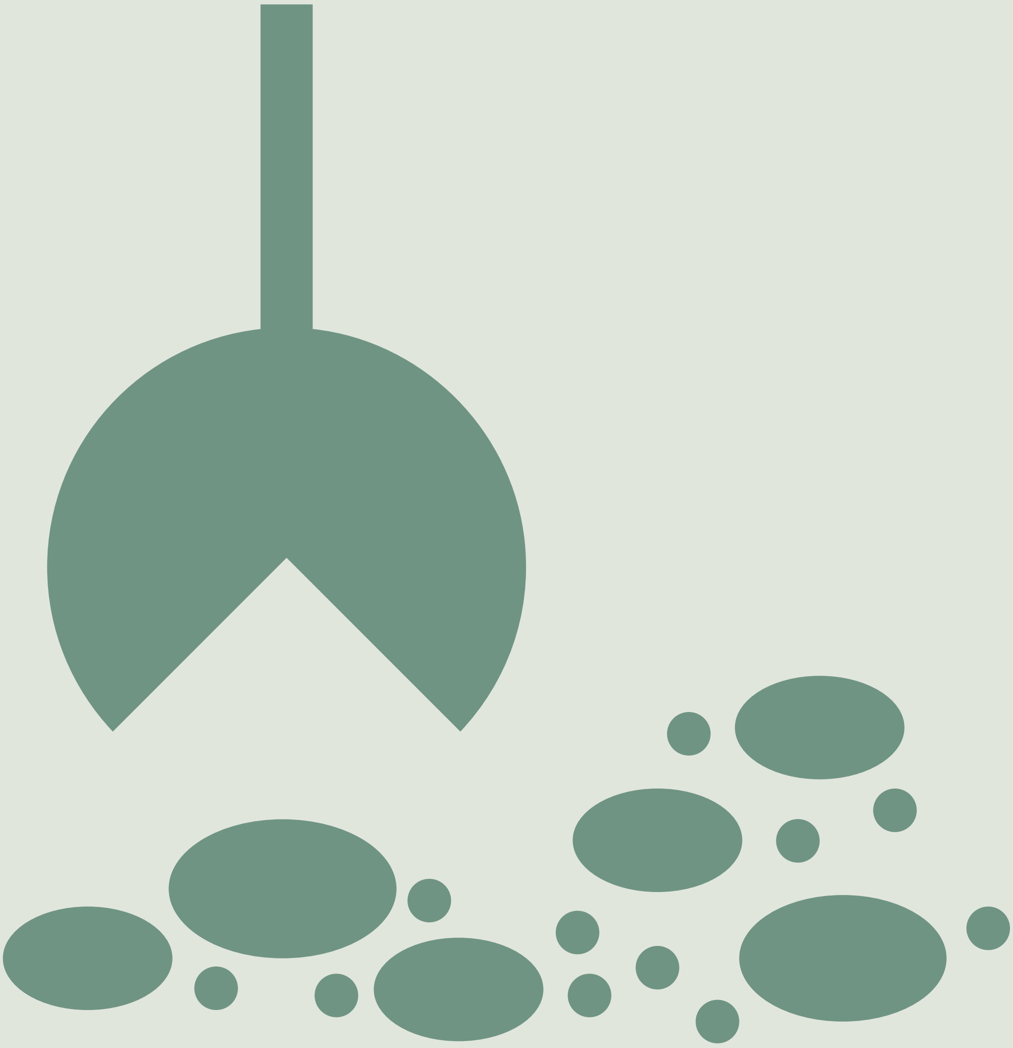
Impacts on seabed:
Approaches for assessment as step towards successful measures

Co-funded by the European Union

Species and biotopes

2021



HELCOM

ACTION

Co-funded by the European Union

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Impacts on seabed – approaches for assessment as step towards successful measures

Contents

1. Introduction

HELCOM has long history of pressure assessments, starting from the first pollution load compilations in 1987 (HELCOM 1987). The most recent holistic assessment included an array of pressure assessments covering, e.g. underwater noise, marine litter, physical disturbance and loss, introductions of non-indigenous species, inputs of nutrients and hazardous substances, hunting and fishing, as well as an assessment of cumulative effects derived from these (HELCOM 2018a).

Physical disturbance has been identified as a wide-spread pressure affecting the benthic habitats in the Baltic Sea: almost half of the seabed is potentially disturbed by human activities. Bottom trawling and shipping cause the most wide-spread physical disturbance but also more localized human activities, such as dredging, deposition of dredged material, and coastal construction works, contribute to the physical disturbance and loss of benthic habitats (HELCOM 2018b). The 2018 HELCOM holistic assessment did not assess how much of the seabed is adversely impacted or how the potentially disturbed seabed correlates with the state of the seabed since agreed threshold values were not in place. Hence, understanding the impacts of these human activities on the seabed is highly important for increasing our knowledge of the possible needs for new measures to mitigate the physical pressures and conserving/improving the state of the habitats and species. By understanding the pressure pathways, impact chains, spatial extents and recovery times, it is possible to assess the need for and placement of management actions.

Anthropogenic pressures affecting the marine environment can be categorized into three themes; biological pressures (e.g. non-indigenous species, extraction of species), physical pressures (disturbance to the seabed, loss of seabed and changes to hydrological conditions) and inputs of substances, litter and energy (including input of nutrients, hazardous substances, litter and noise) (EC 2017a). The pressures can be also categorized based on their primary way of impact on the marine environment. Such an impact-based categorization was presented in the assessment of cumulative pressures and impacts on the Baltic Sea, where four pressure themes were used: substances, energy, biological and physical pressures (HELCOM 2018b). In this report, the focus is on physical pressures, but biological pressures (non-indigenous species) and inputs of substances (nutrients, hazardous substances and litter) will also be briefly addressed.

Currently, there is no regionally agreed method to assess how physical loss and physical disturbance are adversely affecting the seabed. For these needs, HELCOM is developing regional Baltic wide indicators, for example: an indicator on ‘cumulative impact on benthic biotopes’ as well as an indicator for ‘condition of benthic habitats’ are under development. On a European scale, the European Commission has established a Task Group (TG Seabed) to work with the European wide assessment of seafloor integrity and status of seabed habitats for the Marine Strategy Framework Directive (MSFD) purposes. The overall aim of the group is to establish a common framework for assessment of the seabed and benthic habitats, including proposing European quality standards; threshold values and maximum allowable extent of loss and impact to fulfill the requirements of Commission Decision (EU) 2017/848.

The objective of this report is to provide an overview of existing knowledge on anthropogenic pressures and major impacts on seabed habitats, with a focus on the Baltic Sea region, and to support discussion on a way forward towards sufficient measures for marine management. The report aims to distinguish wide-spread and local impacts and ways to separate adverse effects from non-harmful effects. This report is the product of HELCOM ACTION project and it summarizes results of the projects BalticBOOST (2015-2016), TAPAS (2016-2017), HELCOM SPICE (2017) and HELCOM ACTION (2019-2020) as well as results of recent ICES workshops (WKBEDLOSS, WKBEDPRES1 and WKBEDPRES2) supporting drafting the advice on the seafloor assessment process for physical loss and disturbance to seabed habitats (ICES 2019a). The report also summarizes the state of the benthic habitats in the Baltic Sea and links this with the pressures and human activities. The objective of this is to support the selection of new measures for the update of the Baltic Sea Action Plan in 2021.

2. Pressures in the Baltic Sea

Several human activities at sea and on land cause various pressures in the marine environment. The pressures affecting the seabed and habitats have been studied in several Baltic wide projects and at EU scale. Eutrophication, input of hazardous substances, non-indigenous species, extraction of fish, anthropogenic sound and physical disturbance to seabed have been identified as the most extensive pressures affecting the Baltic Sea marine environment (Figure 1). A European wide assessment of multiple pressures and their combined effects shows similar results, with hazardous substances, pelagic and benthic fishing, physical loss and physical disturbance to seabed are identified as most effecting pressures (Korpinen et al. 2019). Coastal areas are most affected by diffuse sources, such as atmospheric deposition and agricultural pressures (Figure 2). The most extensive pressures, i.e. those that occur widely in waterbodies, rank more highly compared to the more local pressures. For example, in the pressure themes ranked at Baltic scale (Figure 1, HELCOM 2018b), physical loss is not ranked as one of the most extensive regional pressures, due to its limited location, although it's impact is locally severe.

Of the most extensive pressures, based on the sensitivities of the seabed habitats, physical disturbance to seabed, eutrophication and hazardous substances have the highest potential impact on the benthic habitats. This chapter focuses on the pressures affecting seabed and the human activities causing them.

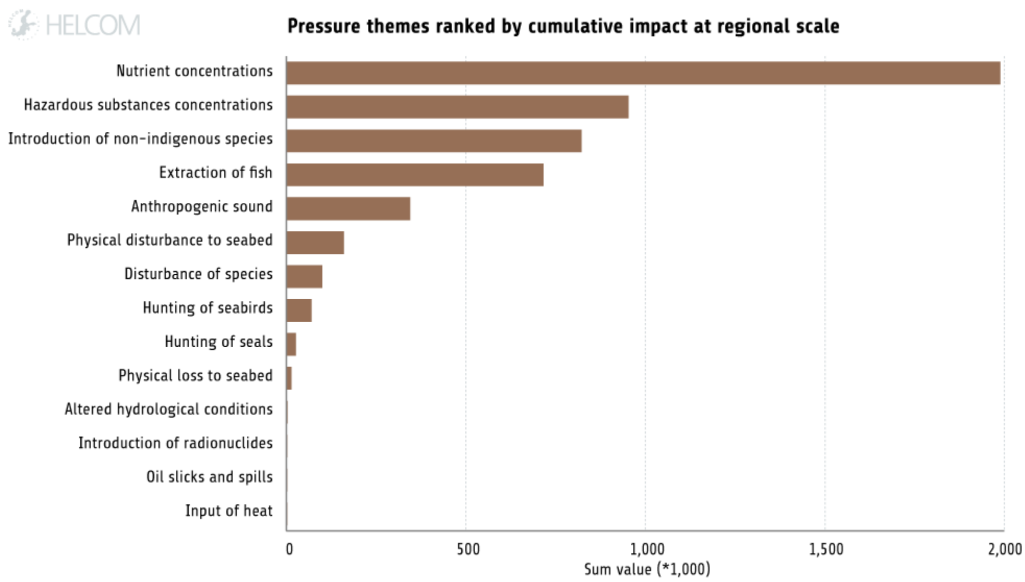


Figure 1. Significant pressures on the Baltic Sea according to the cumulative impact assessment (Baltic Sea Impact Index). For further explanation to the pressures and calculation method, see HELCOM (2018b).

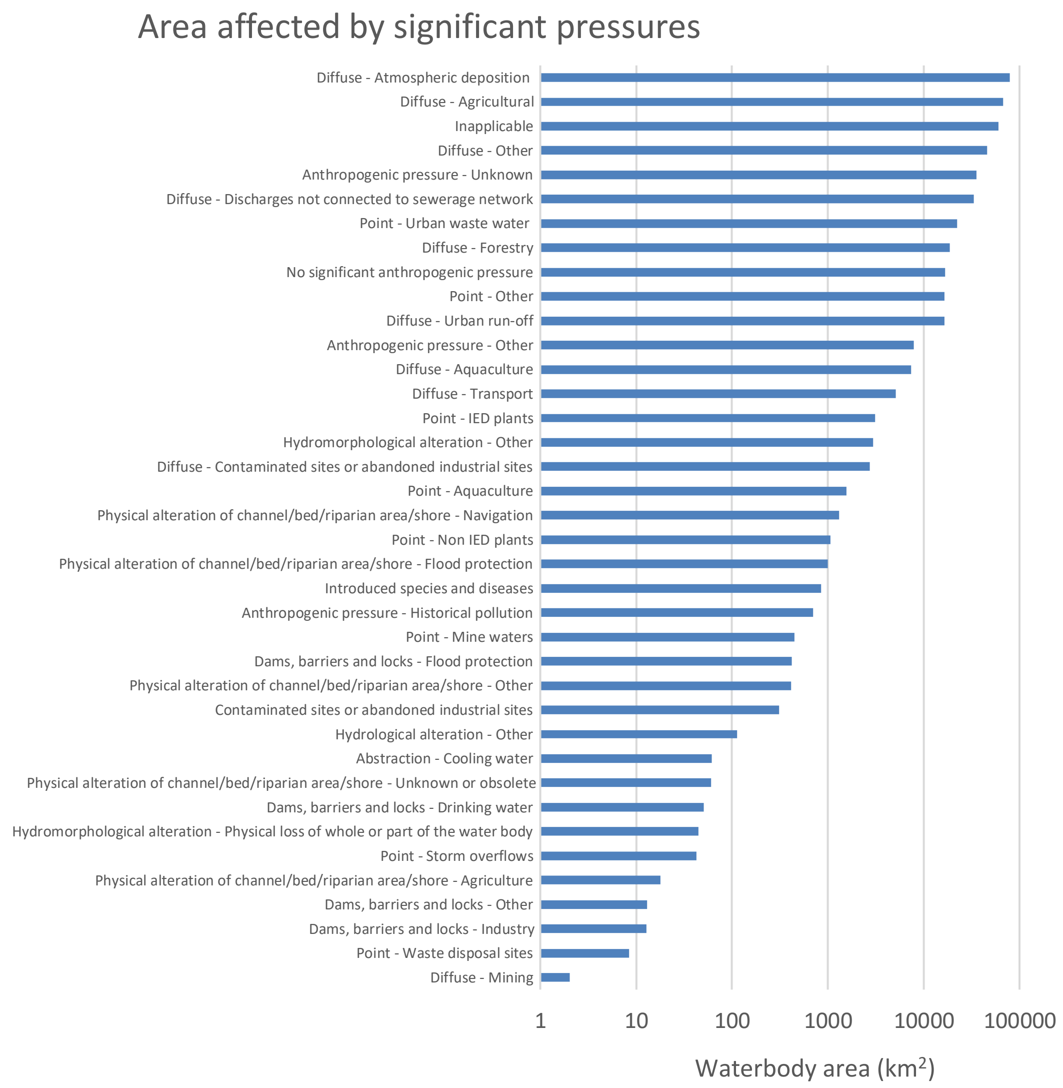


Figure 2. Significant pressures on Baltic Sea coastal waterbodies that prevent the achievement of good ecological status according to the EU Water Framework Directive reporting in 2016. Pressures are ordered according to the extent of a waterbody (i.e. the spatial extent or area) they affect.

2.1 Physical pressures

The physical pressures affecting the seabed and benthic habitats include the physical loss of seabed, physical disturbance to seabed and changes to hydrological conditions. In this section, the significance of physical pressures to the Baltic seabed is considered from the view point of the 2nd HELCOM holistic assessment, the EU MSFD and the EU Water Framework Directive (WFD). The latter two are significant for HELCOM Contracting parties that are also EU Member States.

EU Member States reported the status of seafloor integrity (MSFD Descriptor 6) in their 2018 reporting of MSFD Article 8. EU Member States have also reported national assessments for the extent of physical loss and physical disturbance, as well as adverse effects from physical disturbance (i.e. MSFD D6C1, D6C2 and D6C3). The data were downloaded in October 2020 from the European Environment Agency's (EEA) online portal for 2018 reporting on MSFD Article 8.

Physical loss and disturbance were reported by Denmark, Estonia, Germany, Latvia and Poland (Table 1).

Denmark and Estonia stated unknown status and Germany "not assessed" for both pressures. Poland has set the criterion value in accordance with national methodology for hydromorphological classification of WFD transitional and coastal waters. The status for both physical disturbance and loss is not good in marine areas which are designated as heavily modified waterbodies. Out of 19 Polish reporting units 6 units were reported to have not good status due to heavy modifications. The status of physical loss in the Polish offshore marine areas was good as less than 1% of the marine areas was lost. It should be noted that the MSFD does not require status assessment for the physical loss, disturbance to seabed nor adverse effects from physical disturbance but a status assessment for each broad habitat type due to these pressures (compilation of results in Chapter introduction 5.3).

Table 1. Physical loss (D6C1), disturbance to seabed (D6C2) and adverse effects from physical disturbance (D6C3) in the Baltic Sea as reported by EU Member states in the 2018 reporting of MSFD Article 8. Data accessed via EEA's online portal in October 2020.

Country	Marine Reporting Unit	Physical loss	Physical disturbance to seabed	Adverse effect from physical disturbance
Denmark	BAL-DK-TOTAL	Unknown	Unknown	Unknown
Estonia	BAL-EE-AA	Unknown	Unknown	Good
Latvia	BAL-LV-AAA-006	Good	Not assessed	Not assessed
Lithuania	BAL-LT-AA-01			Good
Lithuania	BAL-LT-AA-02			Good
Lithuania	BAL-LT-AA-03			Good / Not good
Germany	BALDE_MS	Not assessed	Not assessed	Not assessed
Poland	L2-SEA-007-POL	Good	Not assessed	Not assessed
Poland	L2-SEA-008-POL	Good	Not assessed	Not assessed
Poland	L2-SEA-009-POL	Good	Not assessed	Not assessed
Poland	L4-POL-001	Good	Good	Good
Poland	L4-POL-002	Not good	Not good	Not good
Poland	L4-POL-003	Not good	Not good	Not good
Poland	L4-POL-004	Good	Good	Good
Poland	L4-POL-005	Good	Good	Good
Poland	L4-POL-006	Good	Good	Good
Poland	L4-POL-007	Not good	Not good	Not good
Poland	L4-POL-008	Not good	Not good	Not good
Poland	L4-POL-009	Not good	Not good	Not good
Poland	L4-POL-010	Good	Good	Good
Poland	L4-POL-011	Good	Good	Good
Poland	L4-POL-012	Not good	Not good	Not good
Poland	L4-POL-013	Good	Good	Good
Poland	L4-POL-014	Good	Good	Good
Poland	L4-POL-015	Good	Good	Good
Poland	L4-POL-016	Good	Good	Good
Poland	L4-POL-017	Good	Good	Good
Poland	L4-POL-018	Good	Good	Good
Poland	L4-POL-019	Good	Good	Good
Sweden	BAL-SE-AA-BG_Bottniska_Viken			Not assessed
Sweden	BAL-SE-AA-BG_Egentliga_Ostersjon			Not assessed

Under the EU WFD, the ecological status of coastal waters is assessed through several quality elements (incl. macrozoobenthos) and the pressures significantly affecting the waterbody are listed in the WFD reporting. The WFD definitions of the physical pressures are different from the MSFD. Figure 3 gives a summary of the physical pressures under the EU WFD affecting the Baltic Sea coastal waters.

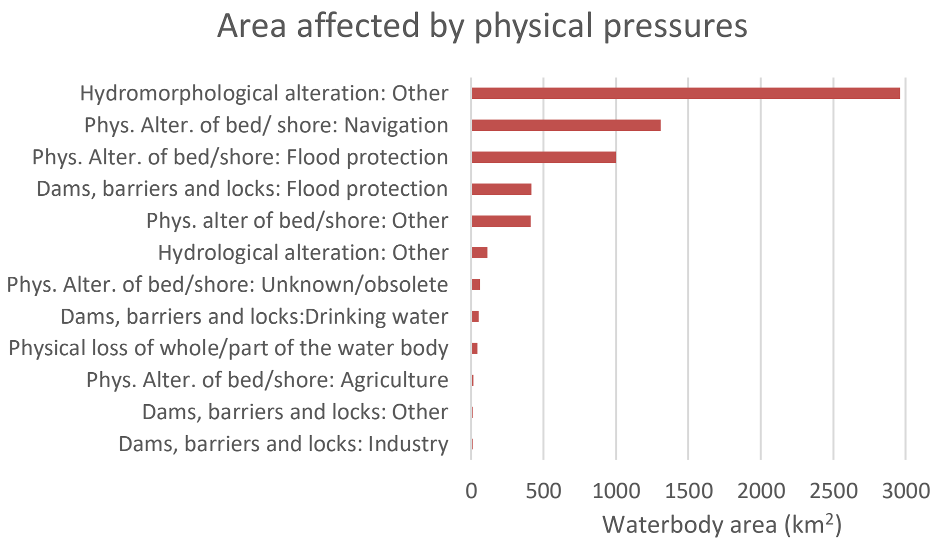


Figure 3. Significant physical pressures on the Baltic Sea coastal waterbodies preventing the good ecological status according to the EU Water Framework Directive reporting in 2016. Pressures are ordered according to the spatial extent (area) of waterbody they affect.

2.1.1 Physical loss

Physical loss has been defined in the revised MSFD Annex III as "physical loss due to **permanent change of seabed substrate or morphology and to extraction of seabed substrate**". In addition, the revised Commission Decision (EU) 2017/848 (EC 2017b) further defines physical loss as "a permanent change to the seabed which has lasted or is expected to last for a period of **two reporting cycles (12 years) or more**". The MSFD criteria for physical loss require an assessment of the spatial extent of seabed area being lost (e.g. as percentage or square kilometers loss per broad habitat type). Here, morphology refers to the seabed topography and bathymetry whereas substrate refers to grain size and substrate type.

