GEAR

Estimating physical disturbance on seabed

Baltic Marine Environment Protection Commission

Seabed loss & disturbance

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Contents

1. Introduction

The Good Environmental Status (GES) of the marine environment is the center point of the Marine Strategy Framework Directive (MSFD) of the European Union (EU). To reach GES or maintain the marine environment in GES, EU Member States are required to take measures (Art 13), set environmental targets for pressures and impacts (Art 10) and assess the status by a set of criteria on GES (Art 8 and 9).

Marine benthic habitats are an important element of the environmental targets and GES criteria and, according to the draft revision of the Commission Decision on GES criteria, for which the Marine Strategy Regulatory Committee gave a positive vote on 10 November (hereafter 'revised COM DEC', these two requirements are closely linked to each other. Both the environmental targets and the GES criteria focus on physical pressures affecting the seabed. Therefore the development of methods to set targets and assess marine benthic habitats is an essential step in the implementation of the MSFD. HELCOM has furthermore been agreed that future work on development environmental targets should focus on joint principles for environmental targets related to damage to seafloor (Outcome of HOD 48-2015, para 3.20).

The work package 3.1 of the HELCOM BalticBOOST project has the objective of developing guidelines to set environmental targets for pressures affecting seabed habitats in the Baltic Sea region. The work was started by gathering a state-of-the-art knowledge base in order to support the understanding of links between activities, pressures and impacts and only then the work continued to develop guidelines for setting the environmental targets which are described in the Deliverable 2 of the WP 3.1.

This report presents the results of establishing the knowledge base and method development. The work was based on two strands: a literature review and case studies. The literature review included only non-fishery pressures since the previous HELCOM project (BALTFIMPA[1]) already focused on fishery literature. The case studies included studies of impacts from maritime construction (e.g. wind farms, a harbour), aggregate extraction, dredging, disposal of dredged matter and fisheries in cooperation with WP 3.2. The case studies were data-driven approaches to analyze the relationship between impacts and the state of environment. Thus, this report is a co-operative product between the two WPs. WP 3.3 furthermore contributed with developing a linkage framework between human activities and physical pressures which is presented as part of this deliverable. SYKE and IOW focused on non-fishery pressures, SLU and DTU Aqua focused on fishery pressures and ICES encompassed all pressures. Chapter 2 presents the WP 3.1 approaches to meet the project objectives and Chapter 3 presents the main results. More detailed results are given in Annexes of the report to support further work.

1 http://www.helcom.fi/helcom-at-work/projects/completed-projects/baltfimpa/

2. Approaches to the meet the WP objectives

2.1. Linkage framework – links from activities to pressures and impacts

A prerequisite for the implementation of Theme 3 work of the project (Physical loss and damage to seabed habitats) was to develop a linkage framework which allows human activities to be linked with physical pressures. This was carried out as part of the WP 3.3 activity. Figure 1 visualizes a simplified linkage framework where human activities are linked to five more specific pressures and these again integrated as two physical pressure types. The linkages help to identify which activities cause the pressures on benthic habitats. The linkage frameworks were compiled in co-operation with the HELCOM TAPAS project[1] on the basis of the works made in the FP7 ODEMM project[2], OSPAR[3], JNCC[4] and INPN[5] (see also Knights *et al.* 2015).

The previous works on linkage frameworks have indicated that several activities exert several pressures which affect the benthic habitats in several ways (see for instance the references in the foot notes) and therefore the work included three physical pressures which are listed in the draft revisions of Annex III of the MSFD:

1. physical loss due to permanent change of seabed substrate or morphology and to extraction of seabed substrate,
2. physical disturbance to seabed, and
3. changes in hydrological conditions.

The two first ones are referred to in this report as 'physical loss' and 'physical disturbance', and the majority of the work focused on these two pressure types. The physical loss is defined in the revised COM DEC 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 physical disturbance is defined as 'a change to the seabed which can be restored if the activity causing the disturbance pressure ceases'. It was noticed that for practical implementation both these categories still need more detailed definitions and the distinction of pressures belonging to each of the two categories based on Baltic-BOOST results are given in Chapter 4, Section 4.1. More detailed results of the linkage framework are given in Annex 1 of this report. As the linkage frameworks in this report aimed to support only the activity-pressure links, we did not elaborate on the pressure-impact links, which are part of the HELCOM TAPAS project. The literature review, however, will support any further work in defining those links also for benthic habitats.

