioactive	0.75	2.62	M	0.7	Class II
3	11	5739.21225	CD	HM	sediment	1.74039046	L	L	H	M	H	Metals	0.525	7.085	Poor	0.56071429	Class II
3	11	5739.21225	CD	HM	biota	1.16061538	H	H	H	M	H	Metals	0.875	11.963	Bad	0.81388889	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	11	228954635	CU	HM	sediment	0.87626539	L	H	H	M	H	Metals	0.775	7.085	Poor	0.56071429	Class II
3	11	5739.21225	HBCD	Org	biota	0.00294134	M	M	H	M	H	HBCD	0.7	11.963	Bad	0.81388889	Class I
3	11	5739.21225	HBCD	Org	sediment	0.00056238	L	M	H	L	H	HBCD	0.525	7.085	Poor	0.56071429	Class II
3	11	5739.21225	HG	HM	biota	3.93372967	H	M	H	H	H	Metals	0.875	11.963	Bad	0.81388889	Class I
3	11	5739.21225	ANT	Org	sediment	0.18568407	L	L	H	M	H	PAHs	0.525	7.085	Poor	0.56071429	Class II
3	11	5739.21225	FLU	Org	sediment	0.01739607	L	L	H	L	H	PAHs	0.4	7.085	Poor	0.56071429	Class II
3	11	5739.21225	PB	HM	biota	0.24115179	H	H	H	M	M	Metals	0.8	11.963	Bad	0.81388889	Class I
3	11	5739.21225	PB	HM	sediment	0.63392829	L	M	H	M	H	Metals	0.65	7.085	Poor	0.56071429	Class II
3	11	5739.21225	SBDE6	Org	biota	29.7066347	H	M	H	M	H	PBDEs	0.75	11.963	Bad	0.81388889	Class I
3	11	5739.21225	TEQDFP	Org	biota	0.35042824	M	M	H	H	H	Dioxins	0.825	11.963	Bad	0.81388889	Class I
3	11	5739.21225	SCB6	Org	biota	0.19943997	H	M	H	M	H	PCBs	0.75	11.963	Bad	0.81388889	Class I
3	11	5739.21225	PFOS	Org	biota	0.16834282	H	H	H	H	H	PFOS	1	11.963	Bad	0.81388889	Class I
3	11	5739.21225	TBSN+	Org	sediment	15.291937	L	M	H	L	H	TBSN+	0.525	7.085	Poor	0.56071429	Class II
3	11		CS137	Radioactive	biota	0.12705113	H	L	H	H	H	Radioactive	0.75	11.963	Bad	0.81388889	Class I
3	11		CS137	Radioactive	water	0.36435243	H	H	H	H	H	Radioactive	1	0.364	H	1	Class I
3	12	3676.91444	CD	HM	sediment	3.19980393	M	H	H	H	H	Metals	0.95	10.082	Bad	0.71785714	Class II
3	12	3676.91444	CD	HM	water	0.14089468	H	H	H	H	H	Metals	1	2.965	M	0.99	Class I
3	12	3676.91444	CD	HM	biota	0.19614998	H	L	H	M	H	Metals	0.625	12.551	Bad	0.71666667	Class II
3	12	3676914436	CU	HM	sediment	1.65298615	M	M	H	H	H	Metals	0.825	10.082	Bad	0.71785714	Class II
3	12	3676.91444	HBCD	Org	biota	0.00219469	M	H	H	M	H	HBCD	0.825	12.551	Bad	0.71666667	Class II
3	12	3676.91444	HG	HM	biota	4.38019788	M	M	H	M	H	Metals	0.7	12.551	Bad	0.71666667	Class II
3	12	3676.91444	ANT	Org	sediment	0.75175816	M	M	H	M	H	PAHs	0.7	10.082	Bad	0.71785714	Class II
3	12	3676.91444	FLU	Org	sediment	0.00515491	M	L	H	L	H	PAHs	0.45	10.082	Bad	0.71785714	Class II
3	12	3676.91444	PB	HM	biota	4.98312661	M	H	H	M	M	Metals	0.75	12.551	Bad	0.71666667	Class II
3	12	3676.91444	PB	HM	sediment	0.29094254	M	H	H	H	H	Metals	0.95	10.082	Bad	0.71785714	Class II
3	12	3676.91444	PB	HM	water	0.37269225	H	H	H	H	H	Metals	1	2.965	M	0.99	Class I
3	12	3676.91444	SBDE6	Org	biota	27.2954694	M	M	H	M	H	PBDEs	0.7	12.551	Bad	0.71666667	Class II
3	12	3676.91444	SBDE6	Org	sediment	0.00349204	H	M	H	L	H	PBDEs	0.625	10.082	Bad	0.71785714	Class II
3	12	3676.91444	TEQDFP	Org	biota	0.37379697	M	M	H	M	H	Dioxins	0.7	12.551	Bad	0.71666667	Class II
3	12	3676.91444	SCB6	Org	biota	0.17677289	M	M	H	M	H	PCBs	0.7	12.551	Bad	0.71666667	Class II

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	12	3676.91444	PFOS	Org	biota	0.11797866	M	M	H	M	H	PFOS	0.7	12.551	Bad	0.71666667	Class II
3	12	3676.91444	PFOS	Org	water	0.75287553	M	H	H	H	H	PFOS	0.95	2.965	M	0.99	Class I
3	12	3676.91444	TBSN+	Org	sediment	20.7716048	L	L	H	M	H	TBSN+	0.525	10.082	Bad	0.71785714	Class II
3	12	3676.91444	TBSN+	Org	water	5	H	H	H	H	H	TBSN+	1	2.965	M	0.99	Class I
3	12		CS137	Radioactive	biota	0.12705113	H	L	H	H	H	Radioactive	0.75	12.551	Bad	0.71666667	Class II
3	12		CS137	Radioactive	water	0.36435243	H	H	H	H	H	Radioactive	1	2.965	M	0.99	Class I
3	13		CS137	Radioactive	biota	0.12705113	H	L	H	H	H	Radioactive	0.75	0.127	H	0.75	Class I
3	13		CS137	Radioactive	water	0.36435243	H	H	H	H	H	Radioactive	1	0.364	H	1	Class I
3	14	8363.97994	CD	HM	sediment	1.15319335	M	M	H	H	H	Metals	0.825	1.766	M	0.53928571	Class II
3	14	8363.97994	CD	HM	water	0.12499459	M	Modeate	H	H	H	Metals		2.829	M	0.50625	Class II
3	14	8363.97994	CD	HM	biota	0.59145237	H	L	H	H	H	Metals	0.75	10.64	Bad	0.809375	Class I
3	14	8363979942	CU	HM	sediment	0.73836039	L	L	H	M	H	Metals	0.525	1.766	M	0.53928571	Class II
3	14	8363.97994	HBCD	Org	biota	0.00054167	M	M	H	M	H	HBCD	0.7	10.64	Bad	0.809375	Class I
3	14	8363.97994	HG	HM	biota	3.05564824	H	M	H	H	H	Metals	0.875	10.64	Bad	0.809375	Class I
3	14	8363.97994	ANT	Org	sediment	0.54824561	L	L	H	L	H	PAHs	0.4	1.766	M	0.53928571	Class II
3	14	8363.97994	FLU	Org	sediment	0.01052632	L	L	H	L	H	PAHs	0.4	1.766	M	0.53928571	Class II
3	14	8363.97994	PB	HM	biota	3.90455626	H	H	H	H	M	Metals	0.925	10.64	Bad	0.809375	Class I
3	14	8363.97994	PB	HM	sediment	0.19443494	M	M	H	H	H	Metals	0.825	1.766	M	0.53928571	Class II
3	14	8363.97994	PB	HM	water	0.19013464	M	M	H	L	H	Metals	0.575	2.829	M	0.50625	Class II
3	14	8363.97994	SBDE6	Org	biota	22.0207285	M	M	H	M	H	PBDEs	0.7	10.64	Bad	0.809375	Class I
3	14	8363.97994	SBDE6	Org	sediment	0.00254669	L	L	H	L	H	PBDEs	0.4	1.766	M	0.53928571	Class II
3	14	8363.97994	TEQDFP	Org	biota	0.35921071	M	M	H	H	H	Dioxins	0.825	10.64	Bad	0.809375	Class I
3	14	8363.97994	SCB6	Org	biota	0.09724824	H	M	H	H	H	PCBs	0.875	10.64	Bad	0.809375	Class I
3	14	8363.97994	PFOS	Org	biota	0.06468151	M	M	H	H	H	PFOS	0.825	10.64	Bad	0.809375	Class I
3	14	8363.97994	PFOS	Org	water	0.34386738	M	M	H	M	H	PFOS	0.7	2.829	M	0.50625	Class II
3	14	8363.97994	TBSN+	Org	sediment	2.0242915	L	L	H	L	H	TBSN+	0.4	1.766	M	0.53928571	Class II
3	14	8363.97994	TBSN+	Org	water	5	H	L	H	H	H	TBSN+	0.75	2.829	M	0.50625	Class II
3	15	1743.53763	CD	HM	biota	0.19791757	H	H	H	M	H	Metals	0.875	16.251	Bad	0.67916667	Class II
3	15	1743.53763	HG	HM	biota	1.62825732	H	H	H	M	H	Metals	0.875	16.251	Bad	0.67916667	Class II
3	15	1743.53763	PB	HM	biota	2.12734618	M	H	H	M	M	Metals	0.75	16.251	Bad	0.67916667	Class II

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	15	1743.53763	SBDE6	Org	biota	35.627081	L	M	H	L	H	PBDEs	0.525	16.251	Bad	0.67916667	Class II
3	15	1743.53763	SCB6	Org	biota	0.11735849	L	M	H	L	H	PCBs	0.525	16.251	Bad	0.67916667	Class II
3	15	1743.53763	PFOS	Org	biota	0.10989011	L	M	H	L	H	PFOS	0.525	16.251	Bad	0.67916667	Class II
3	16	8477.46905	CD	HM	biota	1.26783782	H	M	H	M	H	Metals	0.75	11.512	Bad	0.69545455	Class II
3	16	8477.46905	HBCD	Org	biota	0.00047655	H	L	H	M	H	HBCD	0.625	11.512	Bad	0.69545455	Class II
3	16	8477.46905	HG	HM	biota	1.18926017	H	M	H	M	H	Metals	0.75	11.512	Bad	0.69545455	Class II
3	16	8477.46905	FLU	Org	biota	0.01464365	M	L	H	H	H	PAHs	0.7	11.512	Bad	0.69545455	Class II
3	16	8477.46905	BAP	Org	biota	0.02654281	M	L	H	H	H	PAHs	0.7	11.512	Bad	0.69545455	Class II
3	16	8477.46905	PB	HM	biota	0.2374309	H	M	H	M	M	Metals	0.675	11.512	Bad	0.69545455	Class II
3	16	8477.46905	SBDE6	Org	biota	34.7329543	H	L	H	M	H	PBDEs	0.625	11.512	Bad	0.69545455	Class II
3	16	8477.46905	TEQDFP	Org	biota	0.33179957	M	M	H	M	H	Dioxins	0.7	11.512	Bad	0.69545455	Class II
3	16	8477.46905	SCB6	Org	biota	0.06901545	H	L	H	M	H	PCBs	0.625	11.512	Bad	0.69545455	Class II
3	16	8477.46905	PFOS	Org	biota	0.13171039	H	M	H	M	H	PFOS	0.75	11.512	Bad	0.69545455	Class II
3	16		CS137	Radioactive	biota	0.179	H	L	H	H	H	Radioactive	0.75	11.512	Bad	0.69545455	Class II
3	16		CS137	Radioactive	water	0.49208333	H	L	H	H	H	Radioactive	0.75	0.492	H	0.75	Class I
3	17	594.423263	CD	HM	water	0.35	L	H	H	L	H	Metals	0.65	2.826	M	0.67	Class II
3	17	594423263	CU	HM	sediment	0.37777778	L	H	H	M	H	Metals	0.775	1.63	M	0.6	Class II
3	17	594.423263	ANT	Org	sediment	0.69444444	L	M	H	L	H	PAHs	0.525	1.63	M	0.6	Class II
3	17	594.423263	FLU	Org	sediment	0.0047619	L	M	H	L	H	PAHs	0.525	1.63	M	0.6	Class II
3	17	594.423263	PB	HM	water	0.31538462	L	H	H	L	H	Metals	0.65	2.826	M	0.67	Class II
3	17	594.423263	SBDE6	Org	sediment	0.00322581	L	H	H	L	H	PBDEs	0.65	1.63	M	0.6	Class II
3	17	594.423263	PFOS	Org	water	0.23076923	L	M	H	L	H	PFOS	0.525	2.826	M	0.67	Class II
3	17	594.423263	TBSN+	Org	sediment	2.56410256	L	M	H	L	H	TBSN+	0.525	1.63	M	0.6	Class II
3	17	594.423263	TBSN+	Org	water	5	L	M	H	L	H	TBSN+	0.525	2.826	M	0.67	Class II
3	17		CS137	Radioactive	biota	0.16015278	H	L	H	H	H	Radioactive	0.75	0.16	H	0.75	Class I
3	17		CS137	Radioactive	water	0.42203164	H	H	H	H	H	Radioactive	1	2.826	M	0.67	Class II
3	18	549.698415	CD	HM	biota	0.49542274	H	H	H	M	H	Metals	0.875	14.254	Bad	0.71785714	Class II
3	18	549.698415	HG	HM	biota	2.13580028	H	H	H	M	H	Metals	0.875	14.254	Bad	0.71785714	Class II
3	18	549.698415	PB	HM	biota	1.94737055	L	H	H	L	M	Metals	0.575	14.254	Bad	0.71785714	Class II
3	18	549.698415	SBDE6	Org	biota	32.7142857	L	H	H	L	H	PBDEs	0.65	14.254	Bad	0.71785714	Class II