In a series of workshops (WKBEDPRES1, WKBEDLOSS, WKBEDPRES2) delivering an advice on the seafloor integrity for the MSFD (ICES 2019a), organized by International Council for the Exploration of the Sea (ICES), a group of experts proposed a slightly different definition for physical loss: "any human-induced permanent alteration of the physical habitat from which **recovery is impossible without further intervention**" (ICES 2019b). This definition would mean that a human activity causes physical loss when a habitat type is permanently changed into another habitat type based on a change at EUNIS level 2 (e.g. littoral mud to littoral coarse sediment habitat type as a result of disposal of dredged sediments). Intervention for recovery is seen as an action to remove the “cause of loss” (e.g removing a man-made structure) or active restoration to revert the seabed habitat back to the original habitat or status (ICES 2019b).

In general, irrespective of the time scale (i.e. for loss is 12 years or more) or requirement for intervention, the following activities have been considered to cause physical loss under HELCOM so far. The activities have been described in more detail in HELCOM Report Estimating physical disturbance on seabed (HELCOM 2018c):

- **dredging and sand and gravel extraction activities** in which seabed substrate is removed and the substrate or morphology is completely changed,
- **disposal of dredged material** and other submerged objects on seabed which change the seabed substrate or morphology; very roughly generalized, if the deposited material is totally different as the buried, the original seabed will not recover,
- **built structures** that occupies and covers the seabed; such as wind turbines, pipelines, breakwaters and jetties
- **marinas and harbours** as they are built structures, but also continuous propeller currents can change the seabed morphology and substrate, and
- **land claim** where marine area is filled to create new dry land, leading to loss of seabed.

Physical loss resulting from these activities can be defined according to the following rules of thumb (HELCOM 2018c):

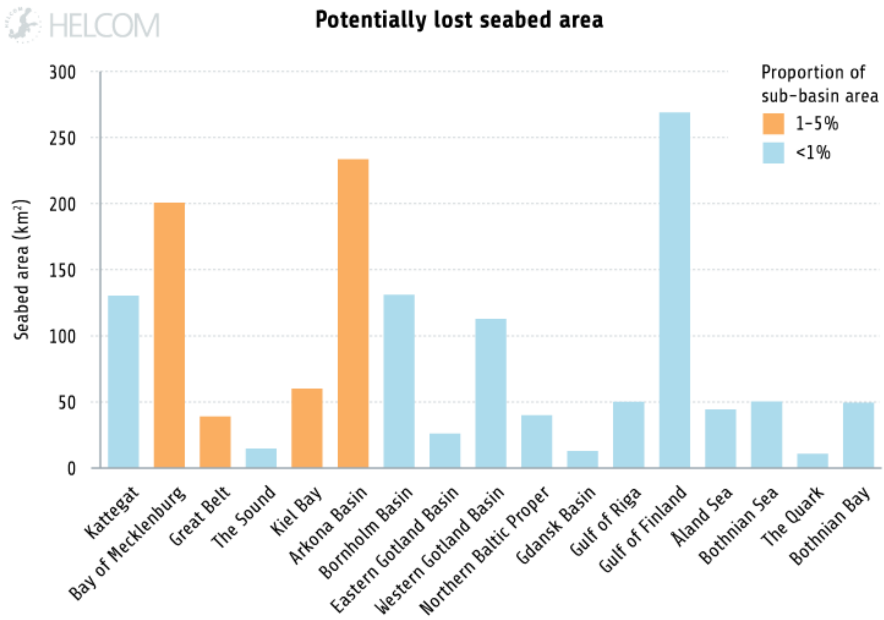
- the core zone of the activity is considered ‘lost’ because the seabed morphology or substrate type has been completely changed **for at least 12 years**, or
- the core zone is **lost forever**, if the site is fully emptied of the substrate type (e.g. particular sediment type/size) or covered by a completely different new substrate type.

The group of ICES experts has defined physical loss in a very similar way, depending on the nature of the human activity (ICES 2019b):

- **Sealed loss** where the seabed is lost because physical structures are built or substrates deposited in to the marine environment,
- **Unsealed loss** is caused by human activities without placing permanent structures but anyway leading to seabed habitat change (e.g. at aggregate extraction sites, extraction of sand and gravel).
- **The loss of biogenic habitat** is a specific more detailed assessment of the loss of biogenic habitat (hard substrate habitat formed by animals or plants) compared to the historical distribution. The loss of biogenic habitat has been lifted as its own category as they tend to be impacted more easily, have very slow recovery and often have limited spatial extent.

The spatial extent of loss is case specific and depends on the footprint of the physical structures or activity. Estimates on the spatial extent of the loss from human activities and man-made structures have been listed in Annex 1.

Physical loss of the seabed resulting from 15 human activities was included in the most recent status assessment of the Baltic sea (HELCOM 2018a). In total, on the regional scale, less than 1% of the seabed in the Baltic sea was lost during the assessment period 2011-2016 (HELCOM 2018b). Spatial differences in loss were seen between the Baltic Sea sub-basins, but no more than 5% loss was estimated in any of the 17 HELCOM sub-basins (
Figure **4.**). The potentially lost area per assessed broad habitat type was also estimated on the whole Baltic Sea scale (
Figure **4.**). Between 1-3% of the total infralittoral sand habitat was lost, while less than 1% of the total area was lost for the other habitat types. The proportional area of broad habitat types lost per sub-basins (Figure 5) shows that human activities leading to loss are mainly activities affecting infralittoral broad habitat types. This, however, gives only a rough estimate of the total loss of the habitats and does not give any estimates on functionality of the remaining habitat. Furthermore, there are several reasons that prevent the current evaluation from being considered as a definitive status assessment, a purpose for which it was not applied. Firstly, the scale of impact from physical loss on wider ecosystem function cannot be ascertained, especially as the data used only considers human activities occurring during a six years period (during 2011-2016) and no historical aspect is addressed. Secondly, while physical loss of less than 5% may be perceived as rather small when comparing with all other pressures occurring at sea (Figure 1) the distribution of the pressures and interlinkage with the habitats on which they are occurring is critical. For example, while loss causing pressures may often occur in very localized areas the loss may end up centralized in a small area of key habitat (e.g. suitable construction sites/substrates or habitat localized in coastal areas also susceptible to flooding) and should such habitat type be already degraded or limited at the local or regional scale the impact could be highly significant. Moreover, such impacts may have more than local impacts should they damage, disrupt or eliminate aspects vital for wider ecosystem functioning.



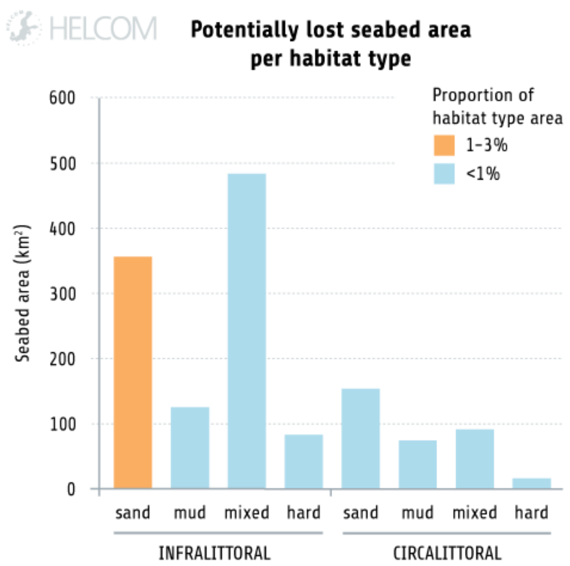


Figure 4. Estimate of seabed area (km2) potentially lost due to human activities per Baltic Sea sub-basin (on the left, presented at HELCOM Scale 2 assessment units, 17 sub-basins). Estimate of area of broad benthic habitat types potentially lost due to human activities (on the right). The estimations are calculated from spatial data of human activities causing physical loss (Source: HELCOM 2018a).

	INFRALITTORAL				CIRCALITTORAL			
	hard	mixed	mud	sand	hard	mixed	mud	sand
Kattegat	1,62	0,81	2,16	0,88	0,00	0,12	0,00	0,05
Great Belt	3,65	1,78	1,23	2,03	NA	0,58	0,21	0,74
The Sound	0,74	4,58	2,03	5,26	NA	6,35	0,00	0,00
Kiel Bay	0,05	0,89	1,84	0,94	0,00	0,03	0,29	0,00
Bay of Mecklenburg	3,39	2,34	0,51	1,74	0,03	0,49	0,04	0,10
Arkona Basin	2,95	3,07	0,45	2,71	0,14	0,06	0,03	0,33
Bornholm Basin	0,35	0,74	0,48	0,34	0,02	0,07	0,06	0,72
Gdansk Basin	0,00	5,61	0,01	1,47	0,00	0,51	0,00	0,06
Eastern Gotland Basin	0,00	0,43	0,08	0,79	0,24	0,05	0,04	0,40
Western Gotland Basin	0,05	0,50	0,60	0,20	0,00	0,01	0,00	0,69
Gulf of Riga	0,25	0,11	0,09	0,25	0,00	0,03	0,00	0,12
Northern Baltic Proper	0,04	0,54	1,21	0,07	0,00	0,03	0,09	0,01
Gulf of Finland	0,77	1,54	2,93	3,79	0,26	0,62	0,25	0,64
Åland Sea	0,23	0,36	0,32	0,33	0,04	0,06	0,08	NA
Bothnian Sea	0,18	0,57	1,33	0,00	0,00	0,00	0,00	0,00
The Quark	0,13	0,22	0,90	0,00	0,01	0,00	0,00	0,00
Bothnian Bay	0,24	0,64	0,19	0,29	0,00	0,00	0,00	0,00

0-1 % 1-2 % 2-3 % >3 %

Figure 5. Estimate of the proportion (%, coloured with ranges) of the broad habitat types potentially lost due to human activities per sub-basin. The estimate is calculated based on the HELCOM HOLAS II BSII datasets and is indicative of the level of impact. The proportion of lost habitat area is calculated in GIS in a 1 km^2 grid. 'NA' means that the habitat type is not represented in the sub-basin.

Based on the spatial data on human activities causing physical loss included in the second holistic assessment of the Baltic Sea (HELCOM 2018b), proportions of human activities contributing to the physical loss per sub-basin were calculated. On the Baltic Sea scale, sand and gravel extraction contribute proportionally the most to the loss of seabed habitats (38%) (Figure 6). Harbours are the second biggest cause of lost seabed (29%), followed by marina structures (11%). The future need for sand and gravel, e.g. for construction activities, could keep the level of the activity high (WWF 2010). Similarly, a similar pattern for shipping and logistics, requiring physical 12arbor structures etc is anticipated (Fidell et al. 2016). Human activities causing physical loss differ between the sub-basins. The relative contributions per total lost area of each sub-basin is shown in Figure 6. Extraction of sand and gravel is causing physical loss in the southern parts of the Baltic Sea but in the northern parts the activity is almost non-existent. On the contrary, marinas are contributing to the loss relatively more in the northern parts of the Baltic Sea.

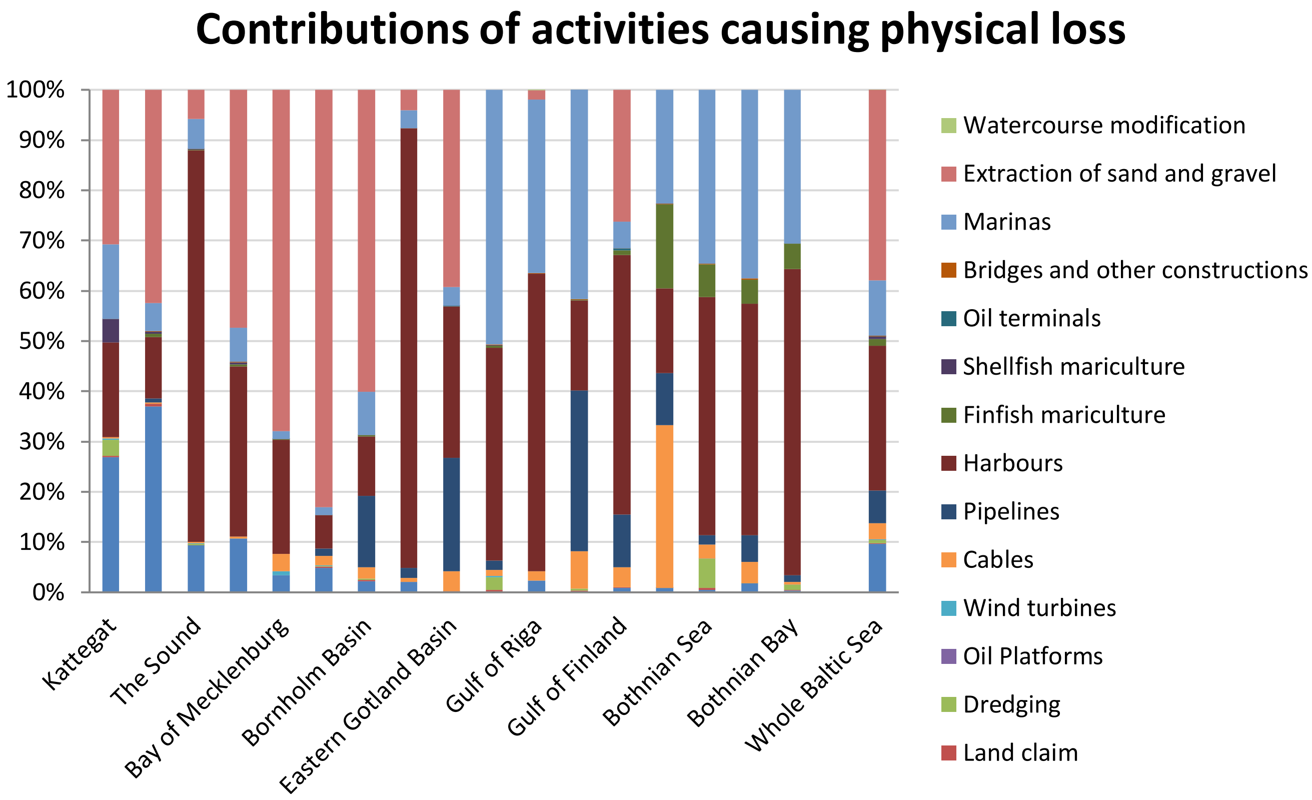


Figure 6. Proportions of human activities causing physical loss per sub-basins of the Baltic Sea. The figures were derived from HELCOM human activities data sets prepared for the aggregated physical loss datalayer in the BSPI development during the HOLAS II process. The total lost area due to each activity per sub-basin was calculated and divided by the total lost area per sub-basin. Figure 4 shows in colour the estimate of proportion (%) of seabed area potentially lost due to human activities per Baltic Sea sub-basin.

There are still large uncertainties and unanswered questions in the physical loss assessments. Most importantly, they always depend on the definition of the time span:

- following the MSFD definition, there is a lower threshold to add physically lost area to the assessment, because an area can be lost even with a twelve-year recovery time; this will add many types of dredging activities into physically lost areas;
- following the ICES definition, only permanent impacts are included to the assessment; this will greatly limit the lost area compared to the previous definition.

Secondly, the lost area always depends on the setting of the historic baseline and availability of historic data. The baseline means here a starting point to the assessment in time. For example, humans have modified coastal areas, shoreline and reefs for centuries, but little data is available from those times. In land uplift areas, such as the northern Baltic Sea, the shoreline modifications from human development are difficult to distinguish from the natural change. For practical reasons, it may be necessary to set up a modern baseline for this assessment.

2.1.2 Physical disturbance

Physical disturbance to the seabed, being temporary or reversible, has been defined in the revised Commission Decision (EU) 2017/848 (EC 2017b) as: "**a change to the seabed from which it can be recover if the activity causing the disturbance pressure ceases**". An assessment of the spatial extent of seabed area being disturbed per broad habitat type is required (e.g. MSFD D6C5), as well as a data layer of the pressures (MSFD D6C2). The HELCOM BalticBOOST project suggests that "because recovery time leading to the physical loss was defined >12 years, disturbance can be refined on the basis of the recovery of **<12 years"** (HELCOM 2018c). However, the Commission Decision (EU) 2017/848 (EC 2017b) does not reflect this temporal threshold of 12 years for seabed to recover from the activity and simply defines that recovery can occur once the pressure ceases. The ICES workshop process (ICES 2019c) and subsequent guidance (ICES 2019a) follows the definition without any specific timespan for recovery, just as long as the original state is expected to be reached.

Several human activities have been identified to cause physical disturbance to seabed habitats. Activities physically modifying and extracting seabed substrate, mobile bottom-contacting fishing, shipping and leisure activities may disturb the seabed habitats directly or indirectly. Quite often the forms of physical disturbance occur outside of the core area of physical loss, as described in the previous chapter. Human activities causing physical disturbance and estimations of their spatial extent are listed in Annex 2.

Physical disturbance can be divided into the following more specific pressure types (HELCOM 2018c):

- **Siltation or sedimentation** is caused by resuspended sediment particles re-settling to new areas as a result of seabed disturbance. Siltation or sedimentation can happen as a result of propeller currents lifting seabed sediment into the water column, leakages from a grab when lifting sediment to a barge, depositing material to seabed or spreading matter from point sources and rivers. If the sedimentation is heavier, it is often called **smothering**.
- **Turbidity** is caused by resuspended sediment particles decreasing the light penetration through the water column to the seabed. Turbidity is usually caused by the same activities as in for siltation or sedimentation.
- **Abrasion** is caused by activities which touch, scrape or press the seabed surface. Bottom-touching activities are different types of demersal fishing, propeller current erosion by shipping and boating in shallow and narrow areas as well as anchoring and mooring.

The ICES workshop process (ICES 2019c) and subsequent guidance (2019a) also identified sub-types for physical disturbance depending on the nature of the pressure:

- **Deposition** means placement of sediment on top of existing substrates in the seabed either directly from human activities (depositing material) or indirectly from changes in hydrological conditions.
- **Removal** means removing the seabed substrate away either because of direct human activity (e.g. dredging) or indirectly from changes in hydrological conditions.
- **Abrasion** means the touching, scraping or pressing the seabed substrate during bottom-touching activities, such as demersal fishing or anchoring. Even tough abrasion can mix the substrates in the seabed, it is considered not to remove them (see difference with "removal").

The physical disturbance to seabed from 15 human activities was included in the most recent assessment of the state of Baltic sea (HELCOM 2018a). Based on the spatial data of human activities causing physical disturbance included in the second holistic assessment (HELCOM 2018b), estimates of seabed area (Figure 7, HELCOM 2018a) and broad habitat types (Figure 8, HELCOM 2018a) potentially disturbed per sub-basin has been calculated. Estimations of the proportions (%) of broad habitat types affected by physical disturbance per sub-basin show that most of the broad habitats in the southern Baltic Sea are potentially widely affected (Figure 8). In the Northern part of the Baltic Sea, infralittoral broad habitats tend to be more potentially impacted than the circalittoral habitats. This may be the result of lacking bottom trawling activity and bigger proportion of shallow water activities such as recreational boating (Figure 9).

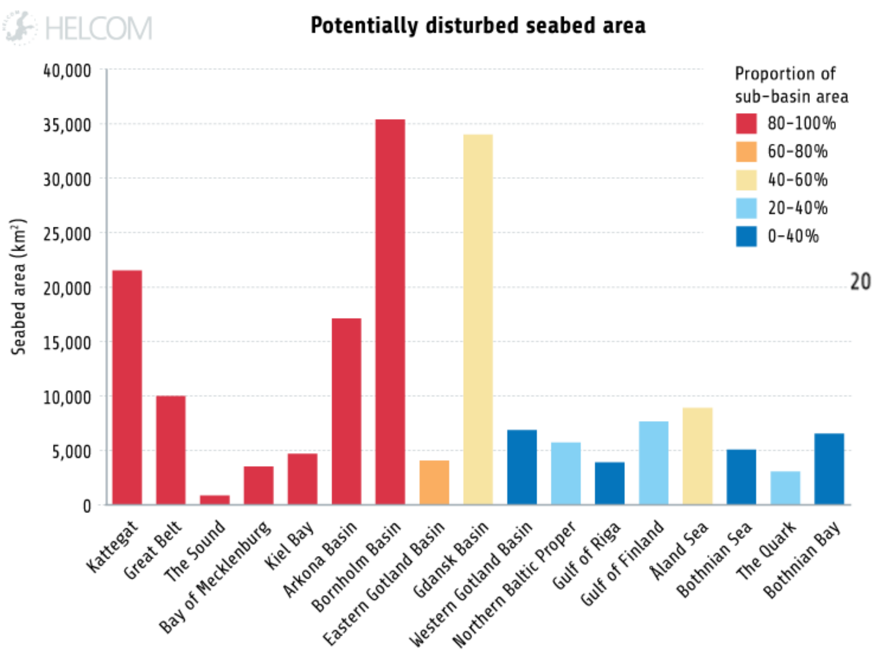


Figure 7. Estimate of seabed area (km2) potentially disturbed due to human activities per Baltic Sea sub-basin. The estimations are calculated from spatial data of human activities causing physical disturbance (Source: HELCOM 2018a).