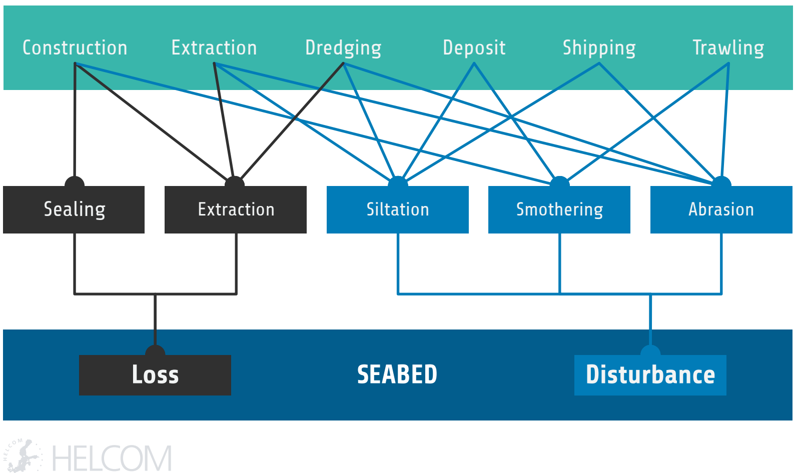

Figure 1. Links between generalized activity types and the physical pressures they exert on the seabed. Black arrows indicate the links leading to physical loss of seabed habitats, whereas blue arrows indicate links to physical disturbance.

1 The HELCOM coordinated EU co-finance project: Development of HELCOM tools and approaches for the Second Holistic Assessment of the Ecosystem Health of the Baltic Sea. http://www.helcom.fi/helcom-at-work/projects/tapas/
2 http://odemm.com/content/linkage-framework
3 http://qsr2010.ospar.org/media/assessments/p00443_BA6_assessment-final.pdf
4 http://jncc.defra.gov.uk/pdf/Final_HBDSEG_P-A_Matrix_Paper_28b_Website_edit%5b1%5d.pdf
5 https://inpn.mnhn.fr/programme/sensibilite-ecologique?lg=en

2.2. Catalogue of activities, pressures and impacts

A literature review was carried out to assess the impacts of human activities on the seabed habitats. The focus of the review was on non-fishery related activities causing physical pressures on the seafloor, as the fishery impacts have been evaluated previously in other projects e.g. the HELCOM BALTFIMPA[6] and EU FP7 BENTHIS[7] projects and this knowledge was made available in the workshops of the project.

The aim of the literature review was to get quantitative estimates on impacts caused by the human activities on the seabed habitats. In addition, information on spatial extent of the pressure and impacts as well as how the habitats recover once the activities have ceased was retrieved. This information enabled:

- comparison of activities in terms of the pressure magnitudes and impacts they exert;
- comparison of activities in terms of the spatial extent of the pressures and impacts;
- applying spatial extents to the pressures from various activities;
- understanding the effect of pressure duration on its impacts;
- getting information of the recovery of different benthic features after activities and pressures have ceased.

To store and report this information WP 3.1 created a catalogue. The catalogue includes information of the type of activity, pressure it is causing, intensity of the pressure, lasting of the pressure, target of the impact, type of impact, magnitude of the impact, spatial extent of the impact, recovery from the impact, region of the study, type of study, and reference to the study cited. In total, > 120 studies with >420 hits for different impacts on benthic habitats were added into the catalogue. The catalogue has been synthesized into a table in Annex 2, summarizing the level of activity and magnitude of pressure and impact on different benthic habitats and species. The case study results from fishing and non-fishing pressures were added to the synthesis after the second workshop of the project, where the fishery and non-fishery pressures and impacts were compared and analyzed (HELCOM 2016 a).

The catalogue and synthesis table is available as an Excel file which is Annex 2 of this deliverable.