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	18	549.698415	SCB6	Org	biota	0.14857143	L	H	H	L	H	PCBs	0.65	14.254	Bad	0.71785714	Class II
3	18	549.698415	PFOS	Org	biota	0.10989011	L	H	H	L	H	PFOS	0.65	14.254	Bad	0.71785714	Class II
3	18		CS137	Radioactive	biota	0.16015278	H	L	H	H	H	Radioactive	0.75	14.254	Bad	0.71785714	Class II
3	18		CS137	Radioactive	water	0.42203164	H	H	H	H	H	Radioactive	1	0.422	H	1	Class I
3	19	622.417851	CD	HM	sediment	1.28297127	M	H	H	M	H	Metals	0.825	1.489	M	0.825	Class I
3	19	622.417851	CD	HM	water	0.5	M	H	H	H	H	Metals	0.95	3.709	M	0.955	Class I
3	19	622.417851	CD	HM	biota	0.19194726	H	H	H	H	H	Metals	1	1.895	M	0.91875	Class I
3	19	622.417851	HG	HM	biota	1.53704251	H	H	H	H	H	Metals	1	1.895	M	0.91875	Class I
3	19	622.417851	PB	HM	biota	1.90007874	H	H	H	H	M	Metals	0.925	1.895	M	0.91875	Class I
3	19	622.417851	PB	HM	sediment	0.82340584	M	H	H	M	H	Metals	0.825	1.489	M	0.825	Class I
3	19	622.417851	PB	HM	water	0.09314165	H	H	H	H	H	Metals	1	3.709	M	0.955	Class I
3	19	622.417851	PFOS	Org	water	4.27885728	H	H	H	M	H	PFOS	0.875	3.709	M	0.955	Class I
3	19	622.417851	TBSN+	Org	water	3	M	H	H	H	H	TBSN+	0.95	3.709	M	0.955	Class I
3	19		CS137	Radioactive	biota	0.16015278	H	L	H	H	H	Radioactive	0.75	1.895	M	0.91875	Class I
3	19		CS137	Radioactive	water	0.42203164	H	H	H	H	H	Radioactive	1	3.709	M	0.955	Class I
3	20		CS137	Radioactive	biota	0.16015278	H	L	H	H	H	Radioactive	0.75	0.16	H	0.75	Class I
3	20		CS137	Radioactive	water	0.42203164	H	H	H	H	H	Radioactive	1	0.422	H	1	Class I
3	21		CS137	Radioactive	biota	0.16015278	H	L	H	H	H	Radioactive	0.75	0.16	H	0.75	Class I
3	21		CS137	Radioactive	water	0.42203164	H	H	H	H	H	Radioactive	1	0.422	H	1	Class I
3	22	108.07867	CD	HM	water	0.25	L	H	H	L	H	Metals	0.65	0.74	Good	0.7375	Class II
3	22	108.07867	PB	HM	water	0.30769231	L	H	H	L	H	Metals	0.65	0.74	Good	0.7375	Class II
3	22	108.07867	TBSN+	Org	water	0.5	L	H	H	L	H	TBSN+	0.65	0.74	Good	0.7375	Class II
3	22		CS137	Radioactive	biota	0.16015278	H	L	H	H	H	Radioactive	0.75	0.16	H	0.75	Class I
3	22		CS137	Radioactive	water	0.42203164	H	H	H	H	H	Radioactive	1	0.74	Good	0.7375	Class II
3	23		CS137	Radioactive	biota	0.13306667	H	M	H	H	H	Radioactive	0.875	0.133	H	0.875	Class I
3	23		CS137	Radioactive	water	0.44411289	H	H	H	H	H	Radioactive	1	0.444	H	1	Class I
3	24	1604.63722	CD	HM	sediment	0.34939012	M	M	H	H	H	Metals	0.825	1.593	M	0.78333333	Class I
3	24	1604.63722	CD	HM	water	0.18515204	M	H	H	H	H	Metals	0.95	0.631	Good	0.94375	Class I
3	24	1604.63722	CD	HM	biota	0.8914763	H	H	H	M	H	Metals	0.875	5.151	Poor	0.66	Class II
3	24	1604637222	CU	HM	sediment	0.63217603	M	M	H	H	H	Metals	0.825	1.593	M	0.78333333	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	24	1604.63722	HBCD	Org	biota	0.00027786	H	M	H	L	H	HBCD	0.625	5.151	Poor	0.66	Class II
3	24	1604.63722	HG	HM	biota	1.15460596	H	M	H	M	H	Metals	0.75	5.151	Poor	0.66	Class II
3	24	1604.63722	FLU	Org	biota	0.01398501	M	L	H	L	H	PAHs	0.45	5.151	Poor	0.66	Class II
3	24	1604.63722	BAP	Org	biota	0.12278456	M	L	H	L	H	PAHs	0.45	5.151	Poor	0.66	Class II
3	24	1604.63722	ANT	Org	sediment	0.83382788	M	M	H	M	H	PAHs	0.7	1.593	M	0.78333333	Class I
3	24	1604.63722	FLU	Org	sediment	0.0182926	H	H	H	M	H	PAHs	0.875	1.593	M	0.78333333	Class I
3	24	1604.63722	PB	HM	biota	1.13655752	H	H	H	M	M	Metals	0.8	5.151	Poor	0.66	Class II
3	24	1604.63722	PB	HM	sediment	0.20173197	M	H	H	H	H	Metals	0.95	1.593	M	0.78333333	Class I
3	24	1604.63722	PB	HM	water	0.19751954	H	H	H	M	H	Metals	0.875	0.631	Good	0.94375	Class I
3	24	1604.63722	SBDE6	Org	biota	12.7533541	M	M	H	L	H	PBDEs	0.575	5.151	Poor	0.66	Class II
3	24	1604.63722	SCB6	Org	biota	0.05125395	M	M	H	L	H	PCBs	0.575	5.151	Poor	0.66	Class II
3	24	1604.63722	PFOS	Org	biota	0.03001763	H	M	H	L	H	PFOS	0.625	5.151	Poor	0.66	Class II
3	24	1604.63722	TBSN+	Org	sediment	1.86693382	L	L	H	M	H	TBSN+	0.525	1.593	M	0.78333333	Class I
3	24	1604.63722	TBSN+	Org	water	0.43497651	M	H	H	H	H	TBSN+	0.95	0.631	Good	0.94375	Class I
3	24		CS137	Radioactive	biota	0.13306667	H	M	H	H	H	Radioactive	0.875	5.151	Poor	0.66	Class II
3	24		CS137	Radioactive	water	0.44411289	H	H	H	H	H	Radioactive	1	0.631	Good	0.94375	Class I
3	25		CS137	Radioactive	biota	0.1469	H	M	H	H	H	Radioactive	0.875	0.147	H	0.875	Class I
3	25		CS137	Radioactive	water	0.47857884	H	H	H	H	H	Radioactive	1	0.479	H	1	Class I
3	26	891.065343	CD	HM	sediment	5.64715864	M	H	H	H	H	Metals	0.95	16.778	Bad	0.815	Class I
3	26	891.065343	CD	HM	water	0.16576157	H	H	H	H	H	Metals	1	0.737	Good	0.895	Class I
3	26	891.065343	CD	HM	biota	0.80751843	H	H	H	M	H	Metals	0.875	11.319	Bad	0.8275	Class I
3	26	891065343	CU	HM	sediment	1.36369408	M	H	H	H	H	Metals	0.95	16.778	Bad	0.815	Class I
3	26	891.065343	HBCD	Org	biota	0.00049959	H	H	H	M	H	HBCD	0.875	11.319	Bad	0.8275	Class I
3	26	891.065343	HG	HM	biota	1.3951739	H	H	H	M	H	Metals	0.875	11.319	Bad	0.8275	Class I
3	26	891.065343	FLU	Org	biota	0.00240704	M	M	H	L	H	PAHs	0.575	11.319	Bad	0.8275	Class I
3	26	891.065343	BAP	Org	biota	0.05716431	M	M	H	H	H	PAHs	0.825	11.319	Bad	0.8275	Class I
3	26	891.065343	FLU	Org	sediment	0.00504792	M	M	H	L	H	PAHs	0.575	16.778	Bad	0.815	Class I
3	26	891.065343	PB	HM	biota	1.53068759	H	H	H	M	M	Metals	0.8	11.319	Bad	0.8275	Class I
3	26	891.065343	PB	HM	sediment	1.75216839	M	H	H	H	H	Metals	0.95	16.778	Bad	0.815	Class I
3	26	891.065343	PB	HM	water	0.27710726	M	H	H	H	H	Metals	0.95	0.737	Good	0.895	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	26	891.065343	SBDE6	Org	biota	31.73684	H	H	H	M	H	PBDEs	0.875	11.319	Bad	0.8275	Class I
3	26	891.065343	SCB6	Org	biota	0.07966469	M	H	H	M	H	PCBs	0.825	11.319	Bad	0.8275	Class I
3	26	891.065343	PFOS	Org	biota	0.03782615	H	H	H	M	H	PFOS	0.875	11.319	Bad	0.8275	Class I
3	26	891.065343	PFOS	Org	water	0.51028151	L	M	H	L	H	PFOS	0.525	0.737	Good	0.895	Class I
3	26	891.065343	TBSN+	Org	sediment	28.7495418	L	M	H	M	H	TBSN+	0.65	16.778	Bad	0.815	Class I
3	26	891.065343	TBSN+	Org	water	0.21522395	H	H	H	H	H	TBSN+	1	0.737	Good	0.895	Class I
3	26		CS137	Radioactive	biota	0.1469	H	M	H	H	H	Radioactive	0.875	11.319	Bad	0.8275	Class I
3	26		CS137	Radioactive	water	0.47857884	H	H	H	H	H	Radioactive	1	0.737	Good	0.895	Class I
3	27		CS137	Radioactive	biota	0.1469	H	M	H	H	H	Radioactive	0.875	0.147	H	0.875	Class I
3	27		CS137	Radioactive	water	0.47857884	H	H	H	H	H	Radioactive	1	0.479	H	1	Class I
3	28	524.539399	CD	HM	water	0.22	L	H	H	M	H	Metals	0.775	0.86	Good	0.825	Class I
3	28	524.539399	CD	HM	biota	0.03173069	M	H	H	M	H	Metals	0.825	10.36	Bad	0.78888889	Class I
3	28	524.539399	HBCD	Org	biota	0.07435665	L	H	H	L	H	HBCD	0.65	10.36	Bad	0.78888889	Class I
3	28	524.539399	HG	HM	biota	1.9855641	H	H	H	M	H	Metals	0.875	10.36	Bad	0.78888889	Class I
3	28	524.539399	PB	HM	biota	0.06276841	H	H	H	M	M	Metals	0.8	10.36	Bad	0.78888889	Class I
3	28	524.539399	PB	HM	water	0.02206413	H	H	H	M	H	Metals	0.875	0.86	Good	0.825	Class I
3	28	524.539399	SBDE6	Org	biota	27.889005	L	H	H	L	H	PBDEs	0.65	10.36	Bad	0.78888889	Class I
3	28	524.539399	TEQDFP	Org	biota	0.58050754	L	H	H	M	H	Dioxins	0.775	10.36	Bad	0.78888889	Class I
3	28	524.539399	SCB6	Org	biota	0.14440969	M	H	H	M	H	PCBs	0.825	10.36	Bad	0.78888889	Class I
3	28	524.539399	PFOS	Org	biota	0.16358036	M	H	H	M	H	PFOS	0.825	10.36	Bad	0.78888889	Class I
3	28	524.539399	TBSN+	Org	water	1	L	M	H	M	H	TBSN+	0.65	0.86	Good	0.825	Class I
3	28		CS137	Radioactive	biota	0.1469	H	M	H	H	H	Radioactive	0.875	10.36	Bad	0.78888889	Class I
3	28		CS137	Radioactive	water	0.47857884	H	H	H	H	H	Radioactive	1	0.86	Good	0.825	Class I
3	29		CS137	Radioactive	biota	0.12483333	L	H	H	H	H	Radioactive	0.9	0.125	H	0.9	Class I
3	29		CS137	Radioactive	water	0.50342121	H	H	H	H	H	Radioactive	1	0.503	Good	1	Class I
3	30	1698.31113	CD	HM	biota	1.22707054	H	H	H	H	H	Metals	1	25.692	Bad	0.85909091	Class I
3	30	1698.31113	HBCD	Org	biota	0.00099955	M	M	H	L	H	HBCD	0.575	25.692	Bad	0.85909091	Class I
3	30	1698.31113	HG	HM	biota	2.49594573	H	H	H	H	H	Metals	1	25.692	Bad	0.85909091	Class I
3	30	1698.31113	FLU	Org	biota	0.07444286	H	H	H	H	H	PAHs	1	25.692	Bad	0.85909091	Class I
3	30	1698.31113	BAP	Org	biota	0.12156439	H	H	H	H	H	PAHs	1	25.692	Bad	0.85909091	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	30	1698.31113	PB	HM	biota	2.08642301	H	H	H	H	M	Metals	0.925	25.692	Bad	0.85909091	Class I
3	30	1698.31113	SBDE6	Org	biota	45.9631956	M	H	H	M	H	PBDEs	0.825	25.692	Bad	0.85909091	Class I
3	30	1698.31113	TEQDFP	Org	biota	32.8729369	L	M	H	L	H	Dioxins	0.525	25.692	Bad	0.85909091	Class I
3	30	1698.31113	SCB6	Org	biota	0.23546907	M	H	H	M	H	PCBs	0.825	25.692	Bad	0.85909091	Class I
3	30	1698.31113	PFOS	Org	biota	0.00931933	H	H	H	M	H	PFOS	0.875	25.692	Bad	0.85909091	Class I
3	30		CS137	Radioactive	biota	0.12483333	L	H	H	H	H	Radioactive	0.9	25.692	Bad	0.85909091	Class I
3	30		CS137	Radioactive	water	0.50342121	H	H	H	H	H	Radioactive	1	0.503	Good	1	Class I
3	31	2141.2936	CD	HM	water	0.21346266	H	H	H	H	H	Metals	1	0.812	Good	0.925	Class I
3	31	2141.2936	CD	HM	biota	0.08571456	H	H	H	M	H	Metals	0.875	42.167	Bad	0.725	Class II
3	31	2141.2936	HBCD	Org	biota	0.20098114	M	M	H	L	H	HBCD	0.575	42.167	Bad	0.725	Class II
3	31	2141.2936	HG	HM	biota	1.63639962	H	M	H	M	H	Metals	0.75	42.167	Bad	0.725	Class II
3	31	2141.2936	FLU	Org	biota	0.01997177	M	L	H	H	H	PAHs	0.7	42.167	Bad	0.725	Class II
3	31	2141.2936	BAP	Org	biota	0.06799769	L	L	H	M	H	PAHs	0.525	42.167	Bad	0.725	Class II
3	31	2141.2936	PB	HM	biota	0.12256624	H	H	H	M	M	Metals	0.8	42.167	Bad	0.725	Class II
3	31	2141.2936	PB	HM	water	0.06610275	H	H	H	H	H	Metals	1	0.812	Good	0.925	Class I
3	31	2141.2936	SBDE6	Org	biota	134.022926	M	M	H	L	H	PBDEs	0.575	42.167	Bad	0.725	Class II
3	31	2141.2936	TEQDFP	Org	biota	3.32568099	M	M	H	M	H	Dioxins	0.7	42.167	Bad	0.725	Class II
3	31	2141.2936	SCB6	Org	biota	0.16634571	H	H	H	M	H	PCBs	0.875	42.167	Bad	0.725	Class II
3	31	2141.2936	PFOS	Org	biota	0.07748669	M	M	H	M	H	PFOS	0.7	42.167	Bad	0.725	Class II
3	31	2141.2936	TBSN+	Org	water	0.84089642	M	M	H	M	H	TBSN+	0.7	0.812	Good	0.925	Class I
3	31		CS137	Radioactive	biota	0.12483333	L	H	H	H	H	Radioactive	0.9	42.167	Bad	0.725	Class II
3	31		CS137	Radioactive	water	0.50342121	H	H	H	H	H	Radioactive	1	0.812	Good	0.925	Class I
3	32	854.313797	CD	HM	water	0.17422174	H	H	H	H	H	Metals	1	1.865	M	0.895	Class I
3	32	854.313797	CD	HM	biota	0.23986583	H	H	H	H	H	Metals	1	18.859	Bad	0.885	Class I
3	32	854.313797	HBCD	Org	biota	0.03149361	M	H	H	L	H	HBCD	0.7	18.859	Bad	0.885	Class I
3	32	854.313797	HG	HM	biota	1.15652942	H	H	H	H	H	Metals	1	18.859	Bad	0.885	Class I
3	32	854.313797	FLU	Org	biota	0.04926222	H	H	H	H	H	PAHs	1	18.859	Bad	0.885	Class I
3	32	854.313797	BAP	Org	biota	0.03899376	H	M	H	H	H	PAHs	0.875	18.859	Bad	0.885	Class I
3	32	854.313797	PB	HM	biota	0.39700196	H	H	H	H	M	Metals	0.925	18.859	Bad	0.885	Class I
3	32	854.313797	PB	HM	water	0.17157627	H	H	H	H	H	Metals	1	1.865	M	0.895	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	32	854.313797	SBDE6	Org	biota	55.4159215	M	H	H	M	H	PBDEs	0.825	18.859	Bad	0.885	Class I
3	32	854.313797	TEQDFP	Org	biota	1.91961074	M	H	H	M	H	Dioxins	0.825	18.859	Bad	0.885	Class I
3	32	854.313797	SCB6	Org	biota	0.32212881	H	H	H	M	H	PCBs	0.875	18.859	Bad	0.885	Class I
3	32	854.313797	PFOS	Org	biota	0.06710332	M	H	H	M	H	PFOS	0.825	18.859	Bad	0.885	Class I
3	32	854.313797	PFOS	Org	water	2.46153846	L	M	H	L	H	PFOS	0.525	1.865	M	0.895	Class I
3	32	854.313797	TBSN+	Org	water	0.90125046	M	H	H	H	H	TBSN+	0.95	1.865	M	0.895	Class I
3	32		CS137	Radioactive	water	0.46183667	H	H	H	H	H	Radioactive	1	1.865	M	0.895	Class I
3	33	285.653304	CD	HM	biota	1.21044549	H	H	H	M	H	Metals	0.875	1.943	M	0.84	Class I
3	33	285.653304	HG	HM	biota	1.41166053	H	H	H	M	H	Metals	0.875	1.943	M	0.84	Class I
3	33	285.653304	FLU	Org	biota	0.03874019	M	H	H	H	H	PAHs	0.95	1.943	M	0.84	Class I
3	33	285.653304	BAP	Org	biota	0.05232529	M	M	H	M	H	PAHs	0.7	1.943	M	0.84	Class I
3	33	285.653304	PB	HM	biota	1.63080917	H	H	H	M	M	Metals	0.8	1.943	M	0.84	Class I
3	33		CS137	Radioactive	water	0.46183667	H	H	H	H	H	Radioactive	1	0.462	H	1	Class I
3	34		CS137	Radioactive	biota	0.03595	L	M	H	H	H	Radioactive	0.775	0.036	H	0.775	Class I
3	34		CS137	Radioactive	water	0.4304437	H	H	H	H	H	Radioactive	1	0.43	H	1	Class I
3	35	685.251294	CD	HM	water	0.1323141	H	H	H	H	H	Metals	1	0.985	Good	0.925	Class I
3	35	685.251294	CD	HM	biota	0.723924	M	H	H	L	H	Metals	0.7	1.151	M	0.62916667	Class II
3	35	685.251294	HG	HM	biota	0.9769871	H	M	H	L	H	Metals	0.625	1.151	M	0.62916667	Class II
3	35	685.251294	FLU	Org	biota	0.2007486	L	M	H	L	H	PAHs	0.525	1.151	M	0.62916667	Class II
3	35	685.251294	BAP	Org	biota	0.2	L	M	H	L	H	PAHs	0.525	1.151	M	0.62916667	Class II
3	35	685.251294	ANT	Org	sediment	3.8174128	M	H	H	H	H	PAHs	0.95	45.444	Bad	0.925	Class I
3	35	685.251294	FLU	Org	sediment	0.17143181	H	H	H	M	H	PAHs	0.875	45.444	Bad	0.925	Class I
3	35	685.251294	PB	HM	biota	0.68207299	M	H	H	L	M	Metals	0.625	1.151	M	0.62916667	Class II
3	35	685.251294	PB	HM	water	0.13937332	H	H	H	H	H	Metals	1	0.985	Good	0.925	Class I
3	35	685.251294	PFOS	Org	water	1.26864789	M	H	H	L	H	PFOS	0.7	0.985	Good	0.925	Class I
3	35	685.251294	TBSN+	Org	sediment	74.7223691	M	H	H	H	H	TBSN+	0.95	45.444	Bad	0.925	Class I
3	35		CS137	Radioactive	biota	0.03595	L	M	H	H	H	Radioactive	0.775	1.151	M	0.62916667	Class II
3	35		CS137	Radioactive	water	0.4304437	H	H	H	H	H	Radioactive	1	0.985	Good	0.925	Class I
3	36	8693.19429	CD	HM	sediment	0.65495002	M	M	H	H	H	Metals	0.825	13.792	Bad	0.83333333	Class I
3	36	8693.19429	CD	HM	water	0.14142136	L	L	H	M	H	Metals	0.525	1.818	M	0.55	Class II