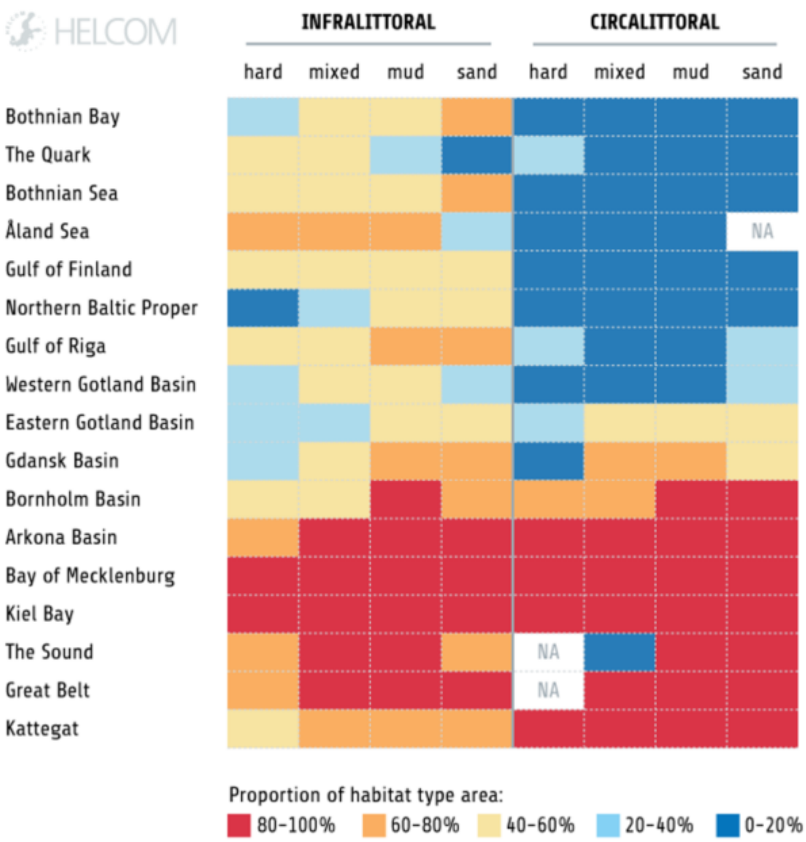


Figure 8. Estimate of the proportion (%, given in ranges) of the different broad habitat types potentially affected by physical disturbance per sub-basin. The estimate is calculated based on the HELCOM HOLAS II BSII datasets and does not reflect the actual level of impact. 'NA' denotes that the habitat type is not represented (Source: HELCOM 2018a).

The proportions of human activities contributing to the physical disturbance per sub-basin was calculated based on the HELCOM data used in the Second holistic assessment and available from HELCOM Maps and Data service (HELCOM MADS). On the Baltic Sea scale, fishing with mobile bottom-contacting gear contributed proportionally to the most (66%) of physical disturbance to seabed habitats (Figure 9). The relative contributions of activities per total disturbed area of each Baltic sub-basin (Figure 9) reveals that the proportion and distribution of human activities causing physical disturbance to the seabed is not uniform throughout the Baltic Sea sub-basin. Also, some area specific phenomena can be recognized. The human activities contributing most to physical disturbance differ between the Eastern Gotland basin and the Western Gotland basin. Fishing with mobile bottom-contacting gear is causing most of the pressure in the southern Baltic Sea while recreational boating is dominating in the northern areas, this is particularly visible to the limited bottom-contacting fishing activity in the north and thus the increase relative importance of other pressures. Both dredging and deposit (disposal) of dredged material tends to be relatively larger in the northern parts of the Baltic Sea.

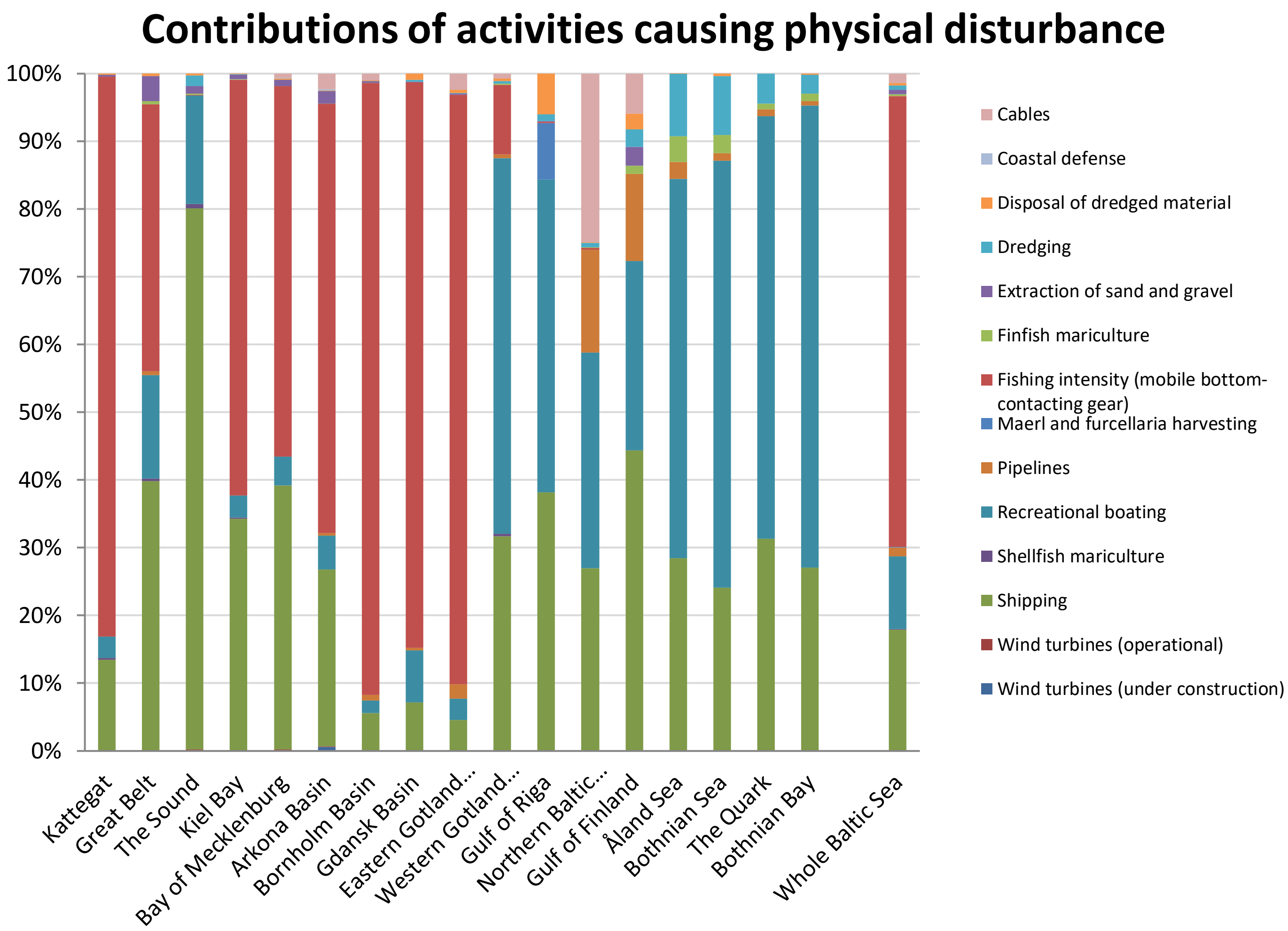


Figure 9. Proportions of human activities causing physical disturbance per sub-basins in the Baltic Sea. The proportions (%) were derived from HELCOM human activity data prepared for the aggregated physical disturbance data layer in the BSPI development during the HOLAS II process. The sum intensity of each human activity per sub-basin was divided by the sum of all activities per sub-basin. Figure 7 shows the estimate of proportion (%) of seabed area potentially disturbed due to human activities per Baltic Sea sub-basin in colour.

2.1.3 Changes to hydrological conditions

Changes to hydrological conditions are caused by built structures altering the natural water flow dynamics and conditions. **Permanent changes in hydrological conditions** take place in the vicinity of the built structure (HELCOM 2018c) but the pressure may have an impact on a larger scale, e.g. altered flow condition caused by large construction projects. Hydrological changes in the flow field may change the seabed habitats via causing erosion, abrasion, resuspension and sedimentation. These indirect effects are, however, difficult to assess and approximations are needed (HELCOM 2018c).

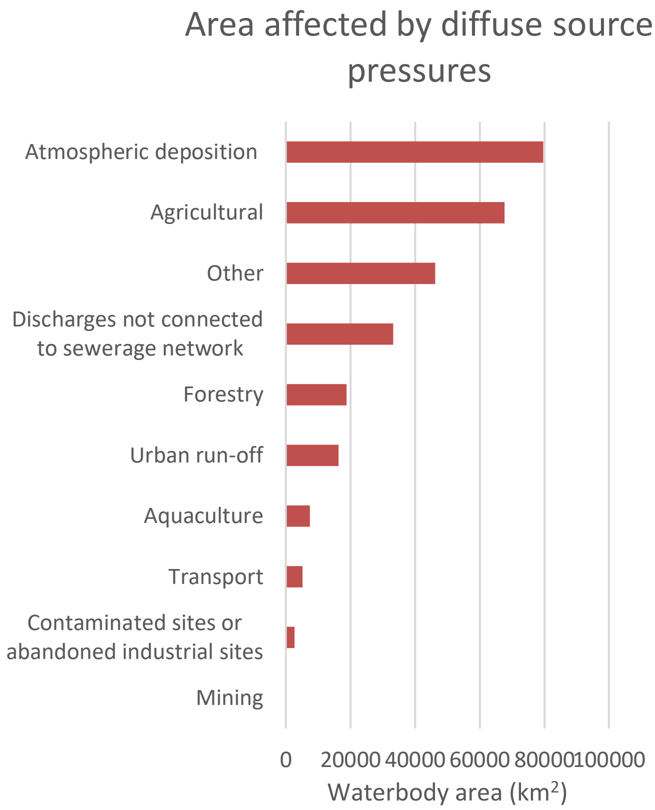
The following activities have been considered to cause changes to hydrological conditions (HELCOM 2018c):

- Activities related to energy production at sea, including operational wind farms, wave energy production as well as oil and gas infrastructure (e.g. oil platforms);
- All built coastal structures such as breakwaters, groynes, marinas and leisure harbours, piers, artificial reefs and islands as well as coastal dams.

Human activities changing hydrological conditions and the spatial extent of the pressure are listed in Annex 3. In addition, the pressure may also be caused by dredging mouths of semi-enclosed bays and, hence, increasing flows. These have been found very destructive to vegetation communities in flads (Rosqvist et al. 2010).

2.2 Input of substances

Pollution from diffuse and point sources were identified contributing significantly to input pressures for the coastal waterbodies in the Baltic Sea (Figure 2). Figure 10 gives a more specific view of pollution and indicates that atmospheric deposition, agricultural run-off and waste waters from scattered dwellings are estimated as much higher pressures than the point sources on coast or inland.



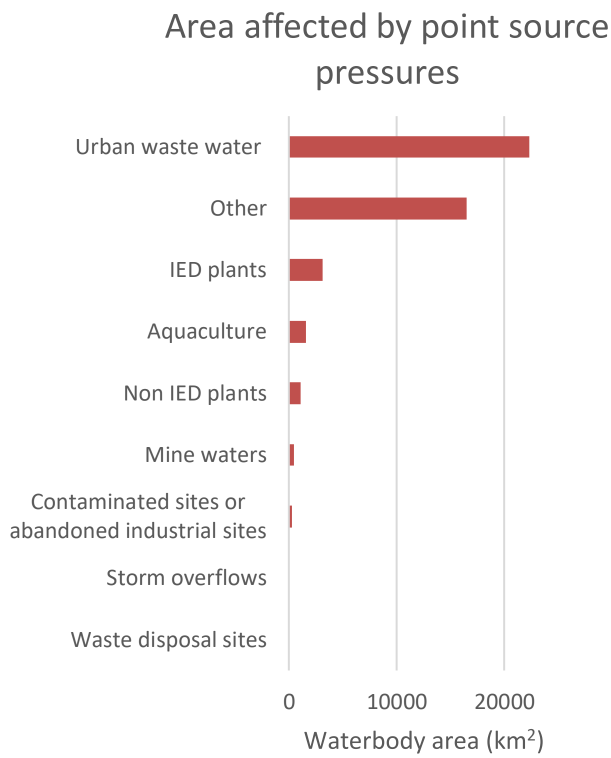


Figure 10. Significant sources of pollution from diffuse (left) and point sources (right) to the Baltic Sea coastal waterbodies preventing the good ecological status according to the EU Water Framework Directive reporting. Pressures are ordered according to the extent area of waterbody they affect.

2.2.1 Input of nutrients and eutrophication

Input of nutrients as a pressure, leading to eutrophication, is major environmental problem of the Baltic Sea and it has been identified as the most extensive pressure affecting the marine environment (Figure 1, HELCOM 2018a). It also emerges as one of the most significant pressures preventing the achievement of good ecological status in Baltic Sea coastal waterbodies (Figure 2). The expert survey carried out in the HELCOM ACTION project identified eutrophication as the main pressure for the benthic habitats (available in December 2020). Eutrophication is the consequence of urbanization, industrialisation, population growth, agricultural practices and intensive animal farming. During the last century alone, the nutrient inputs to the Baltic Sea have increased by 2,5 times for nitrogen and 3,7 times for phosphorus (Savchuk et al., 2008). In 2017, the total inputs of nitrogen and phosphorus to the Baltic Sea were 859,331 tonnes of N and 28,807 tonnes of P (HELCOM 2019). In addition to the input, the sediment-released nutrients, or internal cycling of historical phosphorus accumulation in the seabed sediments, and internal biogeochemical cycle are also considered as a high source (HELCOM 2018d).

Based on the integrated assessment of eutrophication (HELCOM 2018e), the overall status of eutrophication indicates that most of the Baltic sub-basins, as much as 96% of the entire Baltic sea area, is suffering from eutrophication and good environmental status is not achieved (HELCOM 2018e). According to the integrated assessment of eutrophication, good status is reached only in few Swedish and Finnish coastal sub-basins in the Bothnian Bay or Kattegat (HELCOM 2018e). Within the integrated eutrophication assessment, the results of several HELCOM core-indicators were integrated and for coastal areas several national indicators of benthic macrofauna and macrophytes were used (HELCOM 2018e). Oxygen debt and water clarity (especially in the coastal waters) affects the seabed habitats and species utilizing it by limiting the distribution of species and reducing habitat quality. Oxygen debt has been utilized as a factor in the HELCOM core-indicator for status of the benthic macrofauna community (see section 5.4). The anoxic and hypoxic seabed areas cover wide areas in the Bornholm Basin, Gdansk Basin, Baltic Proper and western Gulf of Finland. In these sub-basins, around 24% of the seabed area was affected by anoxia and around 33% of the area was in hypoxic conditions in 2018 (Hansson et al., 2020).

2.2.2 Hazardous substances

Hazardous substances have been identified as the second most extensive pressure affecting the marine environment of the Baltic Sea (Figure 1, HELCOM 2018b). Hazardous substances are also among the most significant pressure (i.e. diffuse atmospheric deposition) affecting the coastal areas and preventing good ecological status in the Baltic Sea coastal waterbodies (Figure 2). In total, thousands of hazardous substances have been identified to occur in the Baltic Sea (HELCOM 2018f). Hazardous substances enter the marine environment via many pathways, such as direct discharges, diffuse sources, oil spills, disposal of contaminated material or airborne deposition. Historic deposits of contaminated sediments can also function as a source for hazardous substances through re-release process or by disturbance (HELCOM 2018f). Thus sediments can function as both sinks and sources of hazardous substances. Deposits of heavily contaminated sediments are often a local phenomenon, where polluted sediments have accumulated in a specific place due to sediment transportation or discharges from human activity such as industry. These areas with contaminated sediments which are often hazardous and toxic to benthic macrofauna.

Numerous hazardous substances are regularly monitored and used in to assess the contamination status of the Baltic Sea, though these only provide a limited picture of the number of substances that may be present. National monitoring may contain larger numbers of substances, but only a limited number of substances or substance groups are addressed by HELCOM regional indicators, and an extensive array of other substances have been identified in other approaches, such as screening. Based on the integrated assessment of hazardous substances (integrating the existing core indicators, HELCOM 2018f), the marine environment is exposed to a high level of hazardous substances and this pressure exists in all sub-basins of the Baltic Sea. Baltic countries monitor hazardous substances in sediment, biota and the water column. Hazardous substances are spread all through the Baltic Sea and their impacts can be recorded all the way through the food web, via accumulation in living organisms (HELCOM 2018f).

Presence of hazardous substances in the seabed sediment can affect the soft-bottom macrofauna species, e.g. by inducing reproduction malfunctions, leading to decreased population persistence (HELCOM 2018g). The reproductive disorder in malformed embryos of amphipods is a HELCOM supplementary indicator used to assess contamination status and currently applied in Swedish and Finnish waters (HELCOM 2018g). Where applied in Swedish and Finnish marine areas of the Western Gotland Basin, Quark, Bothnian Sea and the Northern Baltic Proper good status was not reached in the latter two due to the high rate of embryo malformations indicating adverse effects of hazardous substances in the seabed sediments.

2.2.3 Marine litter

Marine litter is a broad category for a wide range of artificial particles made of different materials such as plastic, rubber, metal and glass. Marine litter enters the marine environment via several pathways and from multiple sources and can be transported far away by winds and sea currents (Eriksen et al. 2014, HELCOM 2018a). Even though all marine litter is originally from land, they can be classified into marine and land-based sources. It has been estimated that 80% of the marine litter is from direct land-based sources (UNEP 2005). The maritime human activities, including shipping and fishing, are the main sources of the marine-based input of litter in the Baltic Sea. This includes fishing gear lost, abandoned or discarded to the sea (also known as ghost nets), which can cause a severe risk to marine mammals, fish and seabirds as they are a risk for entanglement and by-catch (WWF Poland 2015).

Seafloor litter has been surveyed in the Baltic Sea under the BITS (Baltic International Trawl Surveys) monitoring program since 2012 (ICES 2014) by counting how much litter is caught in a fish trawl. The amounts of marine litter from trawling surveys were analysed in the HELCOM SPICE project, and Nilsson (2017) has presented that: "The average total number of seafloor litter items was 58,9 ± 20,9 items per km^2 (average ± 95 confidence interval). The average total weight of items was 85,3 ± 65,2 kg per km^2 (average ± 95% confidence interval). Items made of natural materials were most common both in terms of number of items (44,6%) and in terms of weight (56,6%). Plastic was the second most common material (30,6 % of number of items, 15,7 % of the weight)". The survey does not cover shallow water areas, or the northern sub-basins and it is limited to suitable trawling substrates (Nilsson 2017).

In a study by Urban-Malinga et al. (2018), marine litter occurrence and composition on the seafloor were investigated in Polish Maritime areas. Litter densities between 0 – 223 items per km^2 (original reported unit of measure in hectares) with a mean of 20 items/km^2 were found. In their study, plastic was found to be the most common litter type found (67% of all items). In another study, by Galgani et al. (2000), a total of 126 litter items per km^2 on the seafloor were found in the West Baltic Sea, with plastic item density at 45 items/km^2.

2.3 Non-indigenous species

Non-indigenous species (NIS) are species that have been introduced or spread, due to human activities, into new environments where they would not naturally occur in. All NIS are not harmful, i.e. not all non-indigenous species cause damage and have severe impacts in the marine environment (HELCOM 2018h). Often secondary spread, establishment and impact of NIS are poorly documented or understood due to the extensive monitoring needs, however they may fill niches in the ecosystem, exert competition or direct predation. However, some of the most successful NIS may alter the entire invaded habitat (Olenin & Leppäkoski 1999) causing severe damage to the ecosystem.

Aquaculture and shipping are the major vectors of NIS to the Baltic Sea (Galil et al., 2014). Canals connecting different river systems within Europe are another important vector for spread, and many Ponto-Caspian species have been introduced to the Baltic Sea this way (HELCOM 2018a). In total 140 NIS have been found in the Baltic Sea (HELCOM 2018a). HELCOM has recently assessed (HELCOM 2018h) the number of new introductions of NIS or cryptogenic species to the Baltic Sea region during the assessment period of 2011-2016. During this period, twelve new NIS species arrived in the Baltic Sea. The agreed threshold value for good status is zero new introductions of NIS due to human activities. Hence, good status was not achieved (HELCOM 2018h)

HELCOM has not set up monitoring or assessments for established NIS and eradication is often not a viable management option after establishment and spread. According to HELCOM, the primary aim of management should be on preventing new arrivals and introductions as well as minimizing the effects of the NIS already present in the Baltic Sea (HELCOM 2018a). However, the pressure by established NIS on benthic habitats is noticeable as estimated in the report of pressures in Europe's seas (Korpinen et al. 2019).

3. Pressure impacts

3.1 Impacts of physical pressures on the seabed

Though human activities impact seabed habitats, their impacts are generally discussed through the pressure they are causing and contributing to. As presented above, some human activities may contribute to several physical pressures, but the nature and spatial footprint of the pressure and its component parts can be different. A scheme for pressure footprints of, and resulting from, a single human activity is illustrated in Figure 11. Estimating the spatial extent of a pressure and thus its zone of expected impact is a challenge and sometimes it has to be estimated by buffering, e.g. with using precautionary approach to estimate the “worst case scenario” of the expected impact. In reality it is a challenge to estimate general buffers for pressures as they differ from case to case due to the technical characteristics of human activity (e.g. individual footprint of different size wind turbines or anchors of aquaculture stations) and local environmental conditions.