6 http://www.helcom.fi/helcom-at-work/projects/completed-projects/baltfimpa
7 http://www.benthis.eu/en/benthis.htm

2.3. Case studies in the Baltic Sea

The WP 3.1 carried out six case studies in different parts of the Baltic Sea to investigate how the intensity of human activities affects the benthic habitats and species. In the case studies, two geographical scales were applied: regional and local scale. The purpose of the studies at regional scale was to get an estimate of how large area of the seafloor that is impacted by human activities and to analyse the significance of different human activities on a larger scale. The studies at local scale looked more into the impact of specific human activities in the vicinity of the study area. Three of the case studies targeted fishing activities in cooperation with work package 3.2: one in Femern Belt area, one consisting of several test areas in southern and eastern Swedish coast and one covering the entire Baltic Sea. Three case studies targeted human activities other than fishing: two in German coastal areas and one in Gulf of Finland. The case study approaches are described below and fully in Appendix 3, Supporting material.

2.3.1 Mecklenburg Bight

The case study gives an overview of the main non-fishery activities in one assessment area, the sub-basin Mecklenburg Bight in the Western Baltic, on a rather broad scale (Figure 2). By relating the spatial coverage of human activities to a coarse habitat map in a geographic information system (GIS), the extent of affected habitats was approximated. It is not meant to be an exact analysis of localized impacts and does not claim to be exhaustive. Up-to-date information of human activities was only available in very few cases, because the study was conducted before the data were processed for the HELCOM data call for the second holistic assessment. The case study is a calculated on

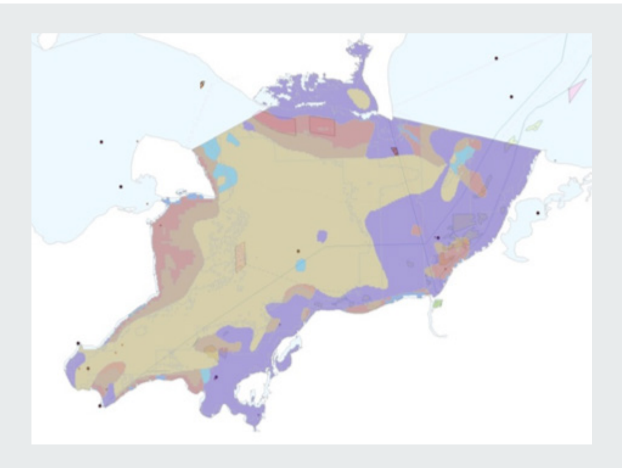

Figure 2. Map of the case study area Mecklenburg Bight where white area represents land, light blue indicates sea and the other colours indicate seabed substrate in the case study area. Other symbols refer to human activities.

the basis of readily and “not-so-readily” available data from HELCOM, ICES or national data services. With a large set of local data the relative extent of several non-fisheries effects were explored in an intensely used area. Full case study report is available as Appendix 3, Supporting material 2.

2.3.2 Plantagenet Ground

The case study location at Plantagenetgrund in Mecklenburg, Germany, was chosen, because in this small area an unusual variety of non-fisheries pressures can be found (Figure 3). It aims at exploring information from sources, which are not usually publicly available, applied to the most accurate high-resolution habitat map with the help of a geographic information system (GIS). However, even though voluminous EIAs (environmental impact analyses) for construction or sediment extraction projects are accessible upon request, the underlying data, like for species or biomass, are not. Therefore a concrete comparison between communities in affected or unaffected areas cannot be carried out to the desirable degree and the analyses had to remain on a less precise level. Still, the case study sheds light on the effort needed to assess physical loss and damage on a small scale, like in Marine Spatial Planning or EIA exercises, in contrast to the sub-basin scale planned for in HOLAS II[8]. In addition, coastal installations like groynes or piers were included in the case study. Full case study report is available as Appendix 3, Supporting material 3.

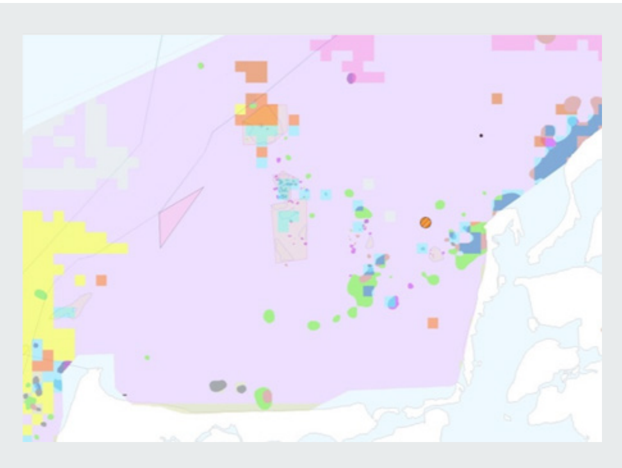

Figure 3. Map of the case study area Plantagenet Grund where white area represents land, light blue indicates sea and the other colours indicate EUNIS level 6 benthic biotopes in the case study area. Other symbols refer to human activities.