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	36	8693.19429	CD	HM	biota	0.82453644	H	H	H	H	H	Metals	1	8.783	Poor	0.975	Class I
3	36	8693194288	CU	HM	sediment	1.17719644	M	M	H	H	H	Metals	0.825	13.792	Bad	0.83333333	Class I
3	36	8693.19429	HBCD	Org	biota	0.00144338	H	H	H	H	H	HBCD	1	8.783	Poor	0.975	Class I
3	36	8693.19429	HG	HM	biota	0.78384715	H	H	H	H	H	Metals	1	8.783	Poor	0.975	Class I
3	36	8693.19429	FLU	Org	biota	0.10462355	H	H	H	H	H	PAHs	1	8.783	Poor	0.975	Class I
3	36	8693.19429	BAP	Org	biota	0.09281388	H	H	H	H	H	PAHs	1	8.783	Poor	0.975	Class I
3	36	8693.19429	ANT	Org	sediment	1.47339702	M	H	H	H	H	PAHs	0.95	13.792	Bad	0.83333333	Class I
3	36	8693.19429	FLU	Org	sediment	0.05805764	H	M	H	M	H	PAHs	0.75	13.792	Bad	0.83333333	Class I
3	36	8693.19429	PB	HM	biota	0.91786093	H	H	H	H	M	Metals	0.925	8.783	Poor	0.975	Class I
3	36	8693.19429	PB	HM	sediment	0.30958012	M	H	H	H	H	Metals	0.95	13.792	Bad	0.83333333	Class I
3	36	8693.19429	PB	HM	water	0.10878566	L	L	H	L	H	Metals	0.4	1.818	M	0.55	Class II
3	36	8693.19429	SBDE6	Org	biota	24.39952	H	H	H	H	H	PBDEs	1	8.783	Poor	0.975	Class I
3	36	8693.19429	TEQDFP	Org	biota	0.34089427	M	M	H	H	H	Dioxins	0.825	8.783	Poor	0.975	Class I
3	36	8693.19429	SCB6	Org	biota	0.29372326	H	H	H	H	H	PCBs	1	8.783	Poor	0.975	Class I
3	36	8693.19429	PFOS	Org	biota	0.01574246	H	H	H	H	H	PFOS	1	8.783	Poor	0.975	Class I
3	36	8693.19429	PFOS	Org	water	3.00886265	L	L	H	L	H	PFOS	0.4	1.818	M	0.55	Class II
3	36	8693.19429	TBSN+	Org	sediment	30.1105742	M	L	H	H	H	TBSN+	0.7	13.792	Bad	0.83333333	Class I
3	36		CS137	Radioactive	water	0.37622118	H	M	H	H	H	Radioactive	0.875	1.818	M	0.55	Class II
3	37		CS137	Radioactive	water	0.42745833	H	M	H	H	H	Radioactive	0.875	0.427	H	0.875	Class I
3	38	320.756213	CD	HM	biota	0.28425774	H	H	H	H	H	Metals	1	69.527	Bad	0.9025	Class I
3	38	320.756213	HBCD	Org	biota	0.00129571	M	H	H	L	H	HBCD	0.7	69.527	Bad	0.9025	Class I
3	38	320.756213	HG	HM	biota	5.63366407	H	H	H	H	H	Metals	1	69.527	Bad	0.9025	Class I
3	38	320.756213	FLU	Org	biota	0.07736727	H	H	H	H	H	PAHs	1	69.527	Bad	0.9025	Class I
3	38	320.756213	BAP	Org	biota	0.11467561	H	H	H	H	H	PAHs	1	69.527	Bad	0.9025	Class I
3	38	320.756213	PB	HM	biota	1.13937761	H	H	H	H	M	Metals	0.925	69.527	Bad	0.9025	Class I
3	38	320.756213	SBDE6	Org	biota	78.6446147	H	H	H	M	H	PBDEs	0.875	69.527	Bad	0.9025	Class I
3	38	320.756213	TEQDFP	Org	biota	133.31151	M	H	H	M	H	Dioxins	0.825	69.527	Bad	0.9025	Class I
3	38	320.756213	SCB6	Org	biota	0.64493654	M	H	H	L	H	PCBs	0.7	69.527	Bad	0.9025	Class I
3	38	320.756213	PFOS	Org	biota	0.01223792	H	H	H	H	H	PFOS	1	69.527	Bad	0.9025	Class I
3	38		CS137	Radioactive	water	0.42745833	H	M	H	H	H	Radioactive	0.875	0.427	H	0.875	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	39	2305.44946	CD	HM	biota	0.5302454	H	M	H	L	H	Metals	0.625	0.629	Good	0.62916667	Class II
3	39	2305.44946	HG	HM	biota	0.31524188	H	M	H	L	H	Metals	0.625	0.629	Good	0.62916667	Class II
3	39	2305.44946	FLU	Org	biota	0.01675561	M	L	H	M	H	PAHs	0.575	0.629	Good	0.62916667	Class II
3	39	2305.44946	BAP	Org	biota	0.01144337	M	L	H	H	H	PAHs	0.7	0.629	Good	0.62916667	Class II
3	39	2305.44946	PB	HM	biota	0.63765958	M	M	H	L	M	Metals	0.5	0.629	Good	0.62916667	Class II
3	39		CS137	Radioactive	biota	0.02887625	H	L	H	H	H	Radioactive	0.75	0.629	Good	0.62916667	Class II
3	39		CS137	Radioactive	water	0.30939838	H	H	H	H	H	Radioactive	1	0.309	H	1	Class I
3	40	6299.16514	CD	HM	sediment	0.32871638	M	M	H	M	H	Metals	0.7	3.265	M	0.7	Class II
3	40	6299.16514	CD	HM	biota	0.60262937	H	H	H	H	H	Metals	1	7.131	Poor	0.96136364	Class I
3	40	6299165136	CU	HM	sediment	0.86531594	M	M	H	H	H	Metals	0.825	3.265	M	0.7	Class II
3	40	6299.16514	HBCD	Org	biota	0.00112345	H	H	H	H	H	HBCD	1	7.131	Poor	0.96136364	Class I
3	40	6299.16514	HG	HM	biota	1.06253688	H	H	H	H	H	Metals	1	7.131	Poor	0.96136364	Class I
3	40	6299.16514	FLU	Org	biota	0.07764463	H	H	H	H	H	PAHs	1	7.131	Poor	0.96136364	Class I
3	40	6299.16514	BAP	Org	biota	0.09301143	H	H	H	H	H	PAHs	1	7.131	Poor	0.96136364	Class I
3	40	6299.16514	ANT	Org	sediment	1.90279642	M	L	H	M	H	PAHs	0.575	3.265	M	0.7	Class II
3	40	6299.16514	FLU	Org	sediment	0.10105771	M	M	H	M	H	PAHs	0.7	3.265	M	0.7	Class II
3	40	6299.16514	PB	HM	biota	1.04095843	H	H	H	H	M	Metals	0.925	7.131	Poor	0.96136364	Class I
3	40	6299.16514	PB	HM	sediment	0.36924814	M	M	H	H	H	Metals	0.825	3.265	M	0.7	Class II
3	40	6299.16514	SBDE6	Org	biota	20.4575684	M	H	H	H	H	PBDEs	0.95	7.131	Poor	0.96136364	Class I
3	40	6299.16514	TEQDFP	Org	biota	0.12040408	M	H	H	H	H	Dioxins	0.95	7.131	Poor	0.96136364	Class I
3	40	6299.16514	SCB6	Org	biota	0.14434921	H	H	H	H	H	PCBs	1	7.131	Poor	0.96136364	Class I
3	40	6299.16514	PFOS	Org	biota	0.02271509	H	H	H	H	H	PFOS	1	7.131	Poor	0.96136364	Class I
3	40	6299.16514	TBSN+	Org	sediment	4.4301504	M	L	H	M	H	TBSN+	0.575	3.265	M	0.7	Class II
3	40		CS137	Radioactive	biota	0.02887625	H	L	H	H	H	Radioactive	0.75	7.131	Poor	0.96136364	Class I
3	40		CS137	Radioactive	water	0.30939838	H	H	H	H	H	Radioactive	1	0.309	H	1	Class I
3	SEA-001	15334.4041	CD	HM	sediment	0.03658334	M	L	H	M	H	Metals	0.575	1.69	M	0.646875	Class II
3	SEA-001	15334.4041	CD	HM	biota	0.77739144	H	M	H	M	H	Metals	0.75	8.806	Poor	0.76944444	Class I
3	SEA-001	1.5334E+10	CU	HM	sediment	1.06141413	M	L	H	H	H	Metals	0.7	1.69	M	0.646875	Class II
3	SEA-001	15334.4041	HBCD	Org	biota	0.00031875	H	H	H	M	H	HBCD	0.875	8.806	Poor	0.76944444	Class I
3	SEA-001	15334.4041	HBCD	Org	sediment	0.00010088	L	M	H	L	H	HBCD	0.525	1.69	M	0.646875	Class II