The difference between physical disturbance and physical loss is a fine line and sometimes hard to evaluate. In cases where good data is available (e.g. in situ data for change of seabed habitat) and where a more detailed spatial scale is relevant, a finer distinction and description of disturbance and loss would be appropriate (HELCOM 2018b, ICES 2019b). In addition to the spatial extent, the temporal dimension of the activities affects the impact. A human activity causing permanent change of the seabed substrate or species composition, e.g. extraction of sand and gravel, can be taking place for long time and lead to loss. As a short-term activity but penetrating deep into the seabed can also lead to loss. However, great effort has been made to develop the HELCOM pre-core indicator ‘Cumulative impact on benthic biotopes’ for estimating the cumulative impacts of physical disturbance and loss to benthic habitats.

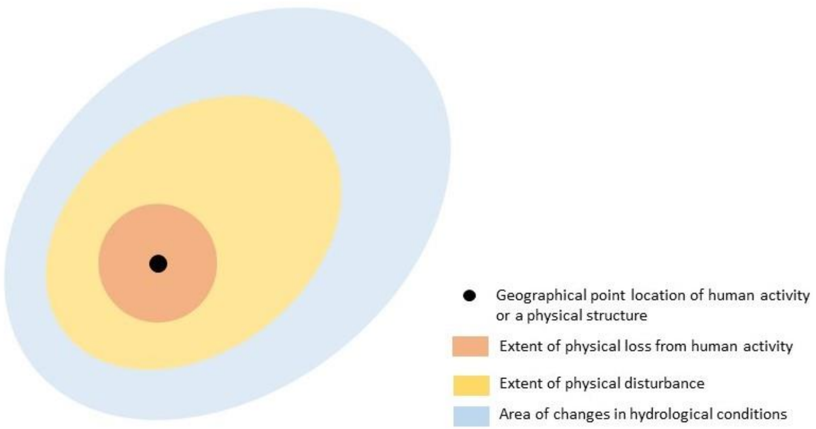


Figure 11. Areas around a human activity may result in impact from several physical pressures. Orange illustrates the zone of physical loss around a human activity or a built structure. The zone of physical disturbance is often larger and extends further. Permanent changes to hydrological conditions is illustrated with blue. The shape of the impacted area for physical disturbance and changes to hydrological conditions depends always on the local hydrological conditions (Modified from ICES 2019b).

In general, human activities impact the seabed through pressure pathways. Thus, identifying the pressure from an activity can help in estimating potential impacts in the environment. The impacts of human activities causing physical pressures on the seabed have been estimated based on the findings from a literature survey (Table 2., HELCOM 2018c).

Table 2. Physical loss and disturbance caused by human activities and their potential impacts on the benthic habitats (Source of the whole table: HELCOM 2018c).

Human activity	Pressure and potential impact in the marine environment
Capital and maintenance dredging	• removal of substrate (physical loss of a habitat) • changes in the seabed topography (altered physical conditions) • resuspension of silt (turbidity) • sedimentation of the dredged matter on nearby areas (smothering if sedimentation is high or siltation if sedimentation is low)
Disposal of dredged matter	• smothering of benthic organisms and changing sediment characteristics (physical loss). However, the effect is strongly affected by the environmental characteristics of the disposal site. • increased siltation; the impacts of disposal of sediment depend on the seafloor habitat type, type and amount of disposed material and distance to the disposal site. • increased sedimentation in the areas surrounding the disposal sites which causes for example mortality and changes in the population structure of benthic organisms. • increased water turbidity (short-term effect)
Sand and gravel extraction	• removal of substrate (more or less complete mortality of benthic organisms) • changes in the seabed topography • resuspension and sedimentation in nearby areas • most often a permanent change in the grainsize composition (due to the sieving of wanted grain size and discharging unwanted matter overboard), water depth and hydrological features
Shipping and ferry traffic	• abrasion because of propeller induced currents • resuspension and siltation of sediments • stress in littoral habitats because of waves • physical disturbance because of anchor dragging • negative effects on the coverage and species richness of benthic vegetation • negative effects on fish dependent on the benthic habitat for spawning or as nursery grounds

Wind turbine construction	• drilling and relocation of land masses (abrasion, smothering, sealing) • siltation and turbidity in the surrounding area • physical loss (area determined by the scour protection)
Wind turbine operation	• hydrological secondary effects caused by averted currents • abrasion effects around the turbines
Placement of cables and pipelines	• changes in sediment composition as cables are covered with sediment extracted elsewhere • siltation • loss of habitats by smothering and sealing • in case of the big gas pipelines the seabed is disturbed through ploughing, explosions, burial and relocations of sediment masses
Motor boating	• same physical impact to benthic habitats as shipping but in a smaller scale • maintenance of boating channels by small-scale dredging in shallow inlets has large impacts on benthic vegetation
Marinas	• decreases in vegetation cover and species richness
Demersal fishing	• decrease of biodiversity, density and mean weight of benthic macrofauna • the main impact is the abrasion which causes direct mortality, bycatch of larger features and abrasion of the seafloor
Land claim	• physical loss of the seabed as a marine area is turned into dry land

The impact of physical loss is perhaps the simplest to define: what is lost is lost. However, when looking into the effects of loss, we must also consider the extent and spatial patterns of the loss taking place, for example is loss concentrated in/on a particular habitat type and consequently what is a sustainable or acceptable level of loss (overall and per habitat type). In addition, aspects such as status and connectivity of the habitat type in question elsewhere in the Baltic Sea may also be relevant to consider. Currently, no threshold values for adverse effects from physical loss have been established or agreed on.

The **impacts of physical disturbance** on the seabed always depend on the sediment/substrate present and species composition at the specific location. The recovery time and resistance to specific pressures may change dependent on such factors (see chapter 3 for sensitivity of habitats). Several studies estimating effects of physical pressures have been identified and a review on them has been done in the BalticBOOST project (HELCOM 2018c). A catalogue containing information of the reported pressures and benthic impacts caused by human activities is available in the annex of 'Estimating physical disturbance on seabed' report (HELCOM 2018c). A summary of highly impacting physical disturbances on some benthic habitats and species is presented in Table 3.

Table 3. Estimates of high impacts of physical disturbance on some benthic species and their state parameters. The given estimates are guidelines only and cannot directly be related to setting threshold values for maximum allowable pressures. The pressure amounts are measured at 0.2-0.9 km distance from the activity, but the level of impact still depends on local environmental factors. The numbers are generally from semi-exposed coast, unless stated otherwise (Source: HELCOM 2018c).

	Physical disturbance causing adverse impacts
Fucus colonization	0,1 g/m^2 (dw) sediment cause poor colonization: only 5% of propagules grow (Berger et al. 2003), 0.2 cm burial, 10 g/m^2 per day sedimentation inhibits colonization (Vatanen et al. 2012)
Fucus growth	7 g/m^2 sediment burial inhibits Fucus photosynthesis and growth (Ari Ruuskanen, unpublished)
Eelgrass mortality (*Zostera marina*)	>50% mortality at 4 cm burial in 24 days; critical sedimentation rates for seagrasses in general are 1.5-13 cm /year (Erftemeijer & Lewis 2006).
Seagrasses in bays	In sheltered bays a marina caused 135 % increase in turbidity as well as 10-82 % decrease of sensitive plant species, 25-29 % increase of plant species indicating eutrophication, ~31 % decrease in vegetation cover and 37 % decrease in plant species (Eriksson et al. 2004); 10 ferries/day caused 55 % increase in turbidity as well as 38-100 % decrease of sensitive plant species, 38-39 % increase of plant species indicating eutrophication, ~29 % decrease in vegetation cover and ~31 % decrease in plant species (Eriksson et al. 2004, Sandström et al. 2005)
Herring fry mortality (detachment)	40-60 g/m^2/d (Vatanen et al. 2012)
Fish juvenile mortality	A marina in sheltered sites caused ~89% less mean catch per unit effort of pike Y-O-Y and increased catches of bleak (benefits of eutrophication) (Sandström et al. 2005); 10 ferries per day caused ~86% less mean catch per unit effort of pike Y-O-Y and increased catches of bleak (benefits of eutrophication) (Sandström et al. 2005).
Benthic fauna mortality (hard substrate fauna)	1-2 cm burial causes high mortality (Essink 1999).
Benthic fauna mortality (soft substrate fauna)	10-40 cm burial kills fauna (58-100% mortality) (Essink 1999, Powilleit et al. 2009).
Benthic fauna mortality (the amphipod *Corophium volutator*)	44% mortality at 2.3 cm burial in a month, 82% mortalit yat 7 cm burial in a month, 99,6% mortality at 10.2 cm burial in a month (Phua et al.2004)
Benthic fauna mortality (the bivalve *Macoma balthica*)	20 % mortality at burial of 10.2 cm (Phua et al. 2004).
Mortality of juvenile *Macoma balthica*	40-60 g/m^2/d (Vatanen et al. 2012)
Benthic fauna community (benthic quality index)	7-9 mg/L suspended solids, turbidity 5-8 NTU caused sub-GES conditions in the indicator (See Figure 9 in HELCOM 2018c)

3.2 Impacts of nutrients and eutrophication

The input of nutrients, leading to eutrophication, is a major pressure impacting the Baltic Sea ecosystem. This is true for both the offshore waters (HELCOM 2018b) and the coastal waters (Figure 12). Excess input of nutrients results in eutrophication which then causes impacts in marine environment. As eutrophication is a process rather than a single pressure factor, it is necessary to distinguish which eutrophication factors impact on benthic marine life. For benthic communities, the major factor is increased prevalence of oxygen-depleted (hypoxic) bottom water and sediment (Diáz and Rosenberg, 2008). In addition to the oxygen conditions, changes in visibility and water clarity have effects on the benthic habitats, for example it limits the growing depth of key species. Input of nutrients also supports the growth opportunistic short-lived macroalgae which can suffocate and destroy other macroalgae habitats (such as eel grass meadows). A full overview of processes related to nutrient loads, concentrations and eutrophication effects can be found in HELCOM 2009, however, this section primarily reviews the current knowledge of hypoxia effects due to its direct relationship with benthic habitats.

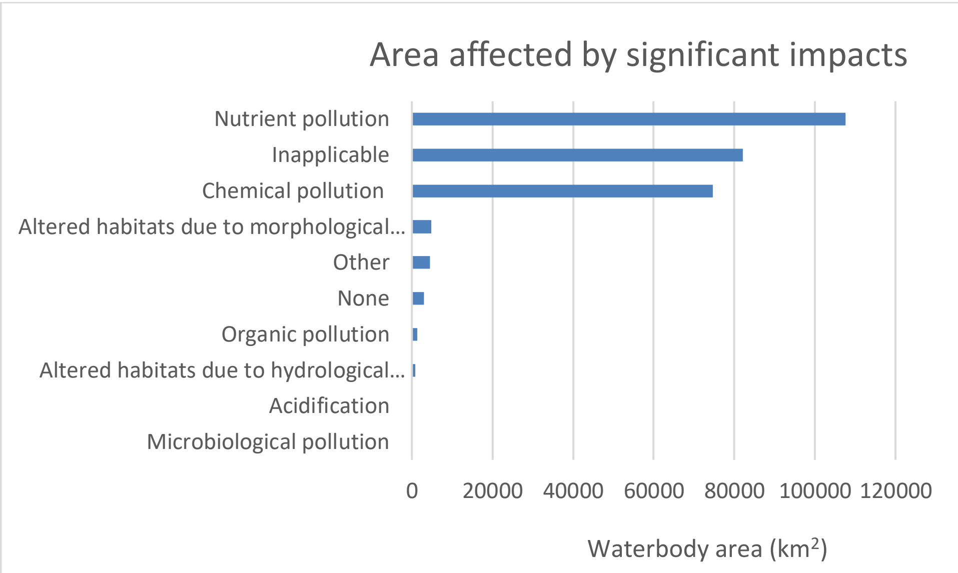


Figure 12. Pressures exerting highest impacts on the coastal waterbodies according to the EU WFD reporting of the Baltic Sea member states in 2016.

Hypoxic conditions start to develop when increased biomass is accumulated on the seabed due to the input of nutrients and eutrophication process, i.e. overproduction (see details in HELCOM 2009). Biomass on the seabed is degraded in biological and chemical processes by benthic consumers which also consume oxygen in the metabolization process (reviewed by Korpinen & Bonsforff 2015). The increased biomass leads to increased number of benthic consumers resulting in conditions with less oxygen. Typically, hypoxia is defined as the oxygen concentration below 2.8 mg L^{-1} (Diaz & Rosenberg 1995, Vaquer-Sunyer & Duarte 2008). A more severe condition of hypoxia is anoxia, which means a total lack of oxygen (0 mg L^{-1}). Anoxia can support conditions for the formation of hydrogen sulfide (H_2S), which maintains anoxia and the released gases may be lethal to organisms (reviewed by Korpinen & Bonsdorff 2015). In the Baltic Sea, macrobenthic communities are significantly inhibited (or absent) in deep areas with anoxia or hypoxia. These communities are mainly characterized by small species living in a shallow zone below the surface of the seabed (Rumohr et al. 1996; Bonsdorff 2006; Villnäs and Norkko 2011). The average number of zoobenthic species decreases with lower oxygen concentrations but the specifics are often site specific as different species tolerate oxygen conditions differently. In the Gulf of Finland, for example, the average number of zoobenthic species triples from an oxygen concentration of 1-2 to 9-10 mg L^{-1} (Rousi et al. 2019).

Hypoxic sediments also continuously release sediment bound phosphate to the water column (HELCOM 2009). Most of the deeper sub-basins of the Baltic Sea are permanently suffering from hypoxia (Karlson et al., 2002; Conley et al., 2009) and therefore HELCOM applies the oxygen debt indicator, rather than the indicator for benthic invertebrates (HELCOM 2018i), as the relevant assessment for these zones. Also, the monitoring of benthic invertebrates has recently been shifted away from the continuously anoxic areas (see https://helcom.fi/action-areas/monitoring-and-assessment/monitoring-manual/). According to the latest HELCOM assessment, hypoxia and anoxia are prevalent in the Bornholm Basin, Baltic Proper and western parts of the Gulf of Finland (HELCOM 2018j).

In the future, the occurrence of hypoxia has been predicted to increase due to the warmer temperatures resulting from climate change. Higher water temperature increases metabolization and lowers oxygen saturation leading to increased hypoxia (Meier et al. 2011). Predicted increases in precipitation would also lead to larger inputs of nutrients and organic matter from catchment areas (Meier et al. 2011), as well as strengthens the stratification reducing water exchange between surface and bottom, resulting in increased eutrophication and knock on effects.

3.3 Impacts of hazardous substances

There are three potential pathways for hazardous substances to impact on benthic species. The benthic organism might take in the polluted sediment through material and sediment they ingest, be affected through the polluted water they live in, and/or through the water inside the sediment (Burton 1992). The pathway of the effect and intensity of impact depends on the species and their natural behavior. Many hazardous substances degrade very slowly, and their impacts on the environment can magnify as they bioaccumulate in the tissues of organisms, especially higher organisms as they pass up the food web (HELCOM 2018f). Furthermore, the combined effect of several contaminants, so called “chemical cocktails” can cause toxic effects differing from the effects of single contaminants.

Hazardous substances in sediments can cause both immediate lethal effects or long-term adverse effects. Many hazardous substances can cause disorders in metabolic processes (Vuori 1994), increase diseases (McDowell et al. 1999), and, potentially, cause effects on the populations by changing the growth, reproduction or survival of the species (Suedel et al. 1996, Sundelin & Eriksson 1998, Matthiessen & Gibbs 1998). Negative impact of contamination on the reproduction of amphipods has been assessed in the Baltic Sea (HELCOM 2018g). The embryos of amphipods are highly sensitive to hazardous substances in the sediment during their embryonic development, resulting in malformations. For example, presence of PAH and PCBs increase the occurrence of malformed embryos of *Monoporeia affinis* (Löf et al. 2015).

3.4 Impacts of marine litter

Impacts of anthropogenic matter, in particular plastic, in the marine environment has been increasingly studied globally. The most visible impact of marine litter on marine species and organisms is the entanglement in plastic/macrolitter (Schrey & Vauk 1987, Carr 1987), but ingestion (e.g. of microlitter) is possibly the more relevant impact for benthic organisms. The ingestion of marine litter, mainly plastic, can result in malfunction in the digestive track (Foekema et al., 2013). Litter in the seafloor impacts seabed habitats mainly through causing physical disturbance (through burying or scraping) on the seafloor or as a source for pollution, but they have also been found to act as a platform for non-indigenous species to spread (Werner et al. 2016).

The discovery of microplastics in marine ecosystems has added concern, as microplastics have been found in the digestive track of marine organisms in several studies (e.g. Lusher et al. 2013, Rummel et al. 2016, Foekema et al. 2013). However, the monitoring of microplastic-related mortality is challenging as injured and dead individuals will be eaten by predators or decomposed rapidly in the natural environments (Laist 1987). Laboratory results suggest, however, that the impact of microplastics on animals could be significant given that microplastics may contain contaminants (e.g. phthalates) (Mato et al. 2001, Thompson et al. 2007, Talsness et al. 2009) and they also have the ability to adsorb contaminants (e.g. lead, aluminum, cadmium) from the seawater (Rochman et al. 2014). Microplastics have also been found to enter the food chain at lower trophic levels (Setälä et al. 2014).

3.5 Impacts of non-indigenous species

Non-indigenous species may impact the ecosystem and biodiversity in various ways, though the detailed impacts or interactions are usually are difficult to predict in advance (HELCOM 2018a). Impacts of NIS depend on the species itself and the habitat it is invading. After invading a habitat, some NIS have altered the community structure and functionality of the ecosystem, for example by causing predation or the introduction of a novel species to the food chain (Leppäkoski, 1984). Depending on their feeding or mobility characteristics, non-indigenous species can alter the physical and chemical composition of bottom sediments, for instance zebra mussels forming hard agglomerations (Werner et al. 2012), round goby feeding on mussel beds till they are totally degraded (Skabeikis et al. 2019) or *Marenzelleria* species bioturbating sediments deeper than the native species (Norkko et al. 2012). In general, other alterations are caused by surface deposit feeders collecting food particles from the seabed and thus changing the sediment surface in very local scale.

4 The sensitivity of habitats to pressures

To assess the condition of seabed habitats, understanding the sensitivity of species and habitats to different pressures is vital. Only when knowing how sensitive a specific species or habitat is (and ideally in relation to a specific pressure) can we estimate the tolerable pressure levels. Here, components affecting sensitivity as well as different sensitivity assessments are presented.

4.1 Components affecting sensitivity

The sensitivity of a species or a habitat to a pressure and its impacts is a product of several factors. The most used characteristics are tolerance or resistance, together with recoverability and/or resilience (Tyler-Walters et al. 2018).

Tolerance/resistance means the ability of a species or habitat to tolerate or resist a pressure without changes in its functions or characteristics. For each of the species (or species groups) and habitats, the resistance or tolerance of a pressure is different. Some species tolerate high specific pressures without any changes in their functions, whereas the same species might not tolerate the same pressure even at relatively low levels. The same differences in response may be observed between different kind of pressures too. Therefore, tolerance depends on numerous factors such as how the pressure is operating, whether it is physical, biological or chemical by nature, as well as on the specific species present. **Recoverability** is also a key parameter and reflects the time taken for a species or habitat to recover once the pressure has been removed. It might take a long time (tens of years) for sensitive species to recover after a pressure is ceased, or certain species may be well adapted and take less time to recover. Recoverability is also dependent on the continuity of the pressure. For example, nutrients and hazardous substances tends to persist in the environment even if new inputs are reduced or eliminated, whereas pressures from other human activities may vanish or reduce directly after stopping or limiting the human activity (such as impulsive sound from explosions) (HELCOM 2018b).

Another factor that may also be relevant is the period of recovery between pressure events, a factor that may directly impact on species that have long growth and development phases. The terms resistance and resilience are both related to the **longevity** of the community (Rijnsdorp et al. 2018). Longevity refers to the life expectancy of species and communities. More sensitive habitats contain a larger proportion of long-living species and its ability to recover from an e.g. benthic trawling occasion takes a long time. On the other hand, habitats formed of short-living species can be much less sensitive to the same human activity as the species may recover faster (Rijnsdorp et al. 2018).

Although resistance, recoverability and longevity form the basis for sensitivity, other factors may also have an effect. Local hydrological, physical and chemical characteristics of the environment affects to the overall sensitivity of the species (Tyler-Walters et al. 2018). If the environmental conditions change, the sensitivity to pressures may also change. Habitats with higher level of **natural disturbance**, i.e. fluctuations in environmental conditions, tend to be dominated by short-living species as long-lived species are more sensitive to such changes in the living conditions (ICES 2019d). In addition, **seasonality** also has an effect on the sensitivity of species and habitats. Seasonal sensitivity might be applicable e.g. with coastal vegetation: being most sensitive to pressures during the growing season (Korpinen et al. 2017a). Other factors that may also influence sensitivity include the occurrence or predominance of multiple pressures, especially if these occur in high frequency or consecutively, as multiple pressures may inhibit the resilience of the resident species as far as tolerance or recoverability factors are concerned.