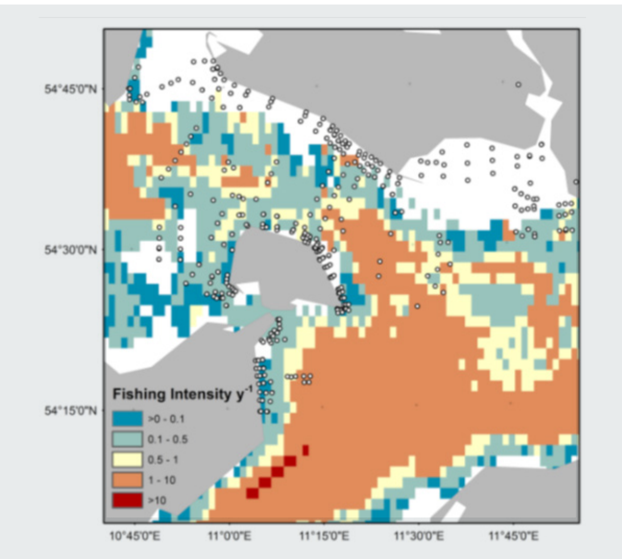

Figure 4. Map of the case study area in the Femern Belt. Colour codes indicate fishing intensity by Danish, German and Swedish vessels (≥ 15 m length) fishing with towed gears (trawls, seiners, dredges) in the Femern Belt area in 2010. The Femern Belt invertebrate sampling stations are included in the map as circles.

2.3.3 Gulf of Finland

In the Gulf of Finland local effects of a large harbour construction work were studied. The harbour construction site was 10 km east of Helsinki. Restricted to a quite small area outside the harbour, the case study analysed pressures caused by construction, dredging, disposal of dredged material, sand extraction, land fill and shipping and their effects on water quality, benthic macrofauna and vegetation. The affected area was monitored before, during and after the construction phase, resulting in a large data set on environmental and biological parameters. In addition, long-term water quality monitoring has been carried out close to the construction site, giving information on background levels on e.g. turbidity and suspended solids. Full case study report is available as Appendix 3, Supporting material 1.

2.3.4 Femern Belt

The Femern Belt case study in the SW Baltic Sea made use of an extensive sampling of benthic macrofauna and analysed that against a suite of hydrographical parameters and the total fishing intensity with hauled fishing gears (as calculated by the BalticBOOST FIT tool, see WP 3.2, Deliverable 1). Fishing intensity was calculated as the fishing effort of hauled gears accumulated within 1000 m radius around each of the benthic invertebrate sampling station during the previous 3 months of the sampling date (Figure 4). The dependency of four variables (macrofauna density, species richness, biomass and average individual mean weight) on fishing intensity was analysed by several statistical models. The performance of the models was compared and the best fitting model was selected to estimate the impacts. Furthermore, it was attempted to identify threshold values of the fishing impacts through different types of plots of the above biological indicators versus fishing intensity. The case study is available as Appendix 3, Supporting material 4.

8 State of the Baltic Sea 2017 – HELCOM Second Holistic Assessment of the Ecosystem Health of the Baltic Sea: http://helcom.fi/helcom-at-work/projects/holas-ii/

2.3.5 Swedish coastal areas

Bottom trawling has been shown to affect benthos in several studies and therefore this pressure was analysed for four Swedish sea areas in the Baltic Sea (Figure 5). The case study combined three different data sources: benthic national monitoring data, fishing activity coupled to logbook data and fishing gear type, and area swept by the specific gear. The purpose was to see how the bottom-trawling fishery at different intensity levels impacts the benthic invertebrate community. Swedish monitoring data of soft benthic sediment assemblages was retrieved from sea areas that are known to be covered by a demersal fishery or are close to areas with demersal fishing activities (Figure 5). Possible relationships between fishing intensity and depth, and multivariate and univariate data on benthos assemblages in 2010 and 2012 were explored with distance-based redundancy analysis (dbRDA) in the DistLM routine in the Primer package. Fishing intensity was calculated as the accumulated fishing intensity for four years before sampling of benthos with a 30% reduction each year beginning with year two. Full case study report is available as Appendix 3, Supporting material 5.