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-001	15334.4041	HG	HM	biota	2.0886968	H	M	H	M	H	Metals	0.75	8.806	Poor	0.76944444	Class I
3	SEA-001	15334.4041	ANT	Org	sediment	0.55845067	M	M	H	M	H	PAHs	0.7	1.69	M	0.646875	Class II
3	SEA-001	15334.4041	FLU	Org	sediment	0.04503886	M	M	H	M	H	PAHs	0.7	1.69	M	0.646875	Class II
3	SEA-001	15334.4041	PB	HM	biota	0.53337379	H	M	H	M	M	Metals	0.675	8.806	Poor	0.76944444	Class I
3	SEA-001	15334.4041	PB	HM	sediment	0.3082656	H	M	H	H	H	Metals	0.875	1.69	M	0.646875	Class II
3	SEA-001	15334.4041	SBDE6	Org	biota	22.8009446	H	M	H	M	H	PBDEs	0.75	8.806	Poor	0.76944444	Class I
3	SEA-001	15334.4041	SBDE6	Org	sediment	0.00034324	L	M	H	L	H	PBDEs	0.525	1.69	M	0.646875	Class II
3	SEA-001	15334.4041	TEQDFP	Org	biota	0.08215817	H	H	H	M	H	Dioxins	0.875	8.806	Poor	0.76944444	Class I
3	SEA-001	15334.4041	SCB6	Org	biota	0.09351051	H	M	H	M	H	PCBs	0.75	8.806	Poor	0.76944444	Class I
3	SEA-001	15334.4041	PFOS	Org	biota	0.01419068	H	M	H	M	H	PFOS	0.75	8.806	Poor	0.76944444	Class I
3	SEA-001	15334.4041	TBSN+	Org	sediment	2.77026354	M	L	H	M	H	TBSN+	0.575	1.69	M	0.646875	Class II
3	SEA-001		CS137	Radioactive	biota	0.02887625	H	L	H	H	H	Radioactive	0.75	8.806	Poor	0.76944444	Class I
3	SEA-001		CS137	Radioactive	water	0.30939838	H	H	H	H	H	Radioactive	1	0.309	H	1	Class I
3	SEA-002	2022.45993	CD	HM	biota	0.88659579	M	H	H	M	H	Metals	0.825	1.411	M	0.82	Class I
3	SEA-002	2022.45993	HG	HM	biota	0.55390823	H	H	H	M	H	Metals	0.875	1.411	M	0.82	Class I
3	SEA-002	2022.45993	FLU	Org	biota	0.09037588	M	H	H	M	H	PAHs	0.825	1.411	M	0.82	Class I
3	SEA-002	2022.45993	BAP	Org	biota	0.09448956	M	H	H	M	H	PAHs	0.825	1.411	M	0.82	Class I
3	SEA-002	2022.45993	PB	HM	biota	1.53044845	M	H	H	M	M	Metals	0.75	1.411	M	0.82	Class I
3	SEA-002		CS137	Radioactive	water	0.37622118	H	M	H	H	H	Radioactive	0.875	0.376	H	0.875	Class I
3	SEA-003	435.483056	CD	HM	biota	1.47792882	M	H	H	L	H	Metals	0.7	13.43	Bad	0.740625	Class II
3	SEA-003	435.483056	HG	HM	biota	3.62236284	H	H	H	M	H	Metals	0.875	13.43	Bad	0.740625	Class II
3	SEA-003	435.483056	FLU	Org	biota	0.05531114	M	H	H	M	H	PAHs	0.825	13.43	Bad	0.740625	Class II
3	SEA-003	435.483056	BAP	Org	biota	0.08004932	M	H	H	H	H	PAHs	0.95	13.43	Bad	0.740625	Class II
3	SEA-003	435.483056	PB	HM	biota	3.86202809	M	H	H	L	M	Metals	0.625	13.43	Bad	0.740625	Class II
3	SEA-003	435.483056	SBDE6	Org	biota	28.7457057	L	H	H	L	H	PBDEs	0.65	13.43	Bad	0.740625	Class II
3	SEA-003	435.483056	SCB6	Org	biota	0.11044895	L	H	H	L	H	PCBs	0.65	13.43	Bad	0.740625	Class II
3	SEA-003	435.483056	PFOS	Org	biota	0.03296703	L	H	H	L	H	PFOS	0.65	13.43	Bad	0.740625	Class II
3	SEA-003		CS137	Radioactive	water	0.42745833	H	M	H	H	H	Radioactive	0.875	0.427	H	0.875	Class I
3	SEA-004	2745.76952	CD	HM	sediment	0.16321488	H	H	H	H	H	Metals	1	3.113	M	0.89	Class I
3	SEA-004	2745.76952	CD	HM	water	0.15842751	M	H	H	H	H	Metals	0.95	0.377	H	0.88333333	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-004	2745.76952	CD	HM	biota	1.12209671	M	M	H	L	H	Metals	0.575	3.287	M	0.66875	Class II
3	SEA-004	2745.76952	HG	HM	biota	3.19680091	M	H	H	L	H	Metals	0.7	3.287	M	0.66875	Class II
3	SEA-004	2745.76952	ANT	Org	sediment	1.45599762	H	H	H	M	H	PAHs	0.875	3.113	M	0.89	Class I
3	SEA-004	2745.76952	FLU	Org	sediment	0.05249704	H	H	H	M	H	PAHs	0.875	3.113	M	0.89	Class I
3	SEA-004	2745.76952	PB	HM	biota	2.21908728	M	H	H	L	M	Metals	0.625	3.287	M	0.66875	Class II
3	SEA-004	2745.76952	PB	HM	sediment	0.51564385	H	H	H	H	H	Metals	1	3.113	M	0.89	Class I
3	SEA-004	2745.76952	PB	HM	water	0.06338237	M	H	H	L	H	Metals	0.7	0.377	H	0.88333333	Class I
3	SEA-004	2745.76952	TBSN+	Org	sediment	4.77450293	M	M	H	M	H	TBSN+	0.7	3.113	M	0.89	Class I
3	SEA-004		CS137	Radioactive	biota	0.03595	L	M	H	H	H	Radioactive	0.775	3.287	M	0.66875	Class II
3	SEA-004		CS137	Radioactive	water	0.4304437	H	H	H	H	H	Radioactive	1	0.377	H	0.88333333	Class I
3	SEA-005	3505.56941	CD	HM	sediment	0.19697902	M	M	H	M	H	Metals	0.7	3.748	M	0.93	Class I
3	SEA-005	3505.56941	CD	HM	water	0.1423789	M	H	H	H	H	Metals	0.95	0.818	Good	0.9	Class I
3	SEA-005	3505.56941	CD	HM	biota	1.36192909	M	M	H	L	H	Metals	0.575	1.491	M	0.66	Class II
3	SEA-005	3505.56941	HG	HM	biota	0.4441146	M	M	H	L	H	Metals	0.575	1.491	M	0.66	Class II
3	SEA-005	3505.56941	FLU	Org	biota	0.05554675	M	M	H	H	H	PAHs	0.825	1.491	M	0.66	Class II
3	SEA-005	3505.56941	BAP	Org	biota	0.02542909	M	M	H	M	H	PAHs	0.7	1.491	M	0.66	Class II
3	SEA-005	3505.56941	ANT	Org	sediment	1.36703308	H	H	H	H	H	PAHs	1	3.748	M	0.93	Class I
3	SEA-005	3505.56941	FLU	Org	sediment	0.06648402	H	H	H	H	H	PAHs	1	3.748	M	0.93	Class I
3	SEA-005	3505.56941	PB	HM	biota	1.44727334	M	H	H	L	M	Metals	0.625	1.491	M	0.66	Class II
3	SEA-005	3505.56941	PB	HM	sediment	0.66381568	H	H	H	H	H	Metals	1	3.748	M	0.93	Class I
3	SEA-005	3505.56941	PB	HM	water	0.03243116	H	H	H	M	H	Metals	0.875	0.818	Good	0.9	Class I
3	SEA-005	3505.56941	TBSN+	Org	sediment	6.08757303	M	H	H	H	H	TBSN+	0.95	3.748	M	0.93	Class I
3	SEA-005	3505.56941	TBSN+	Org	water	1	L	H	H	M	H	TBSN+	0.775	0.818	Good	0.9	Class I
3	SEA-005		CS137	Radioactive	water	0.46183667	H	H	H	H	H	Radioactive	1	0.818	Good	0.9	Class I
3	SEA-006	13548.1698	CD	HM	sediment	0.19502986	H	M	H	H	H	Metals	0.875	2.431	M	0.8125	Class I
3	SEA-006	13548.1698	CD	HM	water	0.04830557	H	M	H	H	H	Metals	0.875	0.699	Good	0.89375	Class I
3	SEA-006	13548.1698	CD	HM	biota	1.22063335	H	H	H	H	H	Metals	1	13.789	Bad	0.91136364	Class I
3	SEA-006	1.3548E+10	CU	HM	sediment	1.36187133	M	L	H	H	H	Metals	0.7	2.431	M	0.8125	Class I
3	SEA-006	13548.1698	HBCD	Org	biota	0.00160253	H	H	H	M	H	HBCD	0.875	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	HBCD	Org	sediment	0.0004257	L	M	H	L	H	HBCD	0.525	2.431	M	0.8125	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-006	13548.1698	HG	HM	biota	1.10269793	H	H	H	H	H	Metals	1	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	FLU	Org	biota	0.05327372	H	M	H	H	H	PAHs	0.875	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	BAP	Org	biota	0.07411262	M	H	H	H	H	PAHs	0.95	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	ANT	Org	sediment	0.70077774	H	H	H	H	H	PAHs	1	2.431	M	0.8125	Class I
3	SEA-006	13548.1698	FLU	Org	sediment	0.05795055	H	H	H	H	H	PAHs	1	2.431	M	0.8125	Class I
3	SEA-006	13548.1698	PB	HM	biota	0.7572942	H	H	H	H	M	Metals	0.925	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	PB	HM	sediment	0.91599315	H	H	H	H	H	Metals	1	2.431	M	0.8125	Class I
3	SEA-006	13548.1698	PB	HM	water	0.00466901	H	M	H	H	H	Metals	0.875	0.699	Good	0.89375	Class I
3	SEA-006	13548.1698	SBDE6	Org	biota	42.0214387	H	M	H	M	H	PBDEs	0.75	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	SBDE6	Org	sediment	0.00025361	L	M	H	L	H	PBDEs	0.525	2.431	M	0.8125	Class I
3	SEA-006	13548.1698	TEQDFP	Org	biota	0.16321755	H	H	H	M	H	Dioxins	0.875	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	SCB6	Org	biota	0.18454139	H	H	H	H	H	PCBs	1	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	PFOS	Org	biota	0.02990626	H	M	H	H	H	PFOS	0.875	13.789	Bad	0.91136364	Class I
3	SEA-006	13548.1698	TBSN+	Org	sediment	3.64351578	H	M	H	H	H	TBSN+	0.875	2.431	M	0.8125	Class I
3	SEA-006	13548.1698	TBSN+	Org	water	0.84089642	M	H	H	M	H	TBSN+	0.825	0.699	Good	0.89375	Class I
3	SEA-006		CS137	Radioactive	biota	0.12483333	L	H	H	H	H	Radioactive	0.9	13.789	Bad	0.91136364	Class I
3	SEA-006		CS137	Radioactive	water	0.50342121	H	H	H	H	H	Radioactive	1	0.699	Good	0.89375	Class I
3	SEA-007	38898.2316	CD	HM	sediment	0.59877036	H	M	H	H	H	Metals	0.875	2.448	M	0.7875	Class I
3	SEA-007	38898.2316	CD	HM	water	0.16234498	H	M	H	H	H	Metals	0.875	0.69	Good	0.8625	Class I
3	SEA-007	38898.2316	CD	HM	biota	2.18292136	H	H	H	H	H	Metals	1	8.774	Poor	0.87045455	Class I
3	SEA-007	3.8898E+10	CU	HM	sediment	1.69087211	H	M	H	H	H	Metals	0.875	2.448	M	0.7875	Class I
3	SEA-007	38898.2316	HBCD	Org	biota	0.00047482	H	H	H	H	H	HBCD	1	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	HBCD	Org	sediment	2.5907E-05	L	L	H	L	H	HBCD	0.4	2.448	M	0.7875	Class I
3	SEA-007	38898.2316	HG	HM	biota	0.80571049	H	M	H	H	H	Metals	0.875	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	FLU	Org	biota	0.01730884	M	L	H	H	H	PAHs	0.7	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	BAP	Org	biota	0.02733756	M	L	H	H	H	PAHs	0.7	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	ANT	Org	sediment	0.27559306	H	M	H	H	H	PAHs	0.875	2.448	M	0.7875	Class I
3	SEA-007	38898.2316	FLU	Org	sediment	0.01963129	H	H	H	H	H	PAHs	1	2.448	M	0.7875	Class I
3	SEA-007	38898.2316	PB	HM	biota	0.99454912	H	M	H	H	M	Metals	0.8	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	PB	HM	sediment	0.59317131	H	H	H	H	H	Metals	1	2.448	M	0.7875	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-007	38898.2316	PB	HM	water	0.12949957	H	M	H	M	H	Metals	0.75	0.69	Good	0.8625	Class I
3	SEA-007	38898.2316	SBDE6	Org	biota	24.6172127	H	M	H	H	H	PBDEs	0.875	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	SBDE6	Org	sediment	0.00025043	L	L	H	L	H	PBDEs	0.4	2.448	M	0.7875	Class I
3	SEA-007	38898.2316	TEQDFP	Org	biota	0.19535787	H	H	H	H	H	Dioxins	1	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	SCB6	Org	biota	0.06070624	H	M	H	H	H	PCBs	0.875	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	PFOS	Org	biota	0.05324433	H	M	H	H	H	PFOS	0.875	8.774	Poor	0.87045455	Class I
3	SEA-007	38898.2316	TBSN+	Org	sediment	3.74682085	H	M	H	H	H	TBSN+	0.875	2.448	M	0.7875	Class I
3	SEA-007	38898.2316	TBSN+	Org	water	0.60950683	M	M	H	H	H	TBSN+	0.825	0.69	Good	0.8625	Class I
3	SEA-007		CS137	Radioactive	biota	0.1469	H	M	H	H	H	Radioactive	0.875	8.774	Poor	0.87045455	Class I
3	SEA-007		CS137	Radioactive	water	0.47857884	H	H	H	H	H	Radioactive	1	0.69	Good	0.8625	Class I
3	SEA-008	3650.84073	CD	HM	sediment	1.28409407	L	M	H	L	H	Metals	0.525	4.083	M	0.725	Class II
3	SEA-008	3650.84073	CD	HM	biota	0.844236	M	M	H	L	H	Metals	0.575	12.911	Bad	0.65625	Class II
3	SEA-008	3650840732	CU	HM	sediment	1.2350446	M	M	H	H	H	Metals	0.825	4.083	M	0.725	Class II
3	SEA-008	3650.84073	HBCD	Org	biota	0.00104189	M	H	H	L	H	HBCD	0.7	12.911	Bad	0.65625	Class II
3	SEA-008	3650.84073	HG	HM	biota	2.55227019	M	M	H	L	H	Metals	0.575	12.911	Bad	0.65625	Class II
3	SEA-008	3650.84073	ANT	Org	sediment	0.49041448	M	H	H	M	H	PAHs	0.825	4.083	M	0.725	Class II
3	SEA-008	3650.84073	FLU	Org	sediment	0.00700424	H	H	H	M	H	PAHs	0.875	4.083	M	0.725	Class II
3	SEA-008	3650.84073	PB	HM	biota	3.12414936	M	H	H	L	M	Metals	0.625	12.911	Bad	0.65625	Class II
3	SEA-008	3650.84073	PB	HM	sediment	0.63647687	L	H	H	M	H	Metals	0.775	4.083	M	0.725	Class II
3	SEA-008	3650.84073	SBDE6	Org	biota	29.7616302	M	M	H	L	H	PBDEs	0.575	12.911	Bad	0.65625	Class II
3	SEA-008	3650.84073	SCB6	Org	biota	0.05132051	M	M	H	L	H	PCBs	0.575	12.911	Bad	0.65625	Class II
3	SEA-008	3650.84073	PFOS	Org	biota	0.04887319	H	M	H	M	H	PFOS	0.75	12.911	Bad	0.65625	Class II
3	SEA-008	3650.84073	TBSN+	Org	sediment	6.3483599	L	M	H	L	H	TBSN+	0.525	4.083	M	0.725	Class II
3	SEA-008		CS137	Radioactive	biota	0.13306667	H	M	H	H	H	Radioactive	0.875	12.911	Bad	0.65625	Class II
3	SEA-008		CS137	Radioactive	water	0.44411289	H	H	H	H	H	Radioactive	1	0.444	H	1	Class I
3	SEA-009	70789.9005	CD	HM	sediment	3.44146824	H	L	H	H	H	Metals	0.75	4.161	M	0.70625	Class II
3	SEA-009	70789.9005	CD	HM	water	0.5	M	L	H	H	H	Metals	0.7	6.299	Poor	0.805	Class I
3	SEA-009	70789.9005	CD	HM	biota	0.25816881	H	H	H	H	H	Metals	1	15.379	Bad	0.85	Class I
3	SEA-009	7.079E+10	CU	HM	sediment	1.1988216	H	M	H	H	H	Metals	0.875	4.161	M	0.70625	Class II
3	SEA-009	70789.9005	HBCD	Org	biota	0.00062602	H	M	H	M	H	HBCD	0.75	15.379	Bad	0.85	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-009	70789.9005	HBCD	Org	sediment	0.00020292	M	L	H	L	H	HBCD	0.45	4.161	M	0.70625	Class II
3	SEA-009	70789.9005	HG	HM	biota	1.33097942	H	H	H	H	H	Metals	1	15.379	Bad	0.85	Class I
3	SEA-009	70789.9005	ANT	Org	sediment	0.10623275	H	L	H	M	H	PAHs	0.625	4.161	M	0.70625	Class II
3	SEA-009	70789.9005	FLU	Org	sediment	0.00980025	H	L	H	H	H	PAHs	0.75	4.161	M	0.70625	Class II
3	SEA-009	70789.9005	PB	HM	biota	1.013238	H	H	H	H	M	Metals	0.925	15.379	Bad	0.85	Class I
3	SEA-009	70789.9005	PB	HM	sediment	0.4732727	H	M	H	H	H	Metals	0.875	4.161	M	0.70625	Class II
3	SEA-009	70789.9005	PB	HM	water	0.16215803	H	L	H	H	H	Metals	0.75	6.299	Poor	0.805	Class I
3	SEA-009	70789.9005	SBDE6	Org	biota	40.5437399	H	M	H	M	H	PBDEs	0.75	15.379	Bad	0.85	Class I
3	SEA-009	70789.9005	SBDE6	Org	sediment	8.4894E-05	M	L	H	L	H	PBDEs	0.45	4.161	M	0.70625	Class II
3	SEA-009	70789.9005	SCB6	Org	biota	0.09222082	H	L	H	M	H	PCBs	0.625	15.379	Bad	0.85	Class I
3	SEA-009	70789.9005	PFOS	Org	biota	0.1002552	H	H	H	H	H	PFOS	1	15.379	Bad	0.85	Class I
3	SEA-009	70789.9005	PFOS	Org	water	10.84153	M	M	H	M	H	PFOS	0.7	6.299	Poor	0.805	Class I
3	SEA-009	70789.9005	TBSN+	Org	sediment	6.53938444	H	M	H	H	H	TBSN+	0.875	4.161	M	0.70625	Class II
3	SEA-009	70789.9005	TBSN+	Org	water	2.15905702	H	M	H	H	H	TBSN+	0.875	6.299	Poor	0.805	Class I
3	SEA-009		CS137	Radioactive	biota	0.16015278	H	L	H	H	H	Radioactive	0.75	15.379	Bad	0.85	Class I
3	SEA-009		CS137	Radioactive	water	0.42203164	H	H	H	H	H	Radioactive	1	6.299	Poor	0.805	Class I
3	SEA-010	26056.4591	CD	HM	sediment	2.48273003	H	M	H	H	H	Metals	0.875	2.706	M	0.878125	Class I
3	SEA-010	26056.4591	CD	HM	biota	3.12891544	H	L	H	M	H	Metals	0.625	13.722	Bad	0.65277778	Class II
3	SEA-010	2.6056E+10	CU	HM	sediment	1.20894656	H	H	H	H	H	Metals	1	2.706	M	0.878125	Class I
3	SEA-010	26056.4591	HBCD	Org	biota	0.00095329	H	M	H	M	H	HBCD	0.75	13.722	Bad	0.65277778	Class II
3	SEA-010	26056.4591	HBCD	Org	sediment	0.00018024	M	H	H	L	H	HBCD	0.7	2.706	M	0.878125	Class I
3	SEA-010	26056.4591	HG	HM	biota	1.07728884	H	L	H	M	H	Metals	0.625	13.722	Bad	0.65277778	Class II
3	SEA-010	26056.4591	ANT	Org	sediment	0.11099101	H	M	H	H	H	PAHs	0.875	2.706	M	0.878125	Class I
3	SEA-010	26056.4591	FLU	Org	sediment	0.01045937	H	M	H	H	H	PAHs	0.875	2.706	M	0.878125	Class I
3	SEA-010	26056.4591	PB	HM	biota	0.64007648	H	L	H	M	M	Metals	0.55	13.722	Bad	0.65277778	Class II
3	SEA-010	26056.4591	PB	HM	sediment	0.3285572	H	H	H	H	H	Metals	1	2.706	M	0.878125	Class I
3	SEA-010	26056.4591	SBDE6	Org	biota	35.7985455	M	L	H	M	H	PBDEs	0.575	13.722	Bad	0.65277778	Class II
3	SEA-010	26056.4591	SBDE6	Org	sediment	0.00018451	M	H	H	L	H	PBDEs	0.7	2.706	M	0.878125	Class I
3	SEA-010	26056.4591	TEQDFP	Org	biota	0.19335746	H	M	H	M	H	Dioxins	0.75	13.722	Bad	0.65277778	Class II
3	SEA-010	26056.4591	SCB6	Org	biota	0.0802264	H	L	H	M	H	PCBs	0.625	13.722	Bad	0.65277778	Class II