4.2 Sensitivity assessments

Sensitivity of benthic species and habitats to different pressures have been assessed in several Baltic wide projects and related to indicator development. Sensitivities have been defined for benthic species e.g. for the Benthic quality index (BQI) as applied in the HELCOM indicator 'State of the soft-bottom macrofauna community' and to inform the specific sensitivity of habitats to bottom-trawling in ICES WKFBI Report (ICES 2016). These sensitivities, as well as Baltic-wide estimates presented below, have been utilized in the HELCOM 'Cumulative impact on benthic biotopes' pre-core indicator to define the sensitivity of seabed habitats. BQI was developed by Rosenberg et al. (2004) for assessing the ecological quality of benthic habitats along the western coast of Sweden and has since been developed for the whole Baltic Sea e.g. by Leonardsson et al. (2009) and Schiele et al. (2016). In a nutshell, BQI combines the diversity of species, abundance and proportion of sensitive and tolerant species. The method is used in HELCOM indicator 'State of the soft-bottom macrofauna community', for which the sensitivity values originate from literature information and expert knowledge in Leonardsson et al. (2009) and calculated values based on taxa occurrence as in Schiele et al. (2016).

Another way of assessing sensitivity is though modelling. Such sensitivity models have been developed, e.g. at ICES, for indicators of the pressure and impact of bottom-contacting fishing gear on the seabed, and to consider trade-offs in the catch and the value of landings (ICES 2017). ICES has developed two methods for assessing the response of benthic communities to fishing pressure with bottom-contacting gear. These methods are focused on longevity (LL1) and population dynamics (PD2). More details can be found in advice by ICES (2017).

Evidence-based **Baltic-wide sensitivity scores for benthic habitats and species** for 19 different pressures were developed based on an expert survey and a literature review in HELCOM TAPAS project (Korpinen et al. 2017a). These were developed for the purposes of cumulative pressure and impact assessment. The Baltic-wide sensitivity estimations are a generalization for the Baltic-scale and enable the analysis of geographical differences for cumulative pressures on species and habitats. The scores range from 0 (low sensitivity) to 1,0 (intermediate sensitivity) and 2,0 (high sensitivity). The TAPAS sensitivity scores for benthic habitats and species are presented in Table 4. Such an approach does enable a simple and transparent analysis across a large geographical area where real and verified sensitivity quantitative data are not available. The Baltic wide sensitivity estimates of benthic habitats and species (Table 4) shows that all of the broad habitat types are sensitive to physical disturbance, input of nutrients, organic matter, hazardous substances and, quite logically, to physical loss. The sensitivity ranges from 1,3 to 1,9 on a range from 0-2 (low to high sensitivity). These Baltic-wide sensitivity scores are suitable for comparing impacts from pressures to several kind of ecosystem components, such as seabed habitats or species, fish and marine mammals within a single integrative analysis. This is specifically relevant in cumulative impact analysis where several different kinds of pressures (physical, substances, biological) are combined and their potential impacts to seabed habitats are estimated.

Table 4. Sensitivity scores of benthic habitats and species in the Baltic Sea, based on literature review and expert survey (modified from Korpinen et al. 2017a).

Sensitivity scores: average	1. Physical loss (permanent effects on the seabed)	2. Physical Disturbance or damage to seabed (temporary or reversible effects)	3. Changes to hydrological conditions (e.g. by constructions impeding water movements)	4. Inputs of continuous anthropogenic sounds (into water)	5. Inputs of impulse anthropogenic sound (into water)	6. Inputs of other form of energy (electromagnetic and seismic waves)	7. Input of heat (e.g. by outfalls from power stations) into water	8. Inputs of hazardous substances	9. Inputs of nutrients	10. Introduction of radionuclides	11. Oil slicks and spills	12. Inputs of litter	13. Inputs of organic matter	14. Disturbance of species due to human presence	15. Extraction of, or mortality/injury to fish	16. Extraction of, or mortality/injury to mammals and seabirds (e.g. hunting, predator control)	17. Introduction of non-indigenous species and translocations	18. Changes in climatic conditions	19. Acidification
1. Infralittoral hard bottom	2,0	1,6	1,2	0,2	0,2	0,6	1,3	1,5	1,3	0,4	1,7	0,4	1,7	0,3	0,6	0,7	1,1	1,4	1,1
2. Infralittoral sand	2,0	1,5	0,9	0,3	0,3	0,5	1,0	1,5	1,3	0,2	1,4	0,3	1,7	0,3	0,3	0,7	0,9	0,7	0,9
3. Infralittoral mud	2,0	1,4	1,1	0,3	0,3	0,6	1,0	1,5	1,3	0,4	1,4	0,4	1,9	0,4	0,3	0,7	0,9	0,8	0,9
4. Circalittoral hard bottom	2,0	1,6	1,4	0,3	0,3	0,6	1,2	1,5	1,3	0,5	1,3	0,4	1,9	0,4	0,8	1,0	1,2	1,5	1,4
5. Circalittoral sand	2,0	1,4	1,1	0,2	0,3	0,5	0,7	1,5	1,2	0,2	0,9	0,3	1,8	0,3	0,3	0,7	1,0	0,7	0,9
6. Circalittoral mud	2,0	1,3	1,3	0,3	0,3	0,8	0,9	1,5	1,2	0,5	1,1	0,5	1,7	0,4	0,6	0,5	0,9	0,7	1,0
7. Furcellaria lumbricalis	2,0	1,7	1,7	0,2	0,3	0,6	1,5	1,5	1,5	0,5	1,5	0,3	1,6	0,6	0,7	0,7	0,8	1,1	0,7
8. Zostera marina	2,0	1,9	1,7	0,2	0,1	0,5	1,6	1,5	1,9	0,6	1,6	0,4	2,0	1,2	0,9	0,8	0,7	1,0	0,6
9. Charophytes	2,0	1,9	1,4	0,0	0,0	0,6	0,9	1,5	1,7	0,4	1,5	0,3	1,8	0,7	0,8	0,7	0,9	0,7	0,6
10. Mytilus edulis	2,0	1,6	1,6	0,2	0,1	0,5	1,0	1,5	0,9	0,5	1,6	0,5	1,5	0,4	0,4	0,2	0,9	1,1	0,9
11. Fucus sp.	2,0	1,7	1,3	0,3	0,3	0,5	1,5	1,5	1,3	0,5	1,4	0,4	1,7	0,6	0,5	0,3	0,8	1,1	0,5
12. Sandbanks which are slightly covered by sea water at all time (1110)	1,9	1,6	1,3	0,2	0,2	0,5	0,9	1,5	1,5	0,4	1,5	0,6	1,9	1,1	0,9	1,0	0,9	0,8	0,6
13. Coastal lagoons (1150)	1,9	1,7	1,6	0,7	0,8	0,6	1,3	1,5	1,5	0,2	1,7	0,6	1,7	1,0	1,1	0,6	1,4	1,3	1,0
14. Large shallow inlets and bays (1160)	1,8	1,6	1,3	0,8	0,9	0,8	1,2	1,5	1,3	0,2	1,6	0,6	1,5	0,9	1,1	0,7	1,3	0,9	1,0
15. Reefs (1170)	2,0	1,6	1,4	0,3	0,3	0,6	1,0	1,5	1,3	0,6	1,9	0,7	1,7	0,8	0,9	1,1	1,2	1,2	0,9
16. Submarine structures made by leaking gas (1180)	1,7	1,2	1,3	1,0	1,0	1,0	1,0	1,5	1,6	0,5	1,8	0,7	1,6	1,0	0,8	1,5	1,4	1,0	2,0
17. Cod abundance	1,0	0,7	0,4	0,2	0,9	0,5	0,7	1,6	1,5	0,6	0,5	0,2	1,1	0,9	1,6	0,7	0,6	1,1	0,3
18. Herring abundance	0,9	0,7	0,7	0,6	1,1	0,5	0,6	1,6	0,7	0,3	0,9	0,1	0,2	0,4	1,2	0,2	0,6	1,0	0,6
19. Distribution of demersal spawning flounder	1,7	1,3	0,8	0,2	0,7	0,6	0,7	1,6	1,6	0,5	1,3	0,4	0,8	1,0	1,8	0,3	0,9	1,4	1,0
20. Abundance of pelagic spawning flounder	1,0	0,8	0,9	0,3	0,7	0,6	0,8	1,6	1,3	0,4	1,1	0,3	0,7	0,9	1,8	0,0	0,8	0,8	1,0
21. Recruitment areas of perch	1,8	1,6	1,2	0,4	0,9	0,7	0,4	1,6	1,4	0,4	1,6	0,4	1,0	1,3	1,6	0,0	1,0	0,5	1,3
22. Recruitment areas of pikeperch	1,8	1,4	1,2	0,6	1,1	0,7	0,3	1,6	0,7	0,5	1,7	0,3	0,9	1,0	2,0	0,5	0,9	0,3	1,0
23. Recruitment areas of roach	1,8	1,5	1,2	0,6	1,0	0,4	0,3	1,6	0,5	0,5	1,7	0,4	0,9	0,8	1,6	0,5	0,9	0,3	1,0

Sensitivities of the Baltic Sea biota and habitats have also been evaluated within the Swedish national marine spatial planning process, Symphony (Hammar et al., 2018). The **Symphony method** is a model-based assessment method developed to support ecosystem-based marine spatial planning in Sweden. Symphony's sensitivity categories take into account both "species, population or group" as well as "habitat" separately. The sensitivity scores of different species, populations or groups and habitats in the Baltic Sea according to the Symphony can be found in Hammar et al. 2018.

Some sensitivity assessments and tools have also been developed in the other sea areas outside of the Baltic Sea region. **Marine Life Information Network (MarLIN)** has developed tools applicable to benthic species and habitats in the UK and Ireland. However, their data and methods can be applied in the Baltic Sea if taking the local differences and characteristics into account. **Biological Traits Information Catalogue (BIOTIC)**, created by MarLIN, scientists and Plymouth Marine Laboratory, contains information on over 40 biological characteristics for selected individual benthic species which eventually affects their sensitivity. The BIOTIC database has been developed for assessing risk from human activities to different species and habitats for the purposes of marine management, conservation and education. The database is open access for searching information both on taxonomic and functional level (MarLIN 2006). Another tool developed by MarLIN is the **Marine Evidence based Sensitivity Assessment (MarESA)**. The MarESA methodology is another platform to compile and assess sensitivities based on scientific knowledge. The sensitivity descriptions of different habitats and species are available on the MarESA webpage under 'Sensitivity'. The MarESA methodology is described in more detail in the guide by Tyler-Walters et al. (2018).

Various methods to derive sensitivity of seabed habitats exist. Selection of the most appropriate method may depend on the purpose of the analysis and the specificities of the required assessment should define which sensitivity approach that should be applied. Another key issue of relevance when dealing with sensitivity, is that ground-truth validation should be included, where possible, as this provides the link to in situ impact from the given presures. Several approaches show sensitivity of a single species or groups of species to a single pressure. However, how this is interpreted and used to predict the potential effects on the whole community or, even more challenging, for the entire broad habitat level, is also critical when developing assessments that apply the sensitivities.

5 Significance of pressures on benthic habitats

5.1 Definition of adversely affected habitats

Adverse effects on habitat condition is described in the MSFD as "alterations in its biotic and abiotic structure and its functions". The term 'adversely affected habitat' has been further discussed in the HELCOM SPICE project. The SPICE project noted that adversely affected habitats can be defined from at least the following three perspectives, as described by Virtanen et al., (2018):

a) "GES status of predominant fauna or flora of the habitat: this approach builds on the available state indicators such as benthic invertebrate indices and macrophyte indicators, which have GES thresholds. These thresholds are already established under other regimes, such as the EU Water Framework Directive (WFD), the EU Habitats Directive or HELCOM core indicators. A habitat status can be assessed by the state indicator alone, but also from the pressure point of view. The intensity of pressure causing the adverse effect can, in principle, be found from the pressure – status correlation (reviewed by Virtanen et al. 2018).

b) State of fauna or flora (not established indicators): biological state parameters can show significant reductions in extent, abundance or condition which are caused by increased pressures. As no GES threshold has been established, the link to the pressure must be shown and the adverse effect is defined from that correlation. The state of the habitat can, however, be assessed either from the pressure or state point of view.

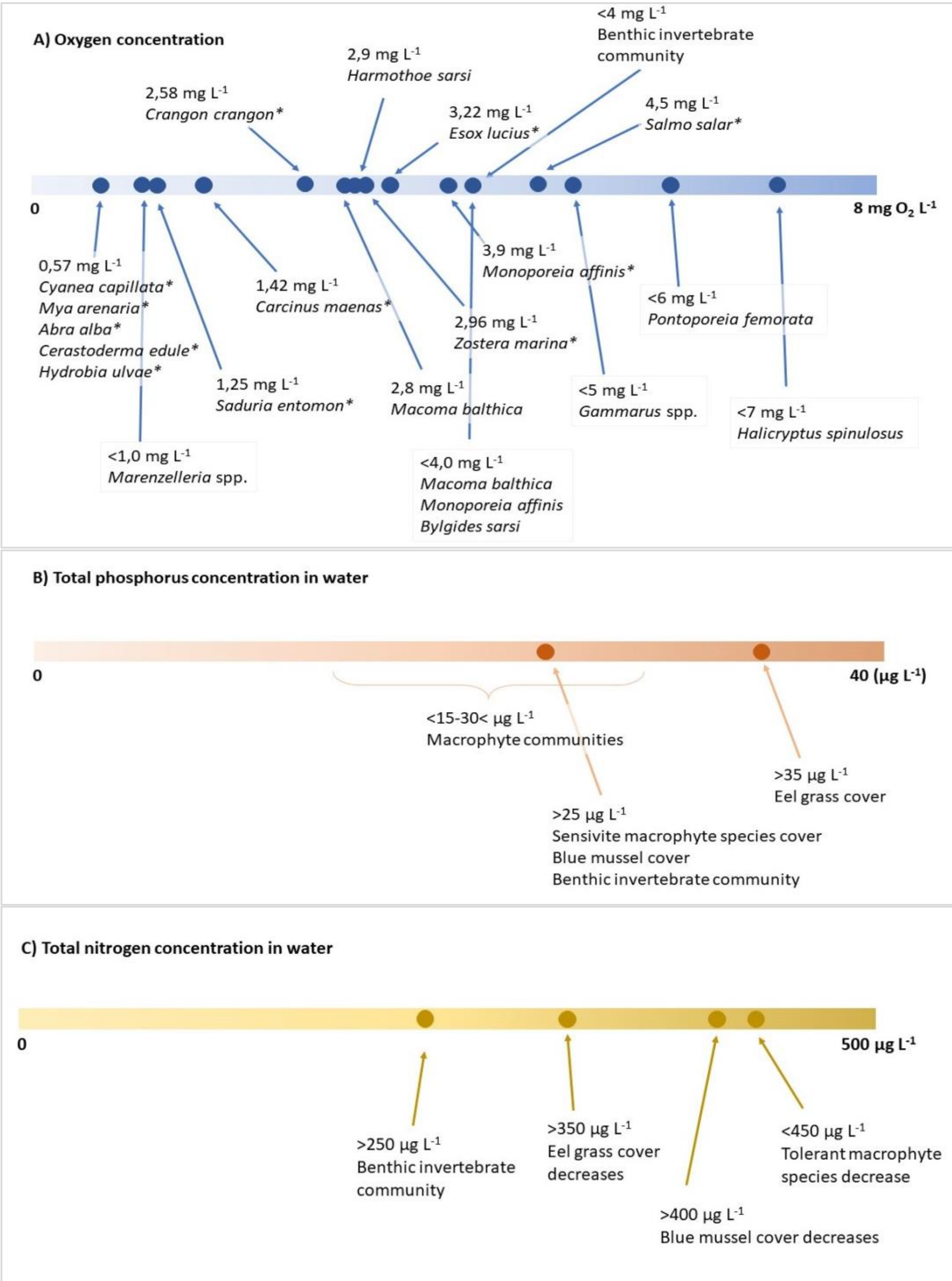
c) Physical or chemical indicators (with GES threshold) or parameters (without a threshold) reflect the living conditions of the predominant fauna or flora of a habitat. A threshold can be found in values where the conditions start deteriorating. These conditions need to be shown to affect the state indicators and they need to be caused by anthropogenic pressures."

These three perspectives, however, do not define adverse effects on habitats or at the whole community level.

5.2 Pressure thresholds for marine benthic ecosystems

Several studies have been done to assess the thresholds of pressures and their adverse effects on the benthic species and habitats. Such thresholds can be used in defining GES levels for species and habitats. Species- and habitat-specific thresholds for different pressures causing 'adverse effects' have been summarized in the HELCOM SPICE project (Figure 13). For the adverse effects of benthic species and habitats, some threshold values have been proposed based on modelled estimates and/or literature reviews for **oxygen concentrations** (mg O_2 L^{-1}), **total phosphorous** (µg L^{-1}), **total nitrogen** (µg L^{-1}), **turbidity** (NTU), **suspended solid matter** (mg L^{-1}) and

humus (mg CDOM L^{-1}) as well as **water transparency** (Secchi depth, in m) (Virtanen et al. 2018, Rousi et al. 2019). Some threshold values are also found **for sensitive and tolerant macrophyte species** in the Northern Baltic Sea, which can be indicator species for infralittoral biotypes. The use of sensitive and tolerant macrophyte species for threshold setting is not simple due to the sensitivities of species to different pressures (Virtanen et al. 2018). One species may be sensitive for one pressure and tolerate another pressure and the effects are often pressure-specific.



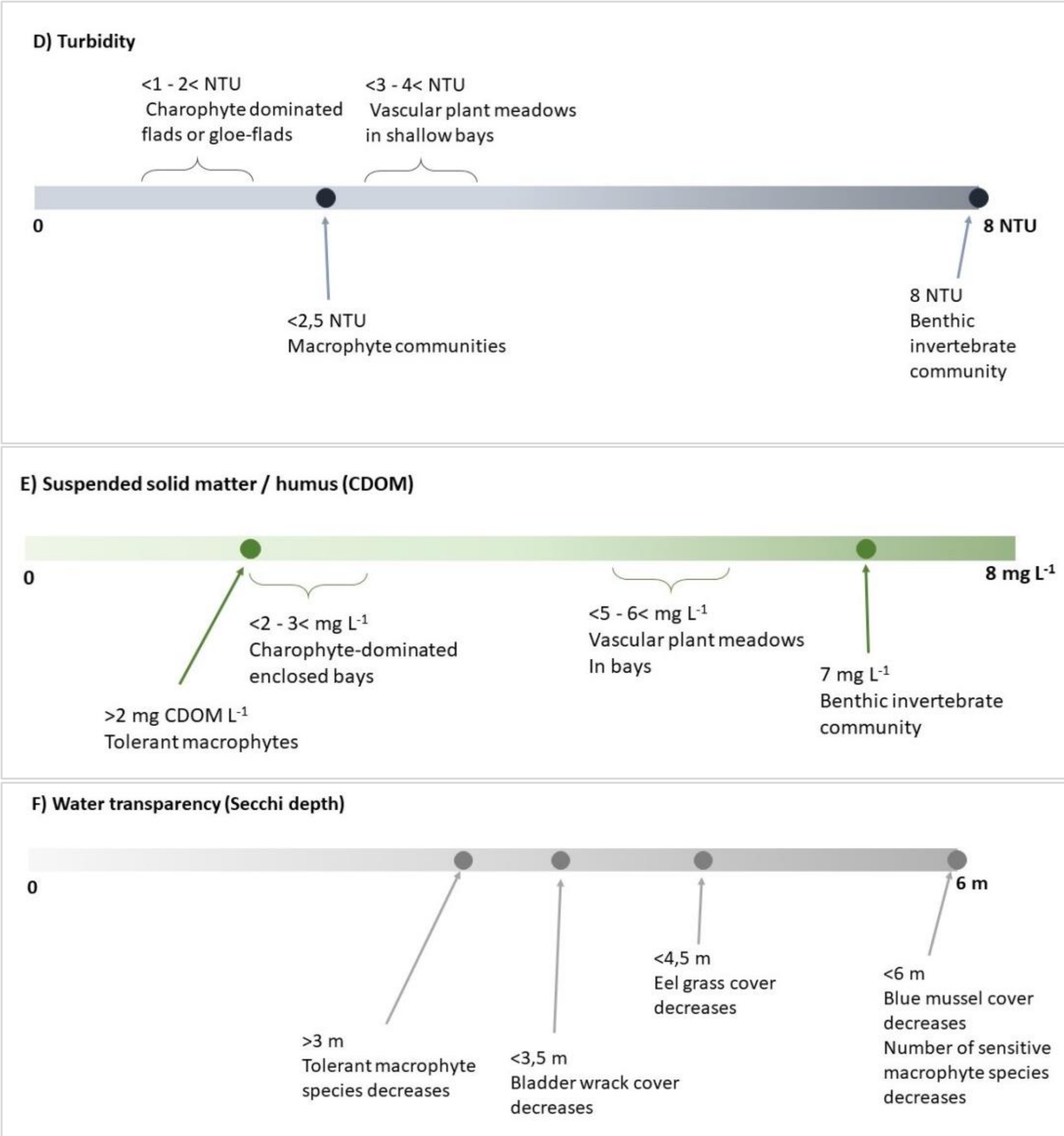


Figure 13. Sensitivity of species (based on survival and abundance changes) in the Northern Baltic Sea to (A) oxygen concentration; sublethal effects are marked with an asterisk. (B) total phosphorous, (C), total nitrogen, (D) turbidity, (E) suspended solid matter and humus and (F) water transparency, as adopted from Virtanen et al. (2018) and Rousi et al. (2019). It should be note that these thresholds are based on local conditions, mostly from the Northern Baltic Sea and therefore, these likely do not represent Baltic-wide thresholds. For more details and literature references, see Virtanen et al. 2018.