2.3.6 Impacts of bottom fishing in the entire Baltic Sea

The case study applied a so-called longevity approach to estimate reduction in biomass of benthic macrofauna after trawling. The trawling data included years 2010 and 2012. The analysis used a recent characterisation of benthic communities to 18 types (Gogina *et al.* 2016) and estimated longevity values for each of the species in the communities. The analysis estimated the frequency of a fishing gear sweeping over a grid cell. Based on that one can estimate how long the species in the grid cell area can be unaffected. By assuming that all animals die after trawling (an unrealistic but simple assumption), one can estimate how much of the community biomass can recover between the fishing occasions. If the assessed community type consists of long-living species, it is assumed that their recovery will take longer time than the recovery of short-living species. Hence, communities with more short-living species will lose less biomass after a trawling event and can tolerate more frequent trawling events than communities with long-living species. Full case study report and detailed methodology is included in Appendix 3, Supporting material 6.

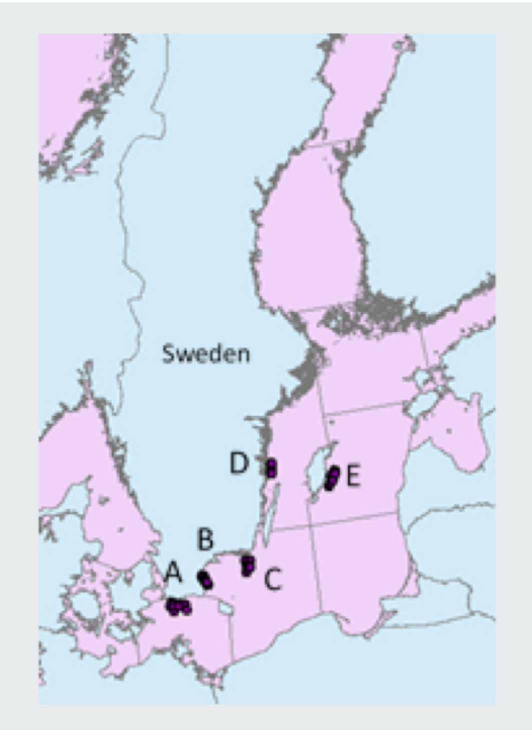

Figure 5. Map of the case study areas in Swedish coastal waters. Circles represent monitoring stations in the Baltic Sea used in the study.
A = Scania, B=Hanö bay west, C=Blekinge, D= Kalmar, E=Gotland.

2.4. Finding maximum allowable pressure levels

The definition of an environmental target (art. 10 of the MSFD) implies that there is a level of maximum allowable pressure (MAP) which is consistent with maintaining GES for impacted species or habitats. Although environmental targets need not be limited to such a MAP level, finding the MAP is highly desirable and also indicated by the list of indicative characteristics for environmental targets in Annex IV of the MSFD. Therefore the WP 3.1 literature review and the case studies made statistical analyses between state and pressure parameters to find any such correlations and MAP levels. The BalticBOOST recommendations on environmental targets are presented in Deliverable 2 of the WP 3.1.

The MAP level is easiest to define if a HELCOM core indicator[9] with a GES threshold can successfully be correlated with a pressure parameter. In such a correlation, the MAP is found at the level of GES threshold. In many cases, the data within the core indicators are, however, too aggregated in space and time (e.g. the oxygen debt indicator) to show statistically significant correlation with pressures

9 HELCOM core indicators are defined by several criteria but they all need to have a threshold which indicates GES. See http://www.helcom.fi/baltic-sea-trends/indicators/ and http://www.helcom.fi/Lists/Publications/BSEP136.pdf for more indormation.

which are measured at spatially more detailed scale. Therefore other state parameters can be more useful, even if the MAP levels are not as straightforward to interpret. In this report, the HELCOM core indicator for benthic macrofauna community was considered in the Gulf of Finland case study as well as in the Swedish fishery case study and analyses against other state parameters were made in the Femern Belt case study and the Gulf of Finland case study.