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-010	26056.4591	PFOS	Org	biota	0.06897488	H	L	H	M	H	PFOS	0.625	13.722	Bad	0.65277778	Class II
3	SEA-010	26056.4591	TBSN+	Org	sediment	3.51051969	H	H	H	H	H	TBSN+	1	2.706	M	0.878125	Class I
3	SEA-010		CS137	Radioactive	biota	0.179	H	L	H	H	H	Radioactive	0.75	13.722	Bad	0.65277778	Class II
3	SEA-010		CS137	Radioactive	water	0.49208333	H	L	H	H	H	Radioactive	0.75	0.492	H	0.75	Class I
3	SEA-011	8674.52249	CD	HM	biota	0.6936689	H	M	H	M	H	Metals	0.75	10.103	Bad	0.63928571	Class II
3	SEA-011	8674.52249	HBCD	Org	biota	0.02630942	L	H	H	L	H	HBCD	0.65	10.103	Bad	0.63928571	Class II
3	SEA-011	8674.52249	HG	HM	biota	1.10145281	H	M	H	M	H	Metals	0.75	10.103	Bad	0.63928571	Class II
3	SEA-011	8674.52249	PB	HM	biota	2.40792695	M	H	H	M	M	Metals	0.75	10.103	Bad	0.63928571	Class II
3	SEA-011	8674.52249	SBDE6	Org	biota	22.3198281	L	M	H	L	H	PBDEs	0.525	10.103	Bad	0.63928571	Class II
3	SEA-011	8674.52249	SCB6	Org	biota	0.07047782	L	M	H	L	H	PCBs	0.525	10.103	Bad	0.63928571	Class II
3	SEA-011	8674.52249	PFOS	Org	biota	0.10989011	L	M	H	L	H	PFOS	0.525	10.103	Bad	0.63928571	Class II
3	SEA-012	27507.8029	CD	HM	sediment	3.59990725	M	L	H	H	H	Metals	0.7	3.332	M	0.584375	Class II
3	SEA-012	27507.8029	CD	HM	biota	3.25673259	H	L	H	M	H	Metals	0.625	6.345	Poor	0.603125	Class II
3	SEA-012	2.7508E+10	CU	HM	sediment	1.02347135	M	L	H	H	H	Metals	0.7	3.332	M	0.584375	Class II
3	SEA-012	27507.8029	HBCD	Org	biota	0.00034825	M	L	H	L	H	HBCD	0.45	6.345	Poor	0.603125	Class II
3	SEA-012	27507.8029	HBCD	Org	sediment	4.5506E-05	L	L	H	L	H	HBCD	0.4	3.332	M	0.584375	Class II
3	SEA-012	27507.8029	HG	HM	biota	0.88545325	H	L	H	M	H	Metals	0.625	6.345	Poor	0.603125	Class II
3	SEA-012	27507.8029	ANT	Org	sediment	0.10038516	M	L	H	M	H	PAHs	0.575	3.332	M	0.584375	Class II
3	SEA-012	27507.8029	FLU	Org	sediment	0.00873036	M	L	H	M	H	PAHs	0.575	3.332	M	0.584375	Class II
3	SEA-012	27507.8029	PB	HM	biota	0.45512993	H	L	H	M	M	Metals	0.55	6.345	Poor	0.603125	Class II
3	SEA-012	27507.8029	PB	HM	sediment	0.33451431	H	L	H	H	H	Metals	0.75	3.332	M	0.584375	Class II
3	SEA-012	27507.8029	SBDE6	Org	biota	13.0994522	M	L	H	M	H	PBDEs	0.575	6.345	Poor	0.603125	Class II
3	SEA-012	27507.8029	SBDE6	Org	sediment	0.00021704	L	L	H	L	H	PBDEs	0.4	3.332	M	0.584375	Class II
3	SEA-012	27507.8029	TEQDFP	Org	biota	0.14228062	H	M	H	M	H	Dioxins	0.75	6.345	Poor	0.603125	Class II
3	SEA-012	27507.8029	SCB6	Org	biota	0.04292259	H	L	H	M	H	PCBs	0.625	6.345	Poor	0.603125	Class II
3	SEA-012	27507.8029	PFOS	Org	biota	0.06441679	H	L	H	M	H	PFOS	0.625	6.345	Poor	0.603125	Class II
3	SEA-012	27507.8029	TBSN+	Org	sediment	4.35779145	M	L	H	M	H	TBSN+	0.575	3.332	M	0.584375	Class II
3	SEA-012		CS137	Radioactive	water	0.47804167	H	L	H	H	H	Radioactive	0.75	0.478	H	0.75	Class I
3	SEA-013	16612.2978	CD	HM	sediment	0.95415008	M	M	H	M	H	Metals	0.7	1.021	M	0.75357143	Class I
3	SEA-013	16612.2978	CD	HM	biota	2.14355605	H	H	H	M	H	Metals	0.875	6.896	Poor	0.84166667	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-013	1661235437	CU	HM	sediment	0.87621127	M	H	H	H	H	Metals	0.95	1.021	M	0.75357143	Class I
3	SEA-013	16612.2978	HBCD	Org	biota	0.00025165	M	H	H	M	H	HBCD	0.825	6.896	Poor	0.84166667	Class I
3	SEA-013	16612.2978	HBCD	Org	sediment	0.00309927	M	H	H	L	H	HBCD	0.7	1.021	M	0.75357143	Class I
3	SEA-013	16612.2978	HG	HM	biota	1.35804361	H	M	H	M	H	Metals	0.75	6.896	Poor	0.84166667	Class I
3	SEA-013	16612.2978	ANT	Org	sediment	0.13829761	M	M	H	M	H	PAHs	0.7	1.021	M	0.75357143	Class I
3	SEA-013	16612.2978	FLU	Org	sediment	0.0103525	M	M	H	L	H	PAHs	0.575	1.021	M	0.75357143	Class I
3	SEA-013	16612.2978	PB	HM	biota	1.97341135	H	H	H	M	M	Metals	0.8	6.896	Poor	0.84166667	Class I
3	SEA-013	16612.2978	PB	HM	sediment	0.35076122	M	H	H	H	H	Metals	0.95	1.021	M	0.75357143	Class I
3	SEA-013	16612.2978	SBDE6	Org	biota	14.7746045	M	M	H	M	H	PBDEs	0.7	6.896	Poor	0.84166667	Class I
3	SEA-013	16612.2978	TEQDFP	Org	biota	0.1966373	H	H	H	H	H	Dioxins	1	6.896	Poor	0.84166667	Class I
3	SEA-013	16612.2978	SCB6	Org	biota	0.07340555	H	H	H	M	H	PCBs	0.875	6.896	Poor	0.84166667	Class I
3	SEA-013	16612.2978	PFOS	Org	biota	0.04047725	H	H	H	H	H	PFOS	1	6.896	Poor	0.84166667	Class I
3	SEA-013	16612.2978	TBSN+	Org	sediment	0.36952651	M	M	H	M	H	TBSN+	0.7	1.021	M	0.75357143	Class I
3	SEA-013		CS137	Radioactive	biota	0.12705113	H	L	H	H	H	Radioactive	0.75	6.896	Poor	0.84166667	Class I
3	SEA-013		CS137	Radioactive	water	0.36435243	H	H	H	H	H	Radioactive	1	0.364	H	1	Class I
3	SEA-014	1896.4211	CD	HM	sediment	0.11509517	M	H	H	H	H	Metals	0.95	0.89	Good	0.7875	Class I
3	SEA-014	1896421105	CU	HM	sediment	1.49836429	M	M	H	H	H	Metals	0.825	0.89	Good	0.7875	Class I
3	SEA-014	1896.4211	HBCD	Org	sediment	0.00028957	L	H	H	L	H	HBCD	0.65	0.89	Good	0.7875	Class I
3	SEA-014	1896.4211	ANT	Org	sediment	0.14251749	M	H	H	M	H	PAHs	0.825	0.89	Good	0.7875	Class I
3	SEA-014	1896.4211	FLU	Org	sediment	0.0161523	M	M	H	M	H	PAHs	0.7	0.89	Good	0.7875	Class I
3	SEA-014	1896.4211	PB	HM	sediment	0.20762449	M	H	H	H	H	Metals	0.95	0.89	Good	0.7875	Class I
3	SEA-014	1896.4211	SBDE6	Org	sediment	0.00050549	L	H	H	L	H	PBDEs	0.65	0.89	Good	0.7875	Class I
3	SEA-014	1896.4211	TBSN+	Org	sediment	0.53802587	H	M	H	M	H	TBSN+	0.75	0.89	Good	0.7875	Class I
3	SEA-014		CS137	Radioactive	biota	0.14994904	H	H	H	H	H	Radioactive	1	0.15	H	1	Class I
3	SEA-015	49443.069	CD	HM	sediment	0.10163926	H	L	H	H	H	Metals	0.75	0.901	Good	0.746875	Class II
3	SEA-015	49443.069	CD	HM	biota	4.27166749	H	H	H	M	H	Metals	0.875	12.919	Bad	0.81944444	Class I
3	SEA-015	4.9443E+10	CU	HM	sediment	1.77989195	H	M	H	H	H	Metals	0.875	0.901	Good	0.746875	Class II
3	SEA-015	49443.069	HBCD	Org	biota	0.00083287	M	L	H	M	H	HBCD	0.575	12.919	Bad	0.81944444	Class I
3	SEA-015	49443.069	HBCD	Org	sediment	0.00042186	M	M	H	L	H	HBCD	0.575	0.901	Good	0.746875	Class II
3	SEA-015	49443.069	HG	HM	biota	0.60863591	H	M	H	M	H	Metals	0.75	12.919	Bad	0.81944444	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-015	49443.069	ANT	Org	sediment	0.17220741	H	M	H	H	H	PAHs	0.875	0.901	Good	0.746875	Class II
3	SEA-015	49443.069	FLU	Org	sediment	0.01631343	H	M	H	H	H	PAHs	0.875	0.901	Good	0.746875	Class II
3	SEA-015	49443.069	PB	HM	biota	0.36532814	H	M	H	M	M	Metals	0.675	12.919	Bad	0.81944444	Class I
3	SEA-015	49443.069	PB	HM	sediment	0.2243879	H	M	H	H	H	Metals	0.875	0.901	Good	0.746875	Class II
3	SEA-015	49443.069	SBDE6	Org	biota	32.9576308	H	M	H	H	H	PBDEs	0.875	12.919	Bad	0.81944444	Class I
3	SEA-015	49443.069	SBDE6	Org	sediment	0.00036303	M	L	H	L	H	PBDEs	0.45	0.901	Good	0.746875	Class II
3	SEA-015	49443.069	TEQDFP	Org	biota	0.20939808	H	H	H	H	H	Dioxins	1	12.919	Bad	0.81944444	Class I
3	SEA-015	49443.069	SCB6	Org	biota	0.09384986	H	M	H	H	H	PCBs	0.875	12.919	Bad	0.81944444	Class I
3	SEA-015	49443.069	PFOS	Org	biota	0.07007932	H	M	H	H	H	PFOS	0.875	12.919	Bad	0.81944444	Class I
3	SEA-015	49443.069	TBSN+	Org	sediment	0.2530896	M	M	H	M	H	TBSN+	0.7	0.901	Good	0.746875	Class II
3	SEA-015		CS137	Radioactive	biota	0.18107361	H	M	H	H	H	Radioactive	0.875	12.919	Bad	0.81944444	Class I
3	SEA-015		CS137	Radioactive	water	0.51846528	H	H	H	H	H	Radioactive	1	0.518	Good	1	Class I
3	SEA-016	2965.17268	CD	HM	biota	4.125	L	M	H	L	H	Metals	0.525	10.705	Bad	0.6375	Class II
3	SEA-016	2965.17268	HG	HM	biota	1	L	H	H	L	H	Metals	0.65	10.705	Bad	0.6375	Class II
3	SEA-016	2965.17268	PB	HM	biota	0.76923077	L	H	H	L	M	Metals	0.575	10.705	Bad	0.6375	Class II
3	SEA-016	2965.17268	SBDE6	Org	biota	23.907563	L	M	H	L	H	PBDEs	0.525	10.705	Bad	0.6375	Class II
3	SEA-016	2965.17268	TEQDFP	Org	biota	0.2013812	L	H	H	L	H	Dioxins	0.65	10.705	Bad	0.6375	Class II
3	SEA-016	2965.17268	SCB6	Org	biota	0.08666667	L	M	H	L	H	PCBs	0.525	10.705	Bad	0.6375	Class II
3	SEA-016	2965.17268	PFOS	Org	biota	0.02692308	L	H	H	L	H	PFOS	0.65	10.705	Bad	0.6375	Class II
3	SEA-016		CS137	Radioactive	biota	0.16132378	H	H	H	H	H	Radioactive	1	10.705	Bad	0.6375	Class II
3	SEA-017	21603.9242	CD	HM	sediment	0.5647572	H	L	H	H	H	Metals	0.75	1.246	M	0.753125	Class I
3	SEA-017	21603.9242	CD	HM	biota	1.79122067	M	L	H	L	H	Metals	0.45	55.82	Bad	0.49444444	Class III
3	SEA-017	2160392423	CU	HM	sediment	1.57975669	H	M	H	H	H	Metals	0.875	1.246	M	0.753125	Class I
3	SEA-017	21603.9242	HBCD	Org	biota	0.00903201	L	M	H	L	H	HBCD	0.525	55.82	Bad	0.49444444	Class III
3	SEA-017	21603.9242	HBCD	Org	sediment	0.00028484	M	M	H	L	H	HBCD	0.575	1.246	M	0.753125	Class I
3	SEA-017	21603.9242	HG	HM	biota	0.96703381	M	L	H	L	H	Metals	0.45	55.82	Bad	0.49444444	Class III
3	SEA-017	21603.9242	ANT	Org	sediment	0.10036468	H	M	H	M	H	PAHs	0.75	1.246	M	0.753125	Class I
3	SEA-017	21603.9242	FLU	Org	sediment	0.00856553	H	M	H	M	H	PAHs	0.75	1.246	M	0.753125	Class I
3	SEA-017	21603.9242	PB	HM	biota	0.26836068	M	L	H	L	M	Metals	0.375	55.82	Bad	0.49444444	Class III
3	SEA-017	21603.9242	PB	HM	sediment	0.41910495	H	M	H	H	H	Metals	0.875	1.246	M	0.753125	Class I