As benthic habitats are strongly influenced by spatial factors, the threshold values for habitat condition in a specific location are not sufficient alone, but also an extent and/or proportion of the entire habitat needs to be evaluated to ascertain overall status. In addition, distribution of habitat in relation to adverse effects should be considered, especially if all of the adverse effects are localized in a small area causing, for example, fragmentation of the habitat (Korpinen et al., 2018). To define the area of potentially impacted habitats, the extent of pressure as a distance threshold could be utilized. Virtanen et al. (2018) analyzed state parameters in relation to distance from a pressure source for some benthic species characteristics of the northern Baltic Sea (Figure 14). The respective spatial distance thresholds or temporal exposure thresholds for benthic habitats still require more work in order to obtain encompassing thresholds for the entire Baltic Sea area.

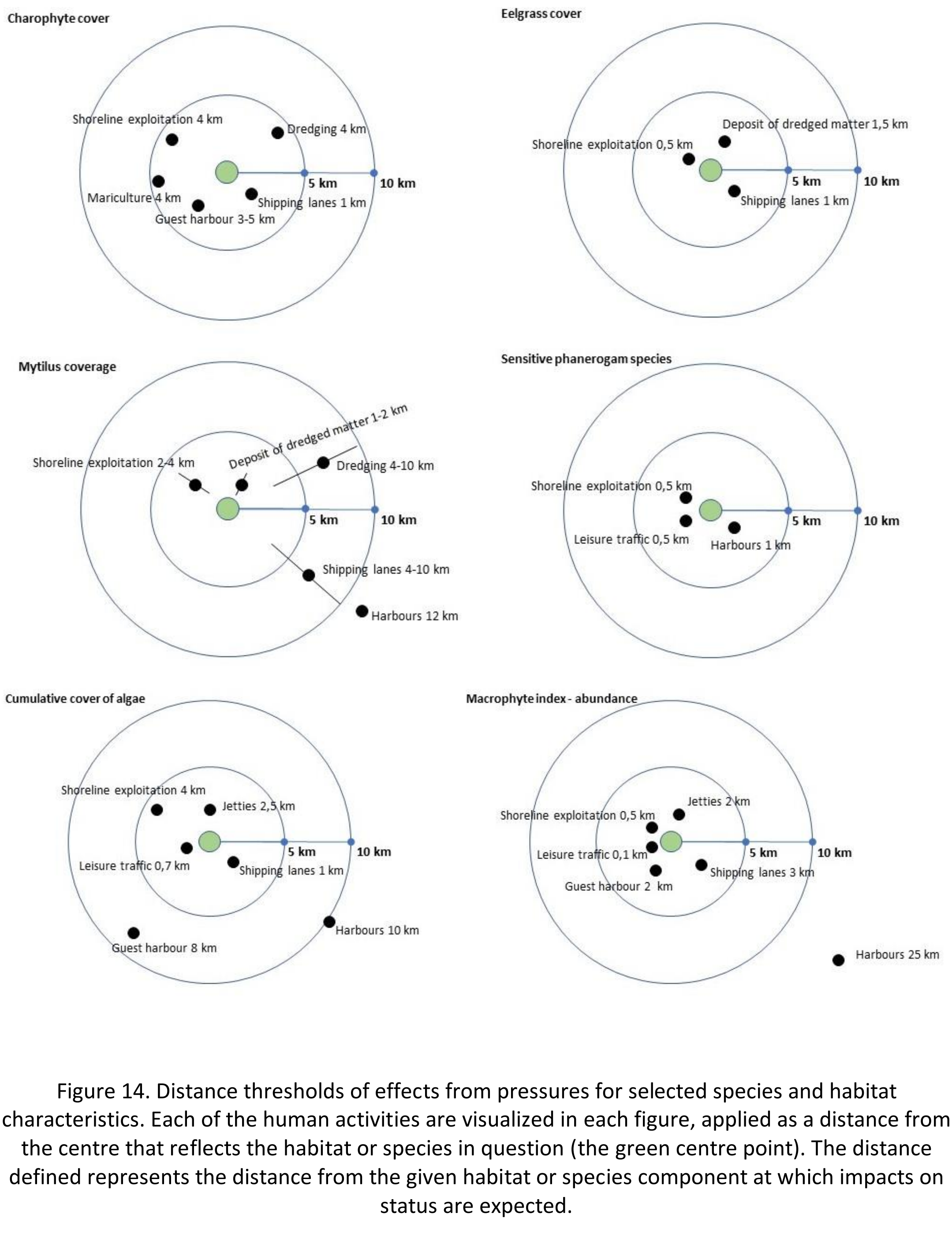


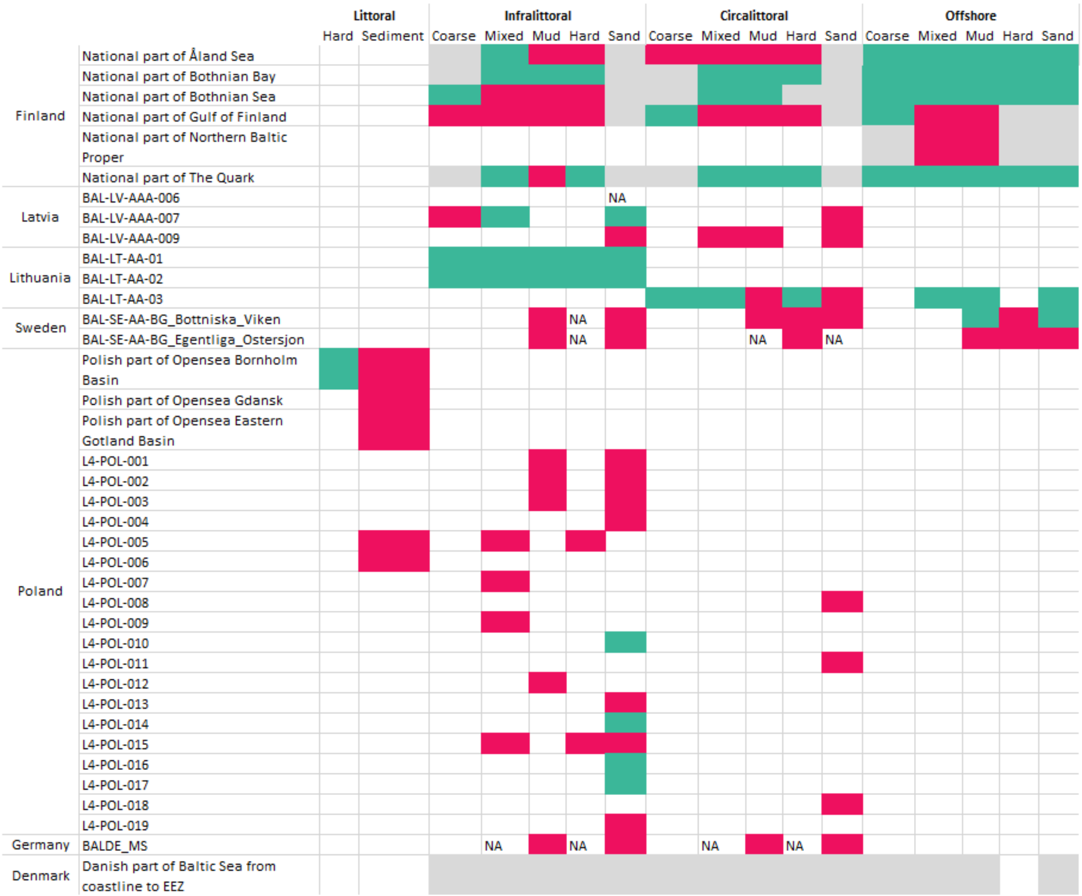
Figure 14. Distance thresholds of effects from pressures for selected species and habitat characteristics. Each of the human activities are visualized in each figure, applied as a distance from the centre that reflects the habitat or species in question (the green centre point). The distance defined represents the distance from the given habitat or species component at which impacts on status are expected.

5.3 EU assessments relevant to the state of the benthic habitats

EU MSFD assessment of benthic broad habitat types

Status of benthic broad habitat types was assessed by seven Baltic Sea EU Member states (Table 5). Estonia has assessed the status of benthic habitats by “other benthic habitats”, shown in next section. Denmark has reported all broad habitat types as unknown status. Finland, Latvia, Lithuania and Poland have reported good status for some benthic broad habitat types, otherwise the assessment result is either not good, unknown or not assessed.

Table 5. Status of the benthic broad habitat types in the Baltic Sea as reported by EU Member states in 2018. The green boxes indicate assessed ‘good’ status, red ‘not good’ status, grey ‘unknown’ and ‘NA’ denotes for not assessed. Finnish assessment of good status is based on low risk. White boxes mean the broad habitat type is not considered to be present in the specific marine area.



EU MSFD assessment of other benthic habitats

Status of other benthic habitats was assessed by three Baltic Sea EU Member states (Table 6). Denmark has reported Water framework directive habitats and habitat directive habitats as unknown. Estonia has assessed all N2000 habitats to be in good status. Germany has reported reefs and sandbanks to be in not good status. No Baltic wide comparisons of status can be done based on this collated information.

Table 6. Status of the other benthic habitats in the Baltic Sea as reported by EU Member states in the 2018 reporting of MSFD Article 8. The green boxes indicate assessed 'good' status, red 'not good' status and grey 'unknown'. 'NA' denotes for not applicable, the broad habitat type is not relevant in the specific marine area.

		Zostera beds in infralittoral sediments	Baltic muddy bottoms of the aphotic zone	Costal/Muddy/ Sandy habitats (WFD)	Estuaries	Large shallow inlets and bays	Mudflats and sandflats not covered by seawater at low tide	Reefs	Sandbanks which are slightly covered by seawater all the time	Sublittoral coarse sediment	Submerged or partially submerged sea caves
Denmark	BAL-DK-TOTAL										
Estonia	BAL-EE-AA										
Germany	BALDE_MS	NA	NA							NA	

EU WFD assessment of seabed-related quality elements in coastal waters

The status of coastal waters is assessed through a set of quality elements under the EU WFD, many of which are related to the state of the seabed. Figure 15 presents results of the 2016 reporting by HELCOM Contracting Parties that are also EU Member States and indicates that the morphological conditions, river continuity and hydrological conditions, where assessed, are generally considered mainly in high status. Where assessed, the status of benthic invertebrates is mainly in good or moderate status, whereas the status of angiosperms poorer status categories were relatively more common. Water transparency and oxygen are important factors for the benthic life; the former was dominantly in moderate status, whereas the oxygen conditions of the coastal waters were assessed mainly to high status in areas it was addressed.

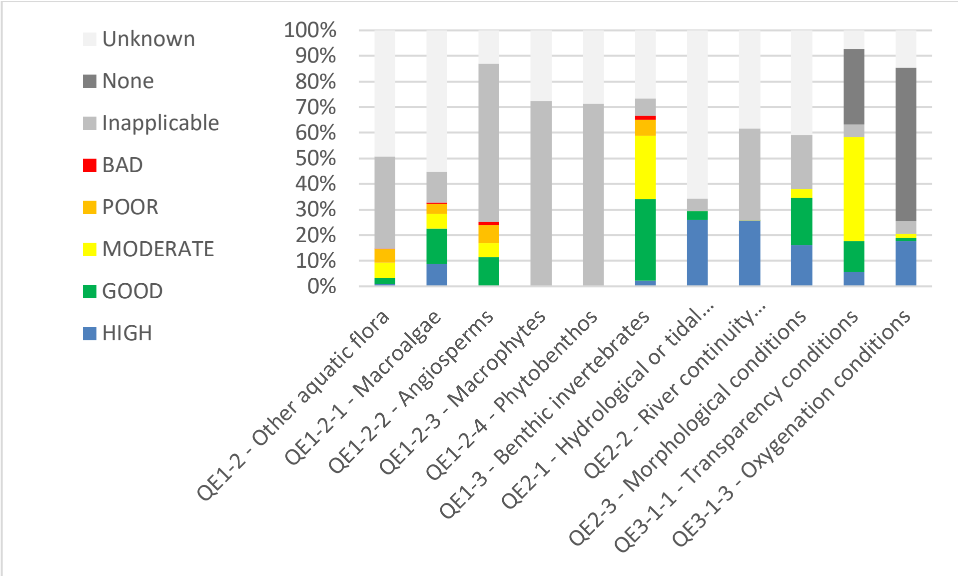


Figure 15. Status of the WFD parameters related to benthic habitats in the Baltic Sea as reported by EU Member states in the 2016 reporting of EU WFD. The y-axis shows the proportion of status classifications in all reported waterbodies.

The assessment of ecological status also includes a quality element 'Hydromorphological conditions' which includes many aspects of physical pressures such as alterations of the seabed, shoreline and river continuity (see Figure 15 above to see the parameters QE2-1, QE2-2 and QE2-3 which together form the assessment of hydromorphological conditions. In the Baltic Sea, the EU member states have only rarely assessed this quality element in the coastal waters in their 2016 reporting: 77% of the waterbody area was assessed to the 'unknown' category, 10% as 'high', 11% as 'good' and 2% as 'moderate'. From this assessment framework it appears that there is high uncertainty in this assessment method or data and it is also possible that the listed physical pressures are not considered significant factors affecting the Baltic coastal waters.

5.4 HELCOM indicators for assessing benthic habitats

An integrated status assessment of benthic habitats was carried out in the last holistic assessment (HELCOM 2018k). This integrated assessment was applied in the open sea areas, using a combination of the two existing and regionally approved indicators for the region: 'State of the soft bottom macrofauna community' and 'oxygen debt' (described below). In coastal areas, the status was assessed using national coastal indicators, as no Baltic-wide indicators on benthic habitats exist for coastal area. The integrated biodiversity status assessment results indicated that the status of benthic habitats was good in six open sea sub-basins: the Kiel Bay, Gulf of Riga and the sub-basins north of Northern Baltic Proper (Åland Sea, Bothnian Sea, The Quark and Bothnian Bay) (HELCOM 2018k).

Currently there is only one Baltic-wide biodiversity core indicator to assess the status of benthic habitats: **'State of the soft-bottom macrofauna community'**. The indicator utilizes monitoring data reported by the countries surrounding the Baltic Sea, as included and described in the HELCOM monitoring manual. Monitored changes in the abundance of sensitive and tolerant species is used together with the diversity of the macrofauna communities to assess the status. The method is based on the Benthic Quality Index (BQI) approach (Leonardsson et al., 2009). In a nutshell, the proportion of sensitive and tolerant species is compared and combined with the number of species found. The more sensitive species and more species in total, the better the status of the macrofauna community (HELCOM 2018i). A more detailed description, including the assessment method and threshold setting is available from the HELCOM Core indicator report (HELCOM 2018i).

The state of the soft-bottom macrofauna community indicator is applicable only in the open sea areas and only for areas above the permanent halocline (HELCOM 2018i). The latest status assessment shows that the soft bottom macrofauna communities above the halocline are in good status in the assessed open sea areas throughout the Baltic Sea, except in the Bay of Mecklenburg (HELCOM 2018i). However, many of the Southern Baltic open sea sub-basins were not included in the assessment as no agreed threshold values currently exist for those specific sub-basins. Therefore, the indicator is not operational across the whole Baltic Sea.

In the areas below the permanent halocline, the core indicator **Oxygen debt** is used to assess the status of benthic habitats. In terms of benthic habitats, the oxygen debt evaluates the potential for conditions to be suitable for macrofauna communities to thrive (HELCOM 2018j). The status of oxygen debt is not good in all the sub-basins where it was assessed, roughly south from the Gulf of Finland until the Bornholm Basin. In the latest status assessment (HELCOM 2018j), results are lacking from the Bothnian Bay, Bothnian Sea and Åland Sea, as no thresholds were set at the time of assessment and further work is required to evaluate the appropriate application of an indicator in these areas. The indicator is not applicable above halocline, meaning not applicable in west of Bornholm Basin (Kattegat, Great Belt, the Sound, Kiel Bay, Bay of Mecklenburg, Arkona Sea). For Gulf of Riga and Quark, no agreed threshold values exist, and therefore there is no assessment result. For more detailed description of the indicator 'Oxygen debt', see HELCOM Core indicator report (HELCOM 2018j).

In the integrated assessment of benthic habitats, both of the used indicators partly depend on the impacts of eutrophication and therefore the assessment results may be biased. The impacts of physical pressures (physical loss and disturbance to the seabed) are lacking and therefore the status could look different from other perspectives. In addition to eutrophication and physical pressures, several other key pressures affecting benthic habitat may occur, for example NIS and hazardous substances. However, there is currently no regionally agreed method to assess e.g. adverse effects to the seabed from physical loss and physical disturbance, though much work is ongoing in the HELOCM Expert Network on benthic habitats. To address these needs, two new indicators are under development: an indicator on 'cumulative impact on benthic biotopes' as well as an indicator for 'condition of benthic habitats' which are both spatial in nature, and aim to provide an assessment based on the best available information (i.e. utilizing monitoring and modeled data as needed and where available). The pre-core HELCOM indicator '**Cumulative impact on benthic biotopes**' (CumI) is under development by the lead countries Germany and Sweden (HELCOM 2020). The indicator evaluates the potential cumulative impact of physical pressures (physical disturbance, and a generated loss aspect) on benthic biotopes from several human activities. The indicator is developed to support HELCOM work and MSFD assessment of D6C1, C2 and C3. The cumulative impact assessment is based on biotope's sensitivities to different pressures (taking into account the magnitude of the pressure). The indicator is well developed with general support for finalizing the work to set thresholds for sub-basins (situation in October 2020). The pre-core indicator **'Condition of benthic habitats'** is also under development in HELCOM. This indicator is estimating the area, extent and quality (status of biological communities), of specific benthic habitats (HELCOM 2017).

5.5 Cross-comparison of environmental assessments and pressures

The status assessments of benthic habitats can be compared with the assessments of pressures in the same areas. Such comparisons can inform of the need to reduce specific pressures or human activities. Successful comparison can even indicate the level of pressures that causes adverse effects in the status of benthic habitats. However, the monitoring data (status) is often collected in other areas where pressures does not occur. Korpinen et al. (2017b) and Virtanen et al. (2018) have shown and underlined that environmental monitoring sites do not show the impacts from wide pressures (e.g. physical disturbance caused by fishing), nor spatially or temporally limited activities as impacts can be missed if there is no spatial overlap with monitoring. Thus it is key to apply monitoring in an optimal way to support status assessment and to scale up point source monitoring to address the broad spatial aspect required by the assessment of benthic habitats.

In the HELCOM SPICE project, a cross-comparison of different environmental pressure and impact datasets was made between the EU Water Framework Directive and the first version of the HELCOM HOLAS II status assessments in the marine waters of Sweden, Finland and Estonia. Furthermore, the correlation between different marine environmental status assessments was examined (Herkül & Martin 2017). Herkül & Martin (2017) compared the 2016 WFD status assessment results with spatial HELCOM HOLAS II data (for the first version, 2011-2015) of integrated assessments of eutrophication, contamination and biodiversity assessments for benthic habitats, pelagic habitats, fish and seals, as well as pressure components of the Baltic Sea Pressure Index (BSPI), Baltic Sea Impact Index (BSII), potential cumulative impacts on benthic habitats, physical disturbance or damage to seabed and physical loss. The WFD status assessment results for several components were extracted in table format and joined to the national coastal water body GIS layers. The results of all assessment products were extracted to 1 x 1 km EEA grid cells for further analyses. More details about the procedure is available in Herkül & Martin (2017).

The analysis of Herkül & Martin (2017) shows that most of the WFD and HOLAS II status assessments correlated significantly with pressure layers (Figure 16). It seemed that, based on the data from three countries, the lower the physical pressures were, the better most of the WFD status assessment results were. This however was not statistically significant for the zoobenthos status assessment, and not that clear for chemical status and the phytobenthos status assessment. The strong correlation between ecological status and hydromorphological changes seems logical as the presence of similar kind of human activities might be used in assessing both the status and pressure. The HOLAS II status assessments of pelagic habitats, fish and seals had contrary results: they had better status with higher pressures (Figure 16, Herkül & Martin 2017). However, the relationship between pressures and HOLAS II status of benthic habitats indicated a strong correlation where the pressure is high, the status is lower. This means that the assessment of pressures could indicate the relative status for some of the environmental components.

The results indicate that even with significant differences in assessment methods and objectives, the status of some marine components can be related to the level of pressures. Especially, the HOLAS II benthic status, WFD ecological status, WFD biological status, WFD physico-chemical status and WFD hydromorphological status in Estonia, Finland and Sweden correlated negatively with physical disturbance assessment of HOLAS II (see Annex 4). Annex 4 includes also more detailed information on the relationships between status classes and pressure levels.