2.5. Towards coherent representation of the physical pressures

The three physical pressure types included in the draft revision of pressure list of the Annex III of the MSFD are very broadly defined (see Section 4.1 for their suggested definition). While the physical loss can rather easily be calculated (once defined operationally), the pressure type 'Physical disturbance on seabed' and 'Changes to hydrological conditions' are more difficult due to the broadness of their definition. For instance, 'physical disturbance' includes all kinds of pressures such as siltation, sedimentation, smothering, abrasion and erosion. How can one compare, e.g., sedimentation and abrasion pressures with each other and produce a data layer of the extent of this pressure?

This difficulty is a principal problem when assessing the status of the benthic habitats according to the revised COM DEC, because no spatial map representing the aggregated pressure 'physical disturbance' can be made without a numerical method to compare the different pressure data sets. Such a practical problem was faced by the HELCOM TAPAS project when producing pressure maps for the cumulative impact index in the Baltic Sea. The Second HELCOM TAPAS workshop on pressure and impact index (6-7 September 2016, Helsinki) made a recommendation to solve this challenge, namely to normalize the underlying data layers between 0-1 and then weight the layers according to their relative significance. As the HELCOM Data and Map Service hosts spatial data layers of human activities, it was recommended that each human activity causing 'physical disturbance' (see the linkage framework in Section 2.1) would be evaluated in relation to other ones and they would be ranked in their importance as exerting pressures or causing impacts. For example, a dredging activity causes high sedimentation rates causing >75% mortality at the vicinity of the site (see results of the literature review in Chapter 3), whereas sedimentation from shipping, cable laying or wind turbine drilling cause lower mortality.

Such ranking of human activities was carried out as part of the BalticBOOST project on the basis of the literature review and the case studies. The Section 4.4 presents the summary results.

3. Results

3.1. Linkage framework

A linkage framework was produced on the basis of the several previous products (see Section 2.1) and adapted to the pressure categories of the revised MSFD Annex III and the pressure list agreed by the Fourth Meeting of the HELCOM HOLAS II core team (HOLAS II 4-2015). The activity – pressure linkage in the linkage framework was limited to benthic pressures only and it was decided for BalticBOOST to cover all activities causing the three types of physical pressures. The impacts were, however, recorded from the three physical pressures to benthic habitats only. A separate work stream under the HELCOM TAPAS project covers other pressures and impacts to all the ecosystem components.

Table 1 presents the activities causing physical disturbance and physical loss, as defined in the linkage framework made in the project. The activities in the table act on very different magnitudes and scales (spatial and temporal).

There are also other pressures affecting benthic habitats and as listed in Table 2. In these 'other pressures' the impacts are either indirect (e.g. changes in water flows), chemical (e.g. causing eutrophication, hypoxia, contamination) or spatially very limited (e.g. input of heat, seismic waves, impulsive sounds). We included the pressure 'changes to hydrological conditions' to Table 2. We did not consider eutrophication or hypoxia/anoxia in the project's Theme 3 work as other reports give more comprehensive estimates of their impacts (e.g. HELCOM 2009, 2013). The linkage framework developed in BalticBOOST is presented in Annex 1 and is also available at the HELCOM web site (http://www.helcom.fi/action-areas/maritime-spatial-planning/human-activities-and-pressures).

3.2. Magnitude of pressures and impacts from human activities

A central objective of the WP 3.1 is an analysis of the dependency of pressures and impacts on the magnitude of a human activity. This work was mainly based on the case studies as the published literature seldom reports the needed information for a statistical analysis. The analysis focused on the pressure type 'physical disturbance'. 'Physical loss' cannot be analysed by this approach because even smallest activities cause loss of the area if they remove seabed substrate, deposit new substrate or build over the seabed. The only variable in the physical loss is the recovery time which may vary from activity to activity or feature to feature. Therefore the main development task for this pressure is to define – in operational terms – which pressures are categorized as 'physical loss'.

Overall, the task to estimate pressure magnitudes was complex and clear dependencies were difficult to find. A summary of the main challenges for this are:

1. the non-fishery activities have spatially limited impacts and the benthic monitoring sites do not capture such local impacts;
2. temporally limited impacts do not overlap with the benthic monitoring frequency;
3. environmental monitoring stations do not capture sufficiently wide pressure gradients and impact gradients from fishing for statistical analyses because they have not been designed to monitor those impacts;
4. physical impacts are difficult to distinguish from eutrophication, contamination or natural processes (e.g. upwelling, wind-forced resuspension, etc.);
5. indicators with GES thresholds are typically spatially and temporally aggregated and hence not adequate for this analysis;
6. often several impacts take place at the same time which makes it difficult to allocate the correct magnitude to specific impacts.