Table A2.2. (Continued). Overview of CHASE integrated assessment input data (derived directly from indicator evaluations). The methodology is described in Annex 1. Assessment unit identity (for coastal areas) can be found in the HELCOM Monitoring and Assessment Strategy Annex 4.in the HELCOM Monitoring and Assessment Strategy Annex 4.

AU_scale	AU	Area_km2	Substance	Type	Matrix	CR	ConfTemp	ConfSpatial	ConfMethod	ConfAcc	ConfThresh	SubstanceGrp	ConfScore	ConSum	QEStatus	QEConfScore	QEConfidence
3	SEA-017	21603.9242	SBDE6	Org	biota	162.830882	L	L	H	L	H	PBDEs	0.4	55.82	Bad	0.49444444	Class III
3	SEA-017	21603.9242	SBDE6	Org	sediment	0.0002857	M	M	H	L	H	PBDEs	0.575	1.246	M	0.753125	Class I
3	SEA-017	21603.9242	TEQDFP	Org	biota	1.17427519	L	M	H	L	H	Dioxins	0.525	55.82	Bad	0.49444444	Class III
3	SEA-017	21603.9242	SCB6	Org	biota	0.16457802	M	L	H	L	H	PCBs	0.45	55.82	Bad	0.49444444	Class III
3	SEA-017	21603.9242	PFOS	Org	biota	0.06336497	L	L	H	L	H	PFOS	0.4	55.82	Bad	0.49444444	Class III
3	SEA-017	21603.9242	TBSN+	Org	sediment	0.85142355	H	M	H	H	H	TBSN+	0.875	1.246	M	0.753125	Class I
3	SEA-017		CS137	Radioactive	biota	0.18987579	H	M	H	H	H	Radioactive	0.875	55.82	Bad	0.49444444	Class III
3	SEA-017		CS137	Radioactive	water	0.3605625	H	M	H	H	H	Radioactive	0.875	0.361	H	0.875	Class I

Annex 3.
Outcomes of the CHASE integrated assessment of hazardous substances applied using Level 4 Assessment Units

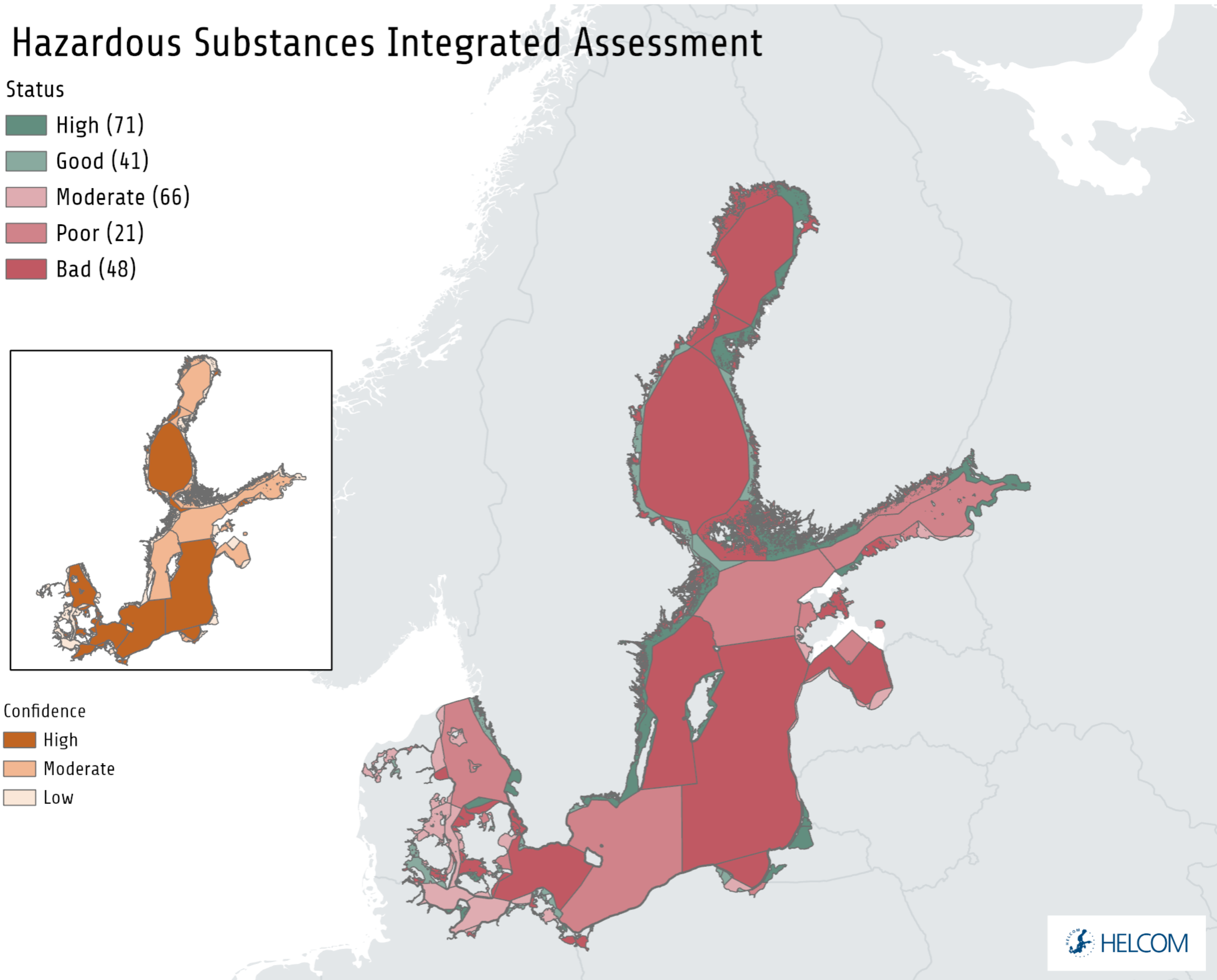

Figure A3.1. The figure provides the CHASE integration applied at HELCOM Assessment Units Level 4.