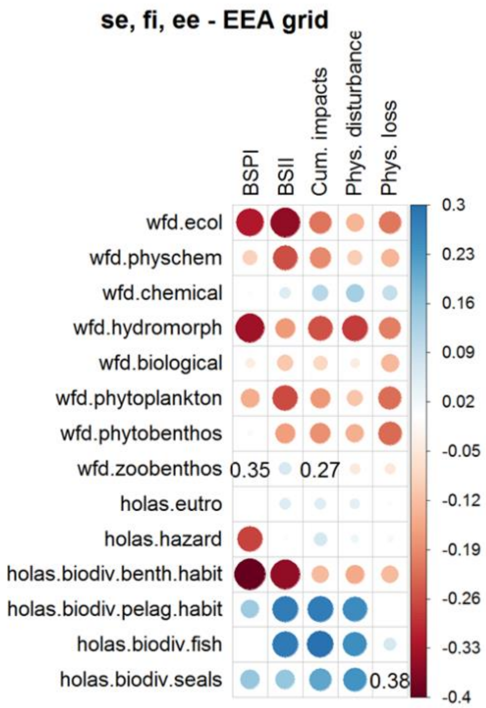


Figure 16. Correlations between assessments (vertical axis) and pressures (horizontal axis). Colors and circle diameters signify the Spearman rank correlation coefficients. Numbers show the p-values in cases where p > 0.05. Dots represent cases where data was not available or there was no variation in the data. Negative correlations show that higher (better) status is related to lower pressures. Positive correlations show that higher (better) status is related to higher pressures (Source: Herkül & Martin 2017).

6 Outlook for the role of pressures in the Baltic benthic habitats

Do we know the significant pressures?

Nutrients, hazardous substances, non-indigenous species, extraction of fish, anthropogenic sound and physical disturbance to seabed have been identified as the most extensive pressures affecting the marine environment in the Baltic Sea (HELCOM 2018b). European wide pressure assessments follow the same pattern: hazardous substances, pelagic and benthic fishing, physical loss and physical disturbance to seabed are the most effecting pressures (Korpinen et al. 2019). The assessment of the main pressures affecting the ecological status in coastal areas shows that the diffuse pollution is by far the most spatially widespread pressure (see Sections 2 and 3.2). Based on the sensitivities of the seabed habitats, physical loss, physical disturbance to the seabed, input of hazardous substances and input of nutrients are the most impacting pressures (HELCOM 2018b). Although there are many assessment frameworks with different objectives and regional differences in the Baltic Sea, and while nutrients and hazardous substances are overarching issues, physical disturbance is also a regionally important pressure, especially in the Southern Baltic Sea where bottom trawling occurs. This latter result is in line with the other European marine regions, especially in the northeast Atlantic Ocean and the Mediterranean Sea, where bottom-touching towed gears are a high and widely spatially distributed activity causing high pressure with adverse effects on the seabed (Hiddink et al. 2017, OSPAR 2017, Korpinen et al. 2019).

In spite of the apparent coherence in the conclusion, there are significant differences between the MSFD, WFD and HELCOM assessments which should be addressed in order to clarify the assessment results and allow more efficient use of assessment resources. We showed in this report how the HELCOM holistic assessment presented the wide extent of physical pressures in the coastal waters whereas a different approach by the EU WFD assessment indicated that the hydromorphological alterations (e.g. caused by construction, dredging, land claim, etc.) indicate good or high status or in the majority of cases the status was not known. The potential synergies between the two EU assessments and the HELCOM approach are obvious and it is highly recommended that efforts should be made to align these approaches. Figure 17 shows a positive example of this possibility: in Finland the hydromorphological status of coastal waters in 2019 was assessed by a few indicators of the extent of human activities in the waterbodies, and the outcome seems to correlate with the HELCOM Baltic Sea Impact Index (BSII). As the hydromorphological status assessment is based on scoring, MSFD D6 assessment is based on areal extent and the HELCOM BSII is based on relative impact values, the way forward may not be simple.

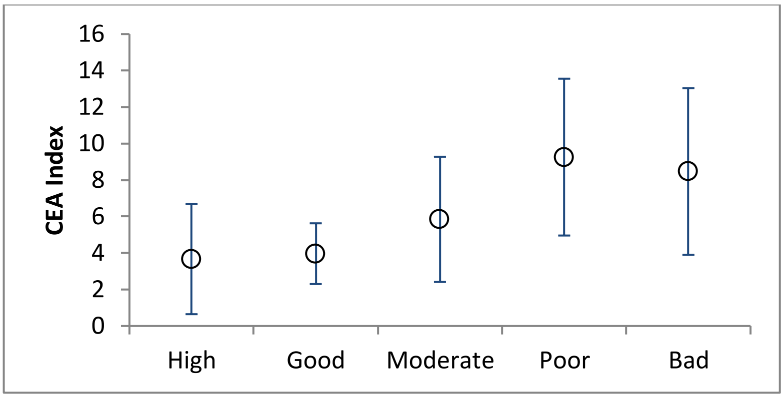


Figure 17. Correlation between the HELCOM Baltic Sea Impact Index (vertical axis) and the EU WFD assessment of hydromorphological status in Finland's coastal waters in 2019. The mean grid value of Baltic Sea Impact Index was assigned to the WFD waterbody and 160 waterbodies were compared.

Do we know the adversely affected benthic habitats?

Current, the Baltic-wide status of the seabed is assessed with only one indicator: State of the soft-bottom macrofauna community, an indicator that is best applied in its current form to support the assessment of eutrophication. This indicator, albeit giving credible and confident results, does not represent all the seabed habitat types or status of species. Thus, it is not possible with the current tools to provide a regional assessment of adversely affected benthic habitats. For benthic habitats and species, a status assessment is required under the MSFD Article 8 reporting. This reporting procedure provides an insight into each country's view on the status of the seabed habitats. In theory the national MSFD assessments on status of seabed habitats holds valuable information on the need of Baltic-wide, or localized, measures when the GES is not achieved. However, the reporting results indicated no coherent Baltic-wide results for status of benthic habitats. Mostly the status of broad habitat types is lacking or unknown. The result was not surprising as the EU member states have not yet agreed on the assessment method for the seabed assessment, nor the relevant threshold values indicative of good status to which an assessment can be carried out.

To improve the status of the benthic habitats, the assessed status of benthic habitats needs to be accompanied by information of pressures, and thus human activities, affecting their status. To assess physical pressures and human activities affecting benthic habitats, the pre-core indicator 'Cumulative impact on benthic biotopes' has been developed. Such tools can indicate how much human activities proportionally contribute to physical disturbance, and thus which human activity potentially causes the most impact. Therefore, we hold the possibility to know which human activities should be most effectively managed.

Do we know the required actions to mitigate the pressure and improve the status?

The different contributions of human activities between the Baltic sub-basins (Figure 6, Figure 9) gives an insight into where there might be different needs for management actions. The measures to mitigate impacts from pressures are clearly scale-dependent: pollution pressures (both eutrophication, i.e. nutrients, and hazardous substances) are widespread and the several assessment results in this report indicate that they should be the focus of strengthened measures. There are however practical consideration and issues such as natural lags that need to be considered when setting measures and focusing on other measures, such as reductions in physical disturbance, may be more practical and also offer more immediate positive results. Information of the local pressures is available from the EU WFD assessments and can be supported by the HELCOM Baltic Sea Impact Index.

Another approach to find mitigation measures is to consider which pressures impact specific ecosystem components. While Baltic-wide information on the sensitivity of species and habitats to different pressures has been collected through the TAPAS project in 2016, the HELCOM ACTION project (Work Package 6) collected spatially more specific information of the most significant pressures for benthic habitats and the human activities behind the pressures (available in December 2020). The ACTION WP6 survey identified five different benthic habitats: coarse substrate dominated by infauna, hard substrate dominated by epifauna, hard substrate dominated by vegetation, soft substrate dominated by infauna and soft substrate dominated by vegetation, and surveyed these in five parts of the Baltic Sea: (1) Gulf of Bothnia, (2) Northern Baltic Proper, Gulf of Riga and Gulf of Finland, (3) Gotland Basins, the Bornholm Basin and Gdansk Basin, (4) Arkona Basin, Mecklenburg Bight, Kiel Bight and Danish Straits, and (5) Kattegat. It is foreseen that the results will support identification of the most relevant pressures and activities for the benthic habitats in the different areas of the Baltic Sea.

In terms of the physical pressures, the spatial data in the HELCOM Map and Data Service indicates that 95% of the physical disturbance of the whole Baltic Sea (estimated by area) is caused by widely spread activities: bottom trawling fisheries, shipping and recreational boating. The rest of the 5% of the area consists of construction works, dredging, sand and gravel extraction and deposition operations as well as aquaculture. For many of these pressures or activities, few measures currently exist, but more is needed to ensure the protection of the habitats. Following the contribution of human activities and potential disturbance and effects to broad habitat types, shipping and bottom trawling fishing are the activities in need of effective measures as 80 to 100 % of the circalittoral broad habitat types in the Southern Baltic Sea west of Bornholm basin are potentially disturbed.

Effective management of shipping, recreational boating and small-scale activities are proportionally more effective north of the Northern Baltic Proper and in the Gulf of Finland, where the contribution of these activities are relatively higher and bottom trawling fisheries generally do not operate. However, most human activities contribute to several pressures and therefore affect the seabed habitats through several pathways.

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Annex 1. Human activities resulting in physical loss of the seabed habitats with spatial extent of their footprint

Human activity	Spatial extent of physical loss and impact (if known)	Reference
Anchoring	Permitted area, area of activity	ICES 2019c

Human activity	Spatial extent of physical loss and impact (if known)	Reference
Aquaculture	Permit area, footprint of anchors, 150 m buffer for pressure	HELCOM 2018b, HELOM 2018c, ICES 2019b, ICES 2019c
Artificial reefs and islands	Footprint should be provided depending on the structure (artificial reefs/wrecks) and mooring	HELCOM 2018c, ICES 2019b
Bathing sites, beaches	300 m buffer for pressure	Korpinen et al. 2017
Beach replenishment		HELCOM 2018c
Breakwaters		HELCOM 2018c
Bridges	2 m buffer for pressure	HELCOM 2018b, HELCOM 2018c
Cables	1.5 m buffer; 0.075-0.15 m radius buffer for cable and 1 m for shielding structure	HELCOM 2018b, ICES 2019b
Cables (under construction)	1-2 m for pressure	Eugeniusz et al. 2003, Kogan et al. 2006, OSPAR 2008 HELCOM 2018c,
Canalisation	Extent of structure	HELCOM 2018c, ICES 2019b
Carbon capture and storage		HELCOM 2018c
Causeways		HELCOM 2018c
Coastal dams, weirs		HELCOM 2018c
Coastal defence and flood protection	50 m buffer for lines, area of polygon for pressure	HELCOM 2018b, HELCOM 2018c, ICES 2019b
Coastal defence and flood protection (under construction)		HELCOM 2018c
Culverting/trenching		HELCOM 2018c
Deposit of dredged material	Area of polygon or a 500 m buffer for pressure	Korpinen et al... 2017, HELCOM 2018c, ICES 2019b
Dredging (both capital and maintenance)	Area of polygon or a 25/50 m buffer for small / large sites	Korpinen et al... 2017, HELCOM 2018b, HELCOM 2018c, ICES 2019b
Extraction of metal ores		HELCOM 2018c
Extraction of minerals		ICES 2019b
Extraction of sand and gravel	Area of polygon (pressure), effects may reach up to 10 km (sediment	Phua et al. (2004), Kortekaas et al. 2010, HELCOM 2018b, HELCOM 2018c

Human activity	Spatial extent of physical loss and impact (if known)	Reference
	erosion from close areas)	
Fishery: Bottom-contacting fishing		ICES 2019b
Groynes		HELCOM 2018c
Harbours (incl. industrial and ferry ports, fishing harbours)	200 m buffer for pressure	HELCOM 2018b, HELCOM 2018c
Land claim	Area of structure or 50 m buffer for points, 30m buffer for lines for pressure	HELCOM 2018b, HELCOM 2018c, ICES 2019b
Large-scale water deviation		HELCOM 2018c
Marinas and leisure harbour	200 m buffer for pressure	HELCOM 2018b, HELCOM 2018c
Military infrastructure (e.g. military firing ranges)		HELCOM 2018c, ICES 2019b
Oil platforms	25 m buffer for pressure, effect distance 50 m	Eastwood et al. 2007, HELCOM 2018b, ICES 2019b
Oil terminals, refineries	200 m buffer for pressure	HELCOM 2018b
Piers		HELCOM 2018c
Pipelines	15 m buffer for pressure	HELCOM 2018b, HELCOM 2018c
Sea walls		HELCOM 2018c
Slipways		HELCOM 2018c
Structures (Tourism, O&G, Transport: operation)	Land use plan / lincenced area / port administration	ICES 2019c
Tunnels		HELCOM 2018c
Waste disposal (munitions)		HELCOM 2018c
Water course modification	50 m buffer for pressure	HELCOM 2018b
Wave energy production	Area should be estimated based on the installation type and moorings from licensing or EIAs	HELCOM 2018c, ICES 2019b
Wind farms (operational)	10-15m radius, 20-30 m buffer for pressure, 1-5 m positive effect on abundance of epifauna, 0-20 m positive effect on abundance of adult fish	Zaaijer & Henderson 2004, Wilhelmsson et al. 2006, Eastwood et al. 2007, OSPAR 2008, Willson 2011, van der Wal & Tamis 2014, HELCOM 2018b, ICES 2019b

Annex 2. Human activities resulting in physical disturbance of the seabed habitats with spatial extent of their footprint (if available).

Human activity	Spatial extent of physical disturbance and impact (if known)	References
Anchoring, mooring, beaching, launching		Eastwood et al. 2007, HELCOM2018c
Aquaculture (finfish and shellfish mariculture)	1 km buffer with linear decline for pressure, 4-9 km effect	Virtanen et al. 2018, HELCOM 2018b, HELCOM 2018c, ICES 2019c
Bathing sites, beaches	1 km buffer for pressure	Korpinen et al. 2017, HELCOM 2018c
Beach replenishment/ nourishment		Dalfsen van JA & Essink K (2001), HELCOM 2018c
Breakwaters	1-2.5 km effect	Virtanen et al. 2018, HELCOM 2018c
Cables		ICES 2019b
Cables (under construction)	1 km buffer with sharp decline for pressure, 100 m - 2 km effect	HELCOM 2018b, HELCOM 2018c
Coastal dams, weirs		HELCOM 2018c
Coastal defence and flood protection		HELCOM 2018c, ICES 2019b
Coastal defence and flood protection (under construction)	500 m buffer with sharp decline for pressure	HELCOM 2018b
Deposit of dredged material	500 m buffer for points and polygons with sharp decline for pressure. Effects: 4 km (fish), 0-3 km (benthos), 2-3 km (vegetation), 0-5km (turbidity), effect up to 10 km on sensitive species	Several references, see HELCOM 2018c; HELCOM 2018b, ICES 2019b, ICES 2019c, Virtanen et al. 2018
Dredging	1 km buffer for pressure, or permitted/licenced area for estimation	Korpinen et al. 2017, ICES 2019b, ICES 2019c
Dredging (maintenance)	500 m buffer with sharp decline for pressure	HELCOM 2018b
Dredging (capital and maintenance)	Effect: 4 km (fish), 3 km (benthos), 3 km (vegetation), 3 km (water turbidity), up to 10 km effect on sensitive species	Several references, see HELCOM 2018c, Virtanen et al. 2018
Extraction of aggregates		ICES 2019b, ICES 2019c
Extraction of metal ores		HELCOM 2018c
Extraction of minerals		ICES 2019b
Extraction of sand and gravel	500 m buffer with sharp decline for pressure. Effect 4 km (fish), 3 km (vegetation), 2 km (benthos)	Several references, see HELCOM 2018c, HELCOM 2018b
Extraction of water		ICES 2019b
Fishery: Bottom-contacting fishing (benthic trawling, benthic seining, demersal long lining, mussels and scallop dredging, netting, potting/creeling)	Generally estimated as Surface Area Ratio (SAR); 0.05 x 0.05 c-square degree grid (reporting unit for VMS data from ICES); Effect 0.1 km (siltation effect).	HELCOM 2018b, HELCOM 2018c, ICES 2019b, ICES 2019c
Groynes		HELCOM 2018c
Harbours (inc.industrial and ferry ports)	10-25 km effect	Virtanen et al. 2018, HELCOM 2018c
Hunting and collecting for other purposes		ICES 2019b
Marinas and leisure harbours	0.5 km buffer for pressure. Effects at site of the activity: 0.5 km (fish), 0.5 km (vegetation); effects might be up to 11 km	Several references, see HELCOM 2018c, Virtanen et al. 2018
Marine plant harvesting: Machine collection (fucoids, kelp), maerl and furcellaria harvesting, reed harvesting		HELCOM 2018b, HELCOM 2018c
Military infrastructure (e.g. military firing ranges)		HELCOM 2018c, ICES 2019b
Oil platforms	0.5 km buffer for pressure	Eastwood et al. 2007, HELCOM 2018c, ICES 2019b
Pipelines		HELCOM 2018b, HELCOM 2018c
Recreational boating and sports	Effects: 0.5 km (water turbidity, 4 m in depth)	Several references, see HELCOM 2018c, Virtanen et al. 2018, HELCOM 2018b, ICES 2019c

Human activity	Spatial extent of physical disturbance and impact (if known)	References
Research, survey and educational activities (e.g. environmental monitoring stations, fish surveys)		HELCOM 2018c, ICES 2019c
Sea walls		HELCOM 2018c
Ship/boat-building facilities		HELCOM 2018c
Shipping and ferry traffic	1 km extent for pressure or permitted area, area of activity. Effects: 1 km (fish), 1 km (water turbidity, 30 m in depth), 0.5 km (vegetation), 0.3 km abrasion (substrate change); , effects might be up to 10 km effect	Rytkönen et al. 2001; Syväranta & Vahteri 2013; HELCOM 2018b, HELCOM 2018c, ICES 2019c; Virtanen et al. 2018

Human activity	Spatial extent of physical disturbance and impact (if known)	References
Structures (Tourism, O&G, Transport: construction)	Land use plan / lincenced area	ICES 2019c
Structures (Tourism, O&G, Transport: operation)	Land use plan / lincenced area	ICES 2019c
Underwater cultural heritage		HELCOM 2018c
Waste disposal (munitions)		HELCOM 2018c
Water course modification (construction)		Korpinen et al. 2017
Wave energy production		HELCOM 2018c
Wildlife watching		HELCOM 2018c
Wind farms (operational)	0.1 km buffer with sharp decline for pressure	HELCOM 2018b, HELCOM 2018c, Eastwood e al. 2007
Wind farms (under construction)	1 km buffer with sharp decline for pressure. Local adverse effect on fish	Andersson 2011, HELCOM 2018b, HELCOM 2018c

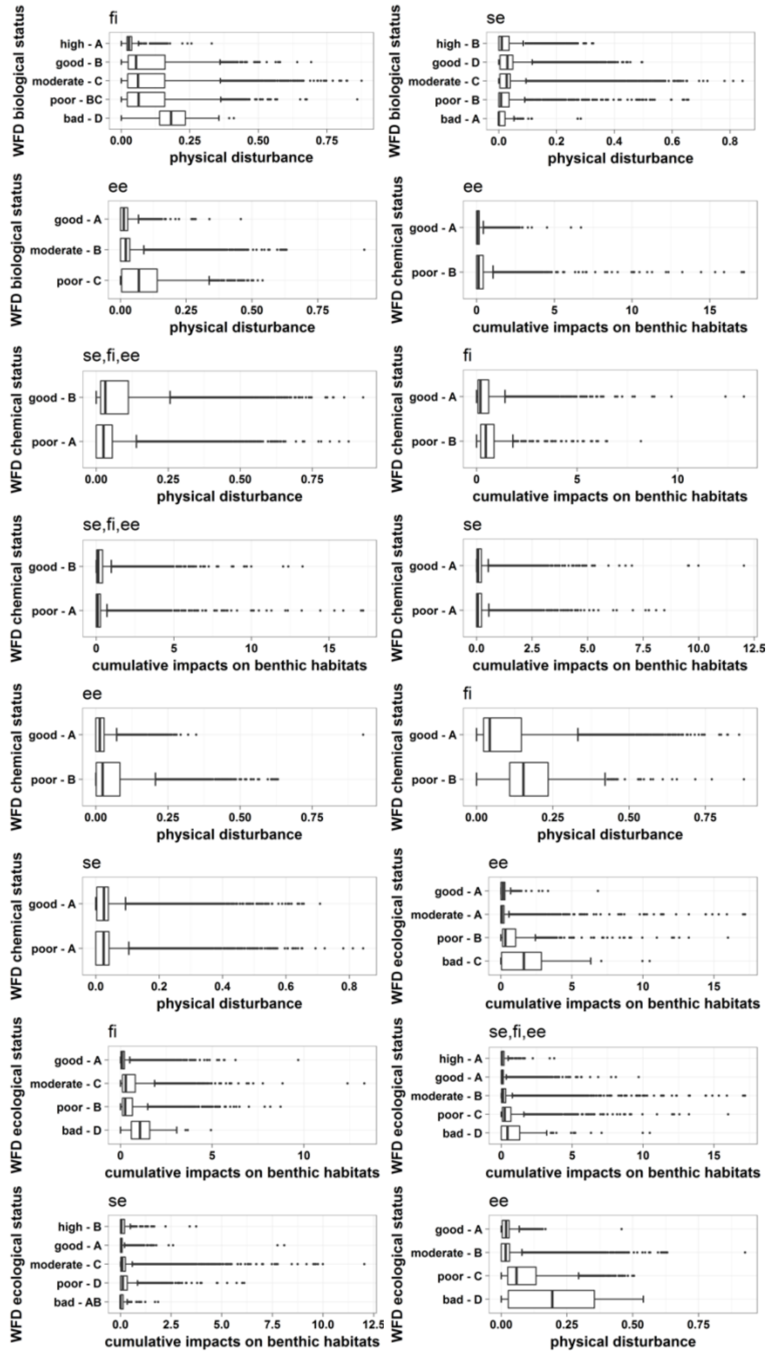
Annex 3. Human activities resulting in changes to hydrological conditions and the spatial extent of the footprint of the pressure or impact (if available).