The synthesis of the literature survey aimed to find out which human activities have been observed to cause impacts on benthic habitats or species. While linkage frameworks may have accurately pointed out links between activities and pressures, it is still a different issue whether an activity actually causes an impact and to what extent as this depends on a number of factors such as frequency, duration and magnitude as well as numerous local environmental factors. In the following paragraphs the main activities causing physical pressures on seabed habitats are described and their impacts are estimated based on the findings from the literature survey.

3.2.1 Capital and maintenance dredging

The pressure causes 'physical loss' and 'physical disturbance' (Table 1).

Dredging is usually divided between two activities: capital dredging and maintenance dredging. Capital dredging is defined as 'Material arising from the excavation of the seabed, generally for construction or navigational purposes, in an area or down to a level (relative to Ordnance Datum) not previously dredged during the preceding 10 years.' (Marine Management Organization).

Table 1a. Human activities causing Change of seabed substrate or morphology (~ physical loss). The pressure definitions are given in Section 4.1 and the lists of human activities are from the linkage framework. Grey colour indicates that the activity was included in the catalogue (Annex 2).

Finfish mariculture
Shellfish mariculture
Wind energy production: wind farms under construction
Wave energy production
Cables, incl. placement
Extraction of metal ores
Extraction of sand and gravel
Pipelines, incl. placement
Permanent land claim (urban, industrial, leisure, agriculture purposes)
Large-scale water deviation
Canalisation
Culverting/trenching
Coastal dams, weirs
Sea walls
Breakwaters
Groynes
Flood protection
Tidal barrages
Artificial reefs and islands
Dredging (Capital/maintenance)
Beach replenishment/ nourishment
Tourism and leisure infrastructure: Piers
Tourism and leisure infrastructure: Marinas and leisure harbours
Tourism and leisure infrastructure: Slipways
Transport infrastructure: Fishing harbours
Transport infrastructure: Industrial and ferry ports (harbours, bunkering points at sea; oil terminals)
Transport infrastructure: Bridges and causeways
Transport infrastructure: Tunnels
Solid waste disposal, incl. deposit of dredged material
Carbon capture and storage (Carbon sequestration)
Military infrastructure (e.g. military firing ranges)
Waste disposal (munitions)

Table 1b. Human activities causing Physical disturbance or damage to the seabed. The pressure definitions are given in Section 4.1 and the lists of human activities are from the linkage framework. Grey colour indicates that the activity was included in the catalogue (Annex 2).

Finfish mariculture*
Shellfish mariculture*
Wind energy production: wind farms under construction*
Wave energy production*
Cables, incl. placement*
Fishery: Potting/Creeling
Fishery: Netting
Fishery: Demersal long lining
Fishery: Benthic trawling
Fishery: Benthic seining
Fishery: Mussels and scallop dredging
Marine plant harvesting: Machine collection (fucoids, kelp)
Marine plant harvesting: Maerl and Furcellaria harvesting
Marine plant harvesting: Reed harvesting
Extraction of metal ores*
Extraction of sand and gravel*
Oil and gas industry infrastructure (Oil platforms)*
Pipelines, incl. placement*
Coastal dams, weirs*
Sea walls*
Breakwaters*
Groynes*
Flood protection*
Tidal barrages*
Dredging (Capital/maintenance)*
Beach replenishment/ nourishment
Tourism and leisure infrastructure: Marinas and leisure harbours*
Tourism and leisure activities: Recreational boating, yachting
Tourism and leisure activities: Beach use (bathing sites, beaches)
Tourism and leisure activities: Wildlife watching
Tourism and leisure activities: Underwater cultural heritage
Transport infrastructure: Industrial and ferry ports (harbours, bunkering points at sea; oil terminals)*
Transport infrastructure: Ship/boat-building facilities*
Transport: Passage of ships/boats
Transport: Mooring, anchoring, beaching, launching
Solid waste disposal, incl. deposit of dredged material*
Military infrastructure (e.g. military firing ranges)
Waste disposal (munitions)
Research and survey: Fish surveys
Research and survey: Environmental monitoring stations

* Activities marked by an asterisk indicate secondary pressures outside the activity's core zone.