Annex 4. Overview of station level trends in hazardous substances

Table A4.1. The table provides an overview of station level trends based on the outputs of the MIME tool (with Cs-137 included subsequently). The summary provides an overview, per substance or substance group, of the stations to which trends could be assigned and the 'direction' of those trends if applicable. An overview is also provided per sampling matrix.

One trend or data series here = 1 station essentially	**FULL DATA**			**INITIAL DATA**					
ALL	Downward arrow	Large filled circle	Upward arrow	Small filled circle	Small open circle				
Substance or substance group	Downward trend	No detectable trend stable'	Upward trend	Full data but no trend	Initial data	Number of full assessments	Number of full in GES	Total number of data series	Total number in GES
Hexabromocyclododecane (HBCDD)	20	9	1	9	61	30	30	100	100
Polybrominated diphenyl ethers (PBDEs)	5	23	0	14	85	28	0	127	19
Polychlorinated biphenyls (PCBs): Non-dioxin-like-PCBs	16	28	1	10	62	45	42	117	98
Polychlorinated biphenyls (PCBs): Dioxin-like-PCBs, dioxins and furans	6	15	1	1	53	22	22	76	65
Polyaromatic hydrocarbons (PAHs): Benzo(a)pyrene	5	18	0	26	96	23	22	145	137
Polyaromatic hydrocarbons (PAHs): Fluoranthene	7	25	1	44	126	33	33	203	190
Polyaromatic hydrocarbons (PAHs): Anthracene	0	4	0	15	34	4	1	53	19
Polyaromatic hydrocarbons (PAHs) metabolites: 1-hydroxypyrene	0	6	1	5	3	7	6	15	14
Perfluorooctane sulphonate (PFOS)	7	32	1	12	101	40	39	153	131
Mercury	13	72	8	47	181	93	18	321	43
Cadmium	20	70	6	93	214	96	30	403	155
Lead	16	68	3	95	220	87	43	402	119
Copper	0	4	1	15	15	5	1	35	2
Tributyltin (TBT) and imposex	4	24	1	21	98	29	4	148	5
Radioactive substances (Cs-137)	90	31	0	0	17	121	121	138	138
TOTALS	**209**	**429**	**25**	**407**	**1366**	**663**	**412**	**2436**	**1235**

Table A4.1. (Continued). The table provides an overview of station level trends based on the outputs of the MIME tool (with Cs-137 included subsequently). The summary provides an overview, per substance or substance group, of the stations to which trends could be assigned and the 'direction' of those trends if applicable. An overview is also provided per sampling matrix.

	FULL DATA			**INITIAL DATA**					
BIOTA	Downward arrow	Large filled circle	Upward arrow	Small filled circle	Small open circle				
Substance or substance group	Downward trend	No detectable trend	Upward trend	Full data but no trend	Initial data	Number of full assessments	Number of full in GES	Total number of data series	Total number in GES
Hexabromocyclododecane (HBCDD)	20	9	1	9	43	30	30	82	82
Polybrominated diphenyl ethers (PBDEs)	5	23	0	14	66	28	0	108	0
Polychlorinated biphenyls (PCBs): Non-dioxin-like-PCBs	16	28	1	10	62	45	42	117	98
Polychlorinated biphenyls (PCBs): Dioxin-like-PCBs, dioxins and furans	6	15	1	1	53	22	22	76	65
Polyaromatic hydrocarbons (PAHs): Benzo(a)pyrene	5	18	0	26	96	23	22	145	137
Polyaromatic hydrocarbons (PAHs): Fluoranthene	6	21	1	25	91	28	28	144	141
Polyaromatic hydrocarbons (PAHs): Anthracene									
Polyaromatic hydrocarbons (PAHs) metabolites: 1-hydroxypyrene	0	6	1	5	3	7	6	15	14
Perfluorooctane sulphonate (PFOS)	7	32	1	9	72	40	39	121	118
Mercury	13	72	8	47	181	93	18	321	43
Cadmium	18	57	6	47	144	81	16	272	73
Lead	12	58	3	43	154	73	32	270	40
Copper									
Tributyltin (TBT) and imposex	4	24	1	1	7	29	4	37	4
Radioactive substances (Cs-137)	30	3	0	0	17	33	33	50	50
TOTALS	**142**	**366**	**24**	**237**	**989**	**532**	**292**	**1758**	**865**

Table A4.1. (Continued). The table provides an overview of station level trends based on the outputs of the MIME tool (with Cs-137 included subsequently). The summary provides an overview, per substance or substance group, of the stations to which trends could be assigned and the 'direction' of those trends if applicable. An overview is also provided per sampling matrix.

	FULL DATA			**INITIAL DATA**					
SEDIMENT	Downward arrow	Large filled circle	Upward arrow	Small filled circle	Small open circle				
Substance or substance group	Downward trend	No detectable trend	Upward trend	Full data but no trend	Initial data	Number of full assessments	Number of full in GES	Total number of data series	Toital number in GES
Hexabromocyclododecane (HBCDD)	0	0	0	0	18	0	0	18	18
Polybrominated diphenyl ethers (PBDEs)	0	0	0	0	19	0	0	19	19
Polychlorinated biphenyls (PCBs): Non-dioxin-like-PCBs									
Polychlorinated biphenyls (PCBs): Dioxin-like-PCBs, dioxins and furans									
Polyaromatic hydrocarbons (PAHs): Benzo(a)pyrene									
Polyaromatic hydrocarbons (PAHs): Fluoranthene	1	4	0	19	35	5	5	59	49
Polyaromatic hydrocarbons (PAHs): Anthracene	0	4	0	15	34	4	1	53	19
Polyaromatic hydrocarbons (PAHs) metabolites: 1-hydroxypyrene									
Perfluorooctane sulphonate (PFOS)									
Mercury									
Cadmium	0	6	0	18	24	6	5	48	21
Lead	2	4	0	18	25	6	3	49	37
Copper	0	4	1	15	15	5	1	35	2
Tributyltin (TBT) and imposex	0	0	0	12	42	0	0	54	1
Radioactive substances (Cs-137)									
TOTALS	**3**	**22**	**1**	**97**	**212**	**26**	**15**	**335**	**166**

Table A4.1. (Continued). The table provides an overview of station level trends based on the outputs of the MIME tool (with Cs-137 included subsequently). The summary provides an overview, per substance or substance group, of the stations to which trends could be assigned and the 'direction' of those trends if applicable. An overview is also provided per sampling matrix.

	FULL DATA			INITIAL DATA					
WATER	Downward arrow	Large filled circle	Upward arrow	Small filled circle	Small open circle				
Substance or substance group	Downward trend	No detectable trend	Upward trend	Full data but no trend	Initial data	Number of full assessments	Number of full in GES	Total number of data series	Toital number in GES
Hexabromocyclododecane (HBCDD)									
Polybrominated diphenyl ethers (PBDEs)									
Polychlorinated biphenyls (PCBs): Non-dioxin-like-PCBs									
Polychlorinated biphenyls (PCBs): Dioxin-like-PCBs, dioxins and furans									
Polyaromatic hydrocarbons (PAHs): Benzo(a)pyrene									
Polyaromatic hydrocarbons (PAHs): Fluoranthene									
Polyaromatic hydrocarbons (PAHs): Anthracene									
Polyaromatic hydrocarbons (PAHs) metabolites: 1-hydroxypyrene									
Perfluorooctane sulphonate (PFOS)	0	0	0	3	29	0	0	32	13
Mercury									
Cadmium	2	7	0	28	46	9	9	83	61
Lead	2	6	0	34	41	8	8	83	42
Copper									
Tributyltin (TBT) and imposex	0	0	0	8	49	0	0	57	0
Radioactive substances (Cs-137)	60	28	0	0	0	88	88	88	88
TOTALS	**64**	**41**	**0**	**73**	**165**	**105**	**105**	**343**	**204**

Annex 5. Supplementary supporting information for marine litter

Table A5.1. Median values (2016–2021) for beach litter of different materials and for the categories, Sanitary and medical items (S&M), and Various materials (VM).

Sub-basins	N	Rubber	Metal	Glass	Paper	Textile	Wood	S&M	VM
SEA-001	54	1.0	1.0	0.5	0.0	0.0	3.0	1.0	0.0
SEA-003	18	2.0	7.5	7.0	2.0	8.0	2.5	0.0	0.0
SEA-004	83	0.5	1.0	4.0	0.0	0.0	0.5	0.0	0.0
SEA-005	132	0.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
SEA-006	330	1.0	1.0	0.5	0.0	0.8	0.0	0.0	0.0
SEA-007	202	0.2	1.1	0.3	0.6	0.2	0.5	0.0	0.0
SEA-008	143	0.2	0.9	0.5	0.4	0.3	0.3	0.0	0.0
SEA-009	88	4.0	3.0	1.0	3.0	2.0	2.0	0.0	0.0
SEA-010	54	0.0	1.5	0.0	0.0	0.0	0.2	0.0	0.0
SEA-011	68	2.0	8.0	4.0	27.5	4.5	2.0	0.0	1.5
SEA-012	31	0.5	2.0	1.0	0.0	0.3	3.0	0.0	0.0
SEA-013	133	0.3	1.8	0.5	1.0	0.3	1.5	0.0	0.0
SEA-014	107	0.0	0.3	0.9	0.0	0.0	0.5	0.0	0.0
SEA-015	46	0.0	1.0	0.0	0.5	0.0	1.5	0.0	0.0
SEA-016	5	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
SEA-017	52	0.3	2.6	2.5	2.0	0.3	0.8	0.0	0.0

Table A5.2. Minimum and maximum median values for each sub-basin, N=number of beaches.

Sub-basin	N	median min	median max
SEA-001 Kattegat	3	8	481
SEA-003 The Sound	1	N.A.	N.A.
SEA-004 Kiel Bay	7	9	85
SEA-005 Bay of Mecklenburg	6	10	196
SEA-006 Arkona Basin	20	2	124
SEA-007 Bornholm Basin	9	7	63
SEA-008 Gdansk Basin	6	10	18
SEA-009 E Gotland Basin	19	4	348
SEA-010 W Gotland Basin	3	6	163
SEA-011 Gulf of Riga	30	14	428
SEA-012 N Baltic Proper	2	23	31
SEA-013 Gulf of Finland	10	6	56
SEA-014 Åland Sea	7	19	153
SEA-015 Bothnian Sea	3	12	24
SEA-016 The Quark	1	N.A.	N.A.
SEA-017 Bothnian Bay	3	11	39

Table A5.3. The table shows the aggregations of J-codes (Fleet et al, 2021) into common litter categories, which was necessary to be able to carry out the status assessment on this level of detail. HELCOM Reporting codes included as single-use plastic (SUP) or fisheries related litter (FRL) litter are also displayed.

Materials	Common name	HELCOM Reporting ID	Aggregated litter codes from the "Joint list"	SUP	FRL
Plastic	Plastic six-pack rings	R1	J1	X	
	Plastic bags	R2	J3, J5, J101		
	Plastic bottles	R3	J7, J8, J9, J11, J12, J13		
	Plastic packaging for food and bev-arage	R4	J30, J31, J224, J225, J226, J227	X	
	Larger plastic containers	R5	J14, J15, J16, J18, J65		
	Plastic caps and lids	R6	J21, J22, J23, J24		
	Plastic toys and party poppers	R7	J32		
	Plastic plastes, cutlery, straws and stirrers	R8	J228, J229, J230, J231	X	
	Mesh bags	R9	J238		
	Plastic syringes	R10	J99		
	Plastic gloves (household/gardning)	R11	J40		
	Plastic gloves (professional use)	R12	J41		
	Plastic tags	R13	J43		
	Plastic pieces of nets	R14	J53, J54, J234		X
	Various fishing gear	R15	J42, J44, J45, J46, J47, J57, J58, J60, J61		X
	Rope, string and cords	R16	J49, J232, J233, J235, J242		X
	Plastic fishing line	R17	J59		X
	Floats and boys	R18	J62, J63		
	Plastic strapping bands	R19	J66		
	Plastic sheets	R20	J67, J220		
	Fibre glass items	R21	J68		
	Plastic cigarette lighters	R22	J26		
	Cigarett butts with filters	R23	J27	X	
	Various plastic fragments >2,5 cm	R24	J79, J80, J82, J83, J239, J256, J257		
	Other identifiable plastic litter items	R25	J17, J19, J25, J28, J29, J36, J64, J69, J70, J72, J84, J85, J86, J87, J88, J89, J90, J91, J92, J93, J100, J102, J136, J166, J211, J221, J222, J223, J240, J241, J243, J252, J253		
Rubber	Rubber tyres and belts	R26	J249, J251		
	Rubber condoms	R27	J133		
	Other rubber items	R28	J125, J126, J127, J131, J134, J248, J250		
Textile	Personal clothing items, mixed materials	R29	J137, J138		
	Cloth textile carpet & furnishing	R30	J141		
	Hessian sacks/packaging	R31	J140		
	Other textiles	R32	J139, J143, J145		
Paper	Paper excluding newspaper and magazines	R33	J147, J148, J150, J151, J152, J155, J156, J158, J244, J245, J247		
	Newspapers & magazines	R34	J154		

Table A5.3. (Continued). The table shows the aggregations of J-codes (Fleet et al, 2021) into common litter categories, which was necessary to be able to carry out the status assessment on this level of detail. HELCOM Reporting codes included as single-use plastic (SUP) or fisheries related litter (FRL) litter are also displayed.