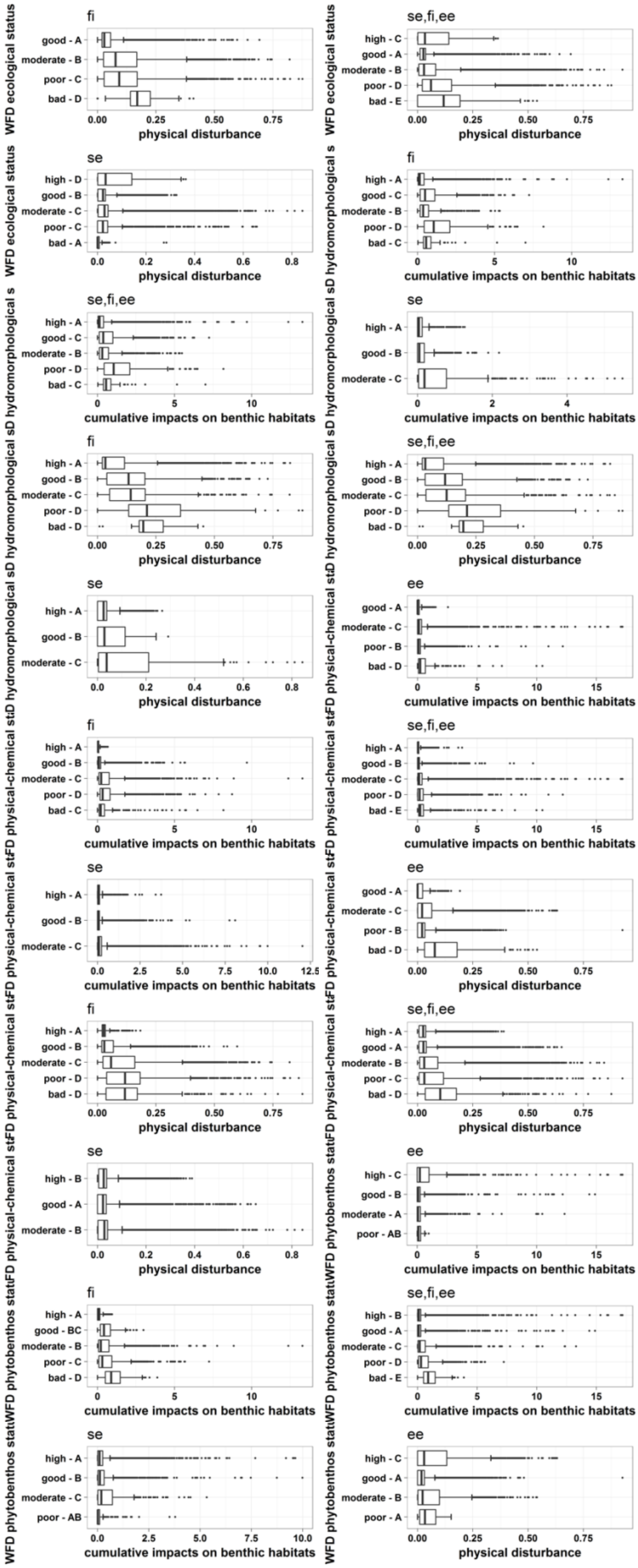
Human activity	**Spatial extent of hydrological changes or their impact (if known)**	**Reference**
Artificial reefs and islands		HELCOM 2018c
Breakwaters		HELCOM 2018c
Coastal dams, weirs		HELCOM 2018c
Coastal defence and flood protection	Very rapid normalization of the conditions from the site seawards.	Martin et al. 2005
Groynes		HELCOM 2018c
Hydropower dams	1 km2 surrounding area for pressure	HELCOM 2018b
Marinas and leisure harbours		HELCOM 2018c
Oil platforms	0.5 km buffer around each turbine for pressure	HELCOM 2018b
Piers		HELCOM 2018c
Water course modification	1 km buffer for pressure	HELCOM 2018b
Wave energy production		HELCOM 2018c
Wind farms (operational)	0.1 – 0.3 km for pressure	Eastwood et al. 2007, HELCOM 2018b

Annex 4.

Figure A1 presents the more detailed results from WFD status assessments versus different pressures. Figure A2 presents the more detailed results from the HOLAS benthic habitat status assessments versus different pressures. Both figures have been adopted from SPICE Deliverable 4.2.3.

Figure A1. Summary figures of the WFD status assessments versus physical disturbance and cumulative impact index on benthic habitats in Estonia, Finland and Sweden. Letters after status class names (on vertical axis) indicate the results of pairwise post-hoc tests: levels are significantly different if they do not have any letters in common.




WFD ecological status
fi
good - A
moderate - B
poor - C
bad - D
0.00 0.25 0.50 0.75
physical disturbance
se,fi,ee
high - C
good - A
moderate - B
poor - D
bad - E
0.00 0.25 0.50 0.75
physical disturbance
se
high - D
good - B
moderate - C
poor - C
bad - A
0.0 0.2 0.4 0.6 0.8
physical disturbance
fi
high - A
good - C
moderate - B
poor - D
bad - C
0 5 10
cumulative impacts on benthic habitats
WFD hydromorphological status
se,fi,ee
high - A
good - C
moderate - B
poor - D
bad - C
0 5 10
cumulative impacts on benthic habitats
se
high - A
good - B
moderate - C
0 2 4
cumulative impacts on benthic habitats
fi
high - A
good - B
moderate - C
poor - D
bad - D
0.00 0.25 0.50 0.75
physical disturbance
se,fi,ee
high - A
good - B
moderate - C
poor - D
bad - D
0.00 0.25 0.50 0.75
physical disturbance
se
high - A
good - B
moderate - C
0.0 0.2 0.4 0.6 0.8
physical disturbance
WFD physical-chemical status
ee
good - A
moderate - C
poor - B
bad - D
0 5 10 15
cumulative impacts on benthic habitats
fi
high - A
good - B
moderate - C
poor - D
bad - C
0 5 10
cumulative impacts on benthic habitats
se,fi,ee
high - A
good - B
moderate - C
poor - D
bad - E
0 5 10 15
cumulative impacts on benthic habitats
se
high - A
good - B
moderate - C
0.0 2.5 5.0 7.5 10.0 12.5
cumulative impacts on benthic habitats
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good - A
moderate - C
poor - B
bad - D
0.00 0.25 0.50 0.75
physical disturbance
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high - A
good - B
moderate - C
poor - D
bad - D
0.00 0.25 0.50 0.75
physical disturbance
se,fi,ee
high - A
good - A
moderate - B
poor - C
bad - D
0.00 0.25 0.50 0.75
physical disturbance
se
high - B
good - A
moderate - B
0.0 0.2 0.4 0.6 0.8
physical disturbance
WFD phytobenthos status
ee
high - C
good - B
moderate - A
poor - AB
0 5 10 15
cumulative impacts on benthic habitats
fi
high - A
good - BC
moderate - B
poor - C
bad - D
0 5 10
cumulative impacts on benthic habitats
se,fi,ee
high - B
good - A
moderate - C
poor - D
bad - E
0 5 10 15
cumulative impacts on benthic habitats
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high - A
good - B
moderate - C
poor - AB
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cumulative impacts on benthic habitats
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moderate - B
poor - A
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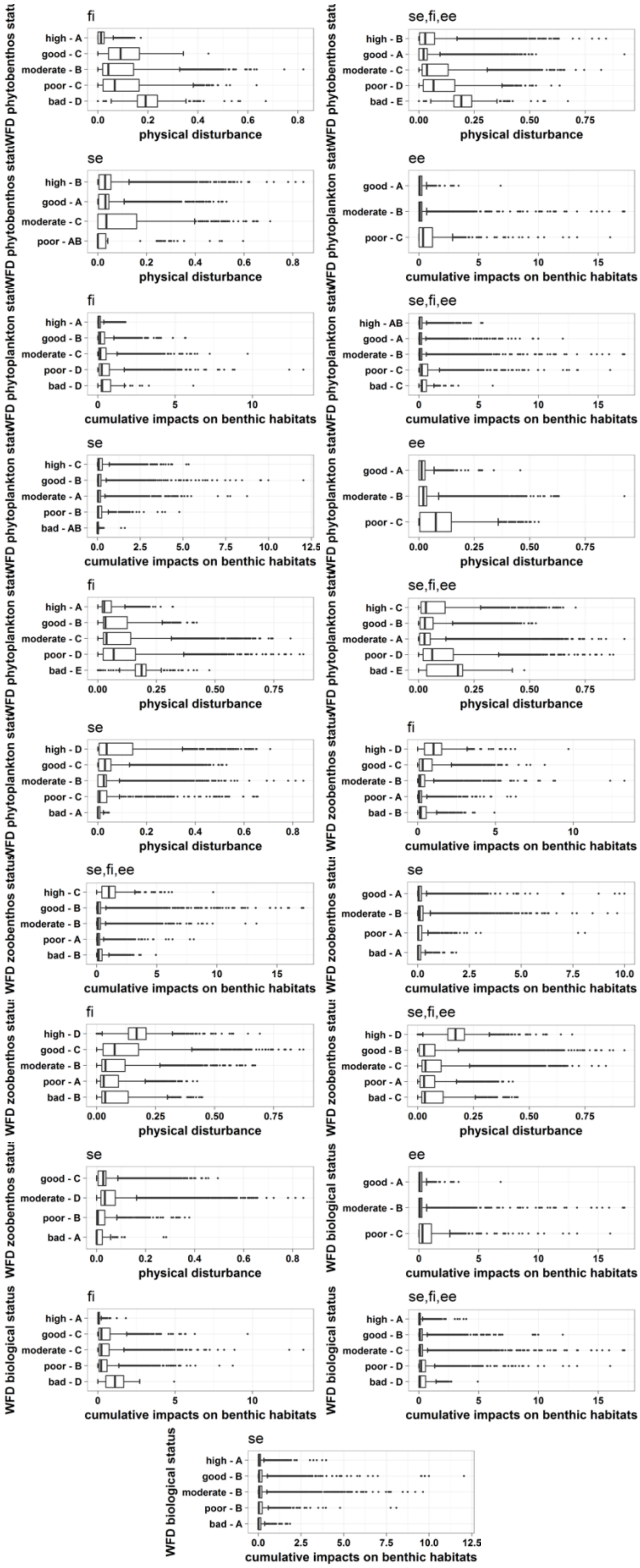
physical disturbance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high - A
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moderate - B
poor - C
bad - D
physical disturbance
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se,fi,ee
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poor - D
bad - E
physical disturbance
se
high - B
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moderate - C
poor - AB
physical disturbance
ee
good - A
moderate - B
poor - C
cumulative impacts on benthic habitats
fi
high - A
good - B
moderate - C
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cumulative impacts on benthic habitats
se,fi,ee
high - AB
good - A
moderate - B
poor - C
bad - C
cumulative impacts on benthic habitats
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poor - B
bad - AB
cumulative impacts on benthic habitats
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physical disturbance
WFD phytoplankton stat
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bad - E
physical disturbance
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physical disturbance
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high - D
good - C
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bad - A
physical disturbance
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cumulative impacts on benthic habitats
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cumulative impacts on benthic habitats
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cumulative impacts on benthic habitats
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moderate - B
poor - A
bad - B
physical disturbance
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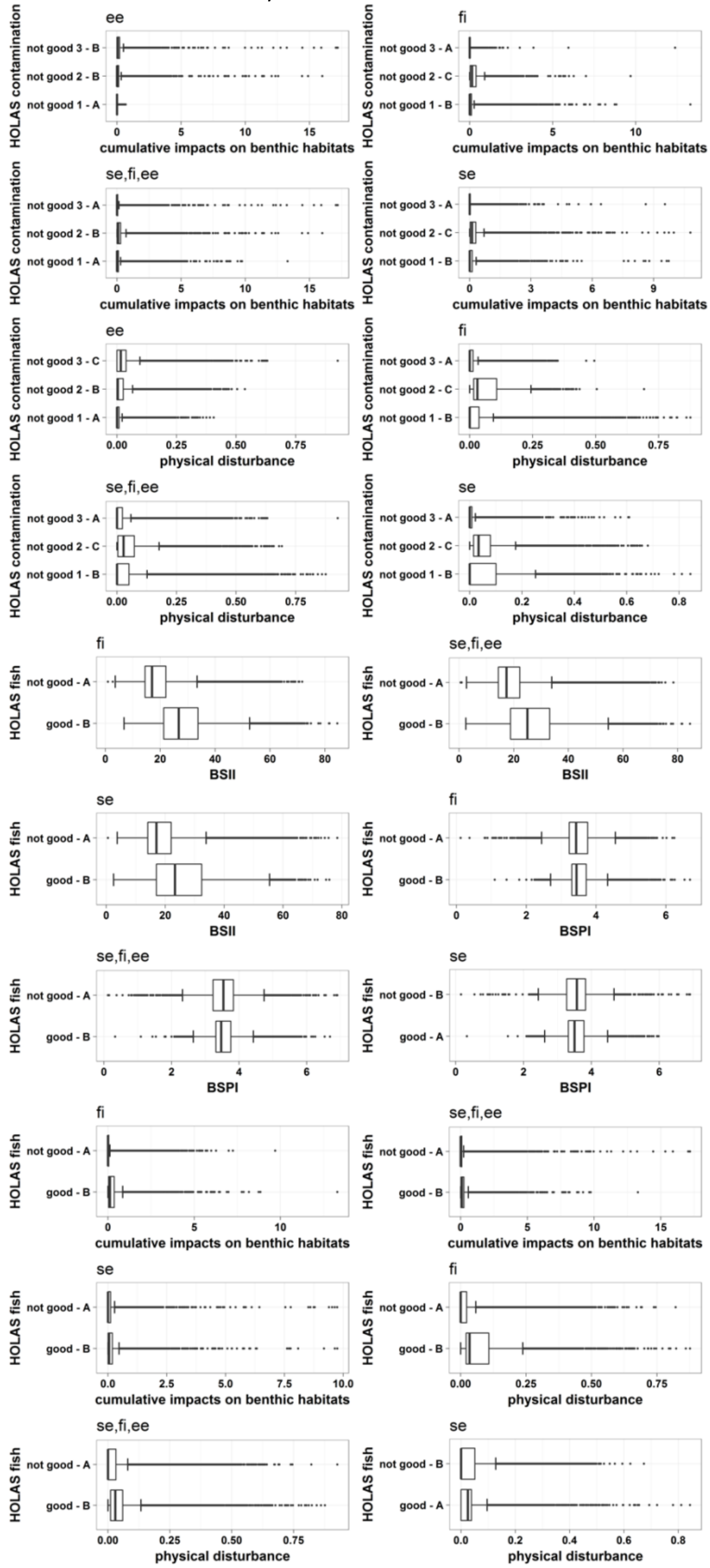
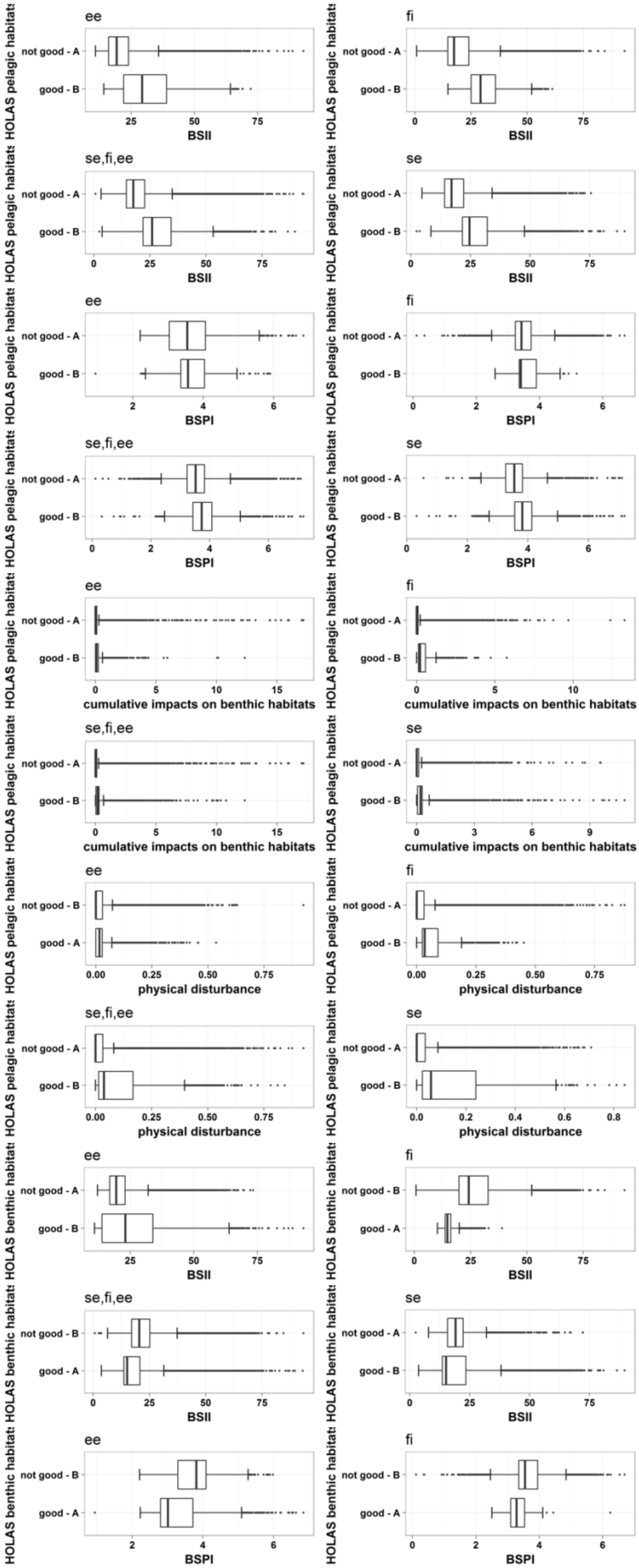
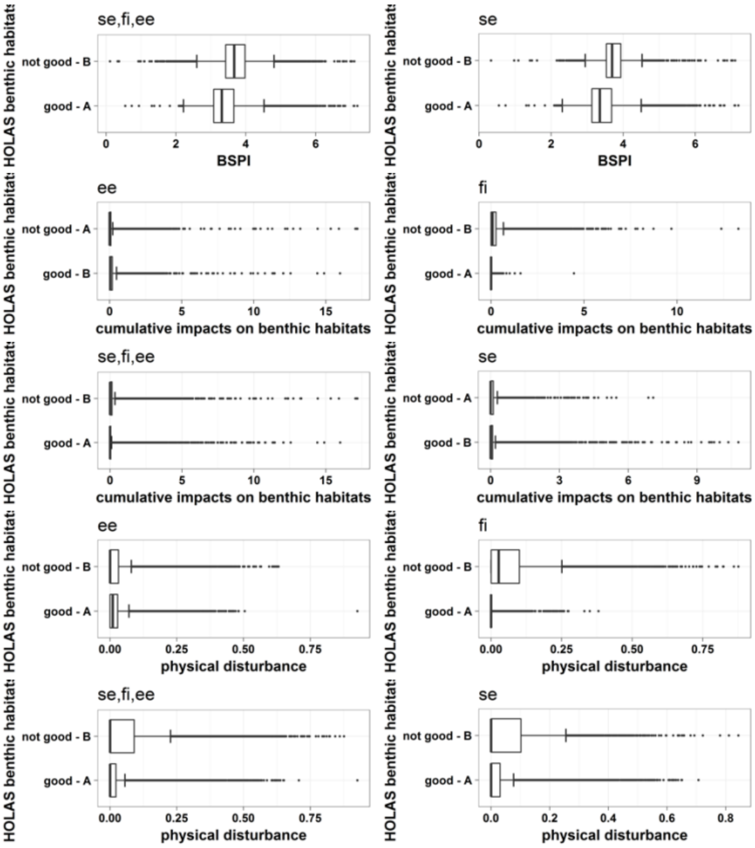
high - D
good - B
moderate - C
poor - A
bad - C
physical disturbance
se
good - C
moderate - D
poor - B
bad - A
physical disturbance
ee
good - A
moderate - B
poor - C
cumulative impacts on benthic habitats
WFD biological status
fi
high - A
good - C
moderate - C
poor - B
bad - D
cumulative impacts on benthic habitats
se,fi,ee
high - A
good - B
moderate - C
poor - D
bad - D
cumulative impacts on benthic habitats
se
high - A
good - B
moderate - B
poor - B
bad - A
cumulative impacts on benthic habitats

Figure A2. HOLAS status assessments versus different pressure inputs. Letters after status class names (on vertical axis) indicate the results of pairwise post-hoc tests: levels are significantly different if they do not have any letters in common.




ee
fi
se,fi,ee
se
HOLAS pelagic habitats
HOLAS benthic habitats
not good - A
good - B
not good - B
good - A
BSII
BSPI
cumulative impacts on benthic habitats
physical disturbance


se,fi,ee
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HOLAS benthic habitats
not good - B
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not good - A
good - B
BSPI
cumulative impacts on benthic habitats
physical disturbance