Materials	Common name	HELCOM Reporting ID	Aggregated litter codes from the "Joint list"	SUP	FRL
Wood	Wooden corks	R35	J159		
	Wooden pallets/boxes	R36	J160, J162, J164		
	Wooden crab/lobster pots	R37	J163		
	Wooden ice-cream sticks, chip forks, chopsticks, toothpicks	R38	J165		
	Other wooden items	R39	J167, J171, J172		
Metal	Metal bottle caps, lids & pull tabs from cans	R40	J178		
	Metal foil wrappers, aluminium foil	R41	J177		
	Wire, wire mesh, barbed wire	R42	J191		
	Metal drinks cans	R43	J175		
	Metal drums, barrels, and paint tins	R44	J187, J190		
	Metal fisheries accessories and lobster/ crab pots	R45	J182, J184		
	Metal disposable BBQs	R46	J179		
	Other metal items and pieces	R47	J130, J174, J176, J180, J181, J186, J188, J193, J194, J195, J198, J199		
Glass	Glass light bulbs and tubes	R48	J202, J205		
	Glass ceramic construction materials (bricks, tiles, cement)	R49	J204		
	Other glass and ceramics	R50	J200, J201, J203, J207, J208, J210, J219		
Sanitary and medical items	Sanitary and medical items, mixed materials	R51	J95, J96, J97, J98, J144, J236, J237, J246		
Organics	Organics	R52	J215		
	Snuff	R54			
Chemicals	Chemicals	R53	J216, J217, J218		
Various materials	Various litter, mixed materials	R55			
Excluded	Micro- and mesolitter	R98			
	Organic waste not food or snuff	R99			

Table A5.4. Significant trends (2016-2021) for Total Count (TC), SUP, FRL, and Plastic litter categories for each sub-basin, N=number of surveys. A negative value indicates a decreasing and a positive one an increasing trend.

Sub-basin	N	TC	SUP	FRL	Plastic
SEA-001 Kattegat	42				
SEA-003 The Sound	18		4.84		
SEA-004 Kiel Bay	61				
SEA-005 Bay of Mecklenburg	132	-2.59	-0.74		-1.41
SEA-006 Arkona Basin	270	-4.92	-0.50	-0.29	-3.34
SEA-007 Bornholm Basin	202	-1.88	-0.82	0.00	-1.37
SEA-008 Gdansk Basin	143	2.53	0.43	0.14	1.37
SEA-009 E Gotland Basin	62	-0.85	-0.32	-0.12	-1.26
SEA-010 W Gotland Basin	54				
SEA-011 Gulf of Riga	47	-3.01	-0.92		-1.34
SEA-012 N Baltic Proper	31				
SEA-013 Gulf of Finland	127	-2.27			-1.86
SEA-014 Åland Sea	104				
SEA-015 Bothnian Sea	46			0.27	1.89
SEA-017 Bothnian Bay	52				

Table A5.5. Significant trends (2016-2021) for beach litter in different materials and for the categories, Sanitary and medical items (S&M), and Various materials (VM). Decreasing or increasing trends, i.e., if the litter situation in the different sub-basins is improving or deteriorating. A negative value indicates a decreasing and a positive one an increasing trend. N=number of surveys.

Sub-basins	N	Rubber	Metal	Glass	Paper	Textile	Wood	S&M	VM
SEA-001	42								
SEA-003	18								
SEA-004	61								
SEA-005	132	0.00		-0.37					
SEA-006	270	0.00	-0.29	0.00	0.00		0.00	0.00	
SEA-007	202		-0.21	-0.06	0.00		0.06	0.00	
SEA-008	143	0.02			0.04		0.65		
SEA-009	62		-0.09	-0.10	-0.08	-0.10			0.00
SEA-010	54						-0.07		
SEA-011	47			-1.75				0.00	
SEA-012	31				0.00		0.47		
SEA-013	127		-0.21	0.00					
SEA-014	104				0.00	-0.11	-0.36		
SEA-015	46								0.00
SEA-017	52								

Table A5.6. Annual model estimates of weight (mass) and number of litter items per km² and probability of non-zero catch. Low and High denotes upper and lower 95% confidence intervals, respectively.

Type	Year	Mass	Mass Low	Mass High	Numbers	Numbers Low	Numbers High	Prob	Prob Low	Prob High
Glass	2012	0.44551	0.416846	0.605422	2.666697	2.049887	4.6012	0.118995	0.09691	0.159982
	2013	0.445517	0.41552	0.599448	2.761062	2.193335	4.360735	0.121539	0.101878	0.152164
	2014	0.445532	0.415663	0.603116	2.54682	2.11194	3.915167	0.115681	0.09878	0.144357
	2015	0.445534	0.416347	0.601324	2.186015	1.773373	3.285524	0.105088	0.087959	0.131793
	2016	0.445536	0.419242	0.58876	1.966743	1.637972	2.926399	0.098137	0.083707	0.122263
	2017	0.445535	0.415385	0.610315	1.835458	1.576828	2.667841	0.093763	0.081616	0.11607
	2018	0.44553	0.420258	0.595185	1.695945	1.487631	2.500857	0.088922	0.078073	0.109695
	2019	0.445532	0.415355	0.590818	1.611645	1.422667	2.347476	0.085892	0.076074	0.105202
	2020	0.445538	0.41616	0.600752	1.721922	1.504383	2.447111	0.089839	0.079622	0.10981
	2021	0.445547	4.22E-01	0.602379	1.889319	1.645482	2.794938	0.095578	0.084314	0.117541
Metal	2012	0.278817	1.80E-01	0.619785	2.415496	1.713901	3.985435	0.129375	0.100189	0.172186
	2013	0.385755	2.77E-01	0.748509	2.438146	1.893202	3.562842	0.130191	0.106718	0.161811
	2014	0.480457	3.44E-01	0.944424	2.761709	2.133311	4.056337	0.141405	0.117079	0.173939
	2015	0.509614	3.70E-01	0.99481	2.981882	2.376366	4.382549	0.148597	0.124847	0.181899
	2016	0.595644	4.36E-01	1.119444	3.362414	2.761102	4.600896	0.16029	0.139066	0.188664
	2017	0.974351	0.755916	1.832887	2.857335	2.435354	3.933275	0.14457	0.127348	0.171623
	2018	0.847165	0.665291	1.509748	2.335822	1.98884	3.196872	0.126469	0.111147	0.152462
	2019	0.82085	0.634643	1.569859	2.428742	2.073584	3.340907	0.129853	0.115408	0.154867
	2020	1.149734	0.913114	2.191056	2.841842	2.437988	3.894713	0.144061	0.127789	0.170499
	2021	1.267442	0.980223	2.323725	2.825967	2.436667	3.814477	0.143539	0.126694	0.169204
Natural	2012	3.620196	2.599513	6.138473	24.2258	14.8885	45.47056	0.286578	0.237343	0.344819
	2013	6.270533	4.736894	10.2066	23.96556	17.84683	36.68562	0.285521	0.254387	0.319997
	2014	8.589439	6.307281	13.89984	29.52924	21.91464	45.49308	0.30604	0.27112	0.343083
	2015	6.089038	4.543524	10.13452	23.10761	16.67773	37.11972	0.281958	0.246298	0.3228
	2016	1.945149	1.430028	3.262926	15.09974	11.76824	21.96961	0.241077	0.215729	0.270829
	2017	1.498057	1.120274	2.472038	7.054283	5.498965	10.34529	0.173207	0.151964	0.200975
	2018	2.554178	1.920114	4.064253	7.510614	5.737608	10.9563	0.178453	0.154115	0.204517
	2019	4.383652	3.43986	6.727153	10.86231	8.541077	16.44772	0.210678	0.186863	0.239442
	2020	4.559681	3.463246	6.994008	17.20075	13.74693	24.98245	0.253434	0.231349	0.281524
	2021	3.029851	2.26182	5.000387	10.00476	7.804954	14.84023	0.203311	0.18126	0.230849
Other	2012	0.683721	0.514082	1.226198	2.058694	1.352842	3.764506	0.098831	0.07242	0.138985
	2013	0.73759	0.578255	1.239436	2.289719	1.695162	3.641892	0.105713	0.085119	0.135802
	2014	0.691079	0.549337	1.168765	2.746594	2.006484	4.240254	0.118162	0.096492	0.146931
	2015	0.711197	0.572256	1.177047	2.877021	2.147301	4.415927	0.121471	0.099127	0.151216
	2016	0.711995	0.569006	1.165453	2.872077	2.254205	4.201782	0.121347	0.102645	0.146192
	2017	0.72062	0.600031	1.149793	3.077284	2.490435	4.390988	0.126364	0.109725	0.149881
	2018	0.691668	0.556739	1.137364	2.698058	2.174886	3.826251	0.116905	0.101081	0.140103
	2019	0.809193	0.674828	1.287875	3.001113	2.486058	4.190662	0.124528	0.109374	0.146998
	2020	1.070679	0.887234	1.708392	4.342105	3.617725	6.02614	0.153068	0.134946	0.176797
	2021	1.19268	0.980058	1.885985	5.488249	4.559938	7.738453	0.172689	0.154007	0.19773
Plastic	2012	0.487681	0.373777	0.7207	24.87626	19.37626	33.8751	0.431346	0.39436	0.472188
	2013	0.943495	0.756934	1.368186	23.13959	19.14885	30.03497	0.42008	0.387667	0.452542
	2014	1.861788	1.484654	2.76175	24.9822	21.09779	32.1469	0.432008	0.403797	0.463863
	2015	2.247397	1.804174	3.089645	26.15674	22.08642	32.79934	0.439155	0.41077	0.468749

Table A5.6. (Continued). Annual model estimates of weight (mass) and number of litter items per km² and probability of non-zero catch. Low and High denotes upper and lower 95% confidence intervals, respectively.

Type	Year	Mass	Mass Low	Mass High	Numbers	Numbers Low	Numbers High	Prob	Prob Low	Prob High
Plastic	2016	1.468015	1.208997	2.055911	26.17116	22.70678	32.16642	0.43924	0.415873	0.46509
	2017	1.432806	1.18836	1.998389	27.55173	24.08117	33.79315	0.447229	0.424877	0.472641
	2018	1.804394	1.53211	2.497888	26.60067	23.31656	32.00716	0.441771	0.41812	0.46523
	2019	2.300702	1.944203	3.106164	27.46569	24.31907	33.13106	0.446743	0.425114	0.471559
	2020	1.960626	1.642817	2.676456	31.11393	27.6549	37.41644	0.466062	0.443813	0.488021
	2021	1.405809	1.191638	1.938309	34.11683	29.81748	40.55215	0.480251	0.460134	0.501182
Rubber	2012	0.016701	0.006594	0.052692	1.320374	1.19597	1.783939	0.077265	0.070489	0.093145
	2013	0.040161	0.019895	0.110751	1.320382	1.172056	1.79269	0.077265	0.069534	0.092778
	2014	0.1163	0.057237	0.305315	1.320377	1.176659	1.788766	0.077265	0.0694	0.092985
	2015	0.252998	0.146836	0.582245	1.320359	1.18573	1.794996	0.077264	0.069904	0.092653
	2016	0.334959	0.206005	0.745389	1.32034	1.18767	1.785075	0.077263	0.069849	0.093129
	2017	0.231329	0.14576	0.524223	1.320283	1.177214	1.774076	0.077261	0.069883	0.092427
	2018	0.28724	0.181615	0.594962	1.320263	1.184293	1.803505	0.07726	0.070016	0.09243
	2019	0.784377	0.525989	1.614402	1.32028	1.184322	1.798943	0.077261	0.070471	0.093248
	2020	1.033477	0.682844	2.232517	1.320312	1.170545	1.772362	0.077262	0.069443	0.09207
	2021	0.543547	0.337187	1.14843	1.320321	1.169866	1.784994	0.077263	0.069823	0.092858
SUP	2012	0.000839	0.000348	0.002243	2.733454	1.724973	4.700086	0.160279	0.112993	0.226453
	2013	0.252307	0.189019	0.407648	6.605985	5.217605	8.963356	0.279195	0.240493	0.325725
	2014	0.410478	0.304204	0.660197	10.08766	7.659662	14.37608	0.346741	0.299268	0.398796
	2015	0.260502	0.192654	0.404333	11.12199	8.652187	15.38066	0.362867	0.316569	0.412637
	2016	0.474416	0.384744	0.707176	10.96174	9.382525	13.95706	0.36046	0.330191	0.396746
	2017	0.546632	0.446862	0.808481	10.58062	9.143428	13.2179	0.354605	0.327293	0.38498
	2018	0.693842	0.567204	1.003291	9.241721	7.762919	11.82625	0.33241	0.300577	0.366714
	2019	0.847749	0.70014	1.197004	11.31024	9.873038	14.08182	0.365653	0.338682	0.397834
	2020	0.86729	0.69867	1.235669	13.22162	11.44637	16.65218	0.391722	0.362727	0.425082
	2021	0.814305	0.659653	1.153089	10.81527	9.439988	13.41733	0.358232	0.33107	0.392356
Fishing.related	2012	0.016902	0.008027	0.053815	1.822417	1.017337	3.420608	0.084898	0.056947	0.12152
	2013	0.058469	0.034531	0.147072	2.266205	1.553602	3.814894	0.097413	0.075346	0.12901
	2014	0.25091	0.142648	0.633787	3.330431	2.256848	5.423839	0.1222	0.096323	0.156589
	2015	0.346305	0.202241	0.85014	4.777329	3.300204	7.479029	0.148297	0.121855	0.180101
	2016	0.222457	0.15339	0.508151	4.819838	3.620443	6.991735	0.14897	0.12868	0.176014
	2017	0.167531	0.110093	0.369704	4.83173	3.741497	6.968711	0.149157	0.13003	0.174202
	2018	0.417742	0.292502	0.936551	4.733385	3.749024	6.69322	0.147597	0.128089	0.171707
	2019	0.879136	0.626643	1.812058	3.659236	2.853184	5.14664	0.128757	0.110982	0.15063
	2020	0.74537	0.527651	1.584376	5.286768	4.219909	7.496612	0.156074	0.137205	0.180269
	2021	0.529883	0.365336	1.112158	6.305216	5.029919	8.796378	0.170013	0.150109	0.192499