Table 2. Other pressures affecting benthic habitats and human activities causing these pressures. Selected activities affecting only benthic habitats have been included from the linkage framework.

Pressure	Activity
Changes to hydrological conditions	— Wind energy production: operational wind farms — Wave energy production — Oil and gas industry infrastructure (Oil platforms) — Breakwaters — Groynes — Artificial reefs and islands — Piers — Marinas and leisure harbours — Coastal dams, weirs
Input of nutrients	— Finfish mariculture — Shellfish mariculture — Urban waste water treatment — Industrial waste water treatment — Industrial animal farming
Input of litter, including micro litter	— Netting — Benthic trawling — Benthic seining
Input of heat	— Fossil fuel energy production — Nuclear energy production
Deposit of contaminated dredged material at sea	— Dredging (capital/ maintenance) — Solid waste disposal, incl. deposit of dredged material
Impulsive noise	— Wind farms under construction — Military infrastructure (e.g. military firing ranges)
Input of organic matter	— Finfish mari-culture — Shellfish mari-culture
Input of seismic waves	— Seismic surveys

- Maintenance dredging is defined as 'Material (generally of an unconsolidated nature) arising: (1) From an area where the level of the seabed to be achieved by the dredging proposed is not lower (relative to Ordnance Datum), than it has been at any time during the preceding 10 years; or (2) From an area for which there is evidence that dredging has previously been undertaken to that level (or lower) during that period.' The main differences in capital and maintenance dredging in terms of impacts is that capital dredging causes loss of natural substrate, sometimes using explosives in rocky seabed, and it targets at a range of different substrate matter while maintenance dredging removes mainly recently deposited fine sediments from already-dredged areas.

According to Vivian *et al.* (2010), dredging is carried out mainly by three methods: hydraulic dredgers (divided to suction dredgers, cutter suction dredgers and trailer suction hopper dredgers), mechanical dredgers (grab dredger, backhoe dredger and bucket ladder dredger) and hydrodynamic dredgers (water injection dredgers, agitation dredgers and underwater plough dredgers). Vivian *et al.* (2010) have made a literature review of the impacts of dredging and they describe the dredging methods and practices used for capital and maintenance dredging.

Dredging causes several effects through a couple of pressures: removal of substrate (causing physical loss of a habitat); changing the seabed topography (causing altered physical conditions); resuspension of contaminants (causing contamination effects); resuspension of nutrients and organic matter (causing eutrophication effects) and silt (causing turbidity); and sedimentation of the dredged matter on nearby areas (causing smothering if sedimentation is high or siltation if the sedimentation is low). Dredged material may come into suspension also during transport to the surface, overflow from barges or leakage of pipelines, during transport between dredging and disposal sites, and during disposal of dredged material (Erftemeijer & Lewis 2006).

The loss of a habitat is more often the case in capital dredging than in maintenance dredging. Maintenance dredging typically takes places in areas with natural sediment transport, so the affected communities are more or less adapted to change. The disposal of those sediments leads to smothering of habitats that can be assessed as loss, if the original sediments differ from the deposited material. However, this is a much debated aspect in the expert groups. In this review, we have simplified these impacts and assume that the actual dredged sites are under constant pressure leading to frequent removal of benthic community and therefore those 'core zones' are considered as physically lost areas.

Sediment plumes causing turbidity and sedimentation are mainly caused by the losses, deliberate and otherwise, that occur during a dredging operation. Fine sediment such as clays and silts generate much higher turbidity than a similar concentration of coarse sediment. Therefore maintenance dredging will likely cause higher turbidity that capital dredging or sand extraction. Turbidity effects decrease rapidly away from the core zone where turbidity up to 500 NTU have been measured at 50-100 m while values close to natural wind-forced turbidity are found at circa 2-3 km distance. Areas where high levels of turbidity are rare, such as seagrass beds, are likely to be far more sensitive to such disturbances (Erftemeijer *et al.* 2006).

In case of the Helsinki case study, which described construction of a large port area, some spatial data was available which enabled better linking between the intensity of the dredging activity and the resulting pressure levels and impacts (see case study in Supporting material). Figure 6 (left panel) presents an example of such a result in case of capital dredging. On the basis of the figure, one can make at least three observations: (1) the pressure increase is not linear but logarithmic (i.e. high pressures are caused already at low activities and the increased activity increase the pressure only marginally), (2) the turbidity pressure decreases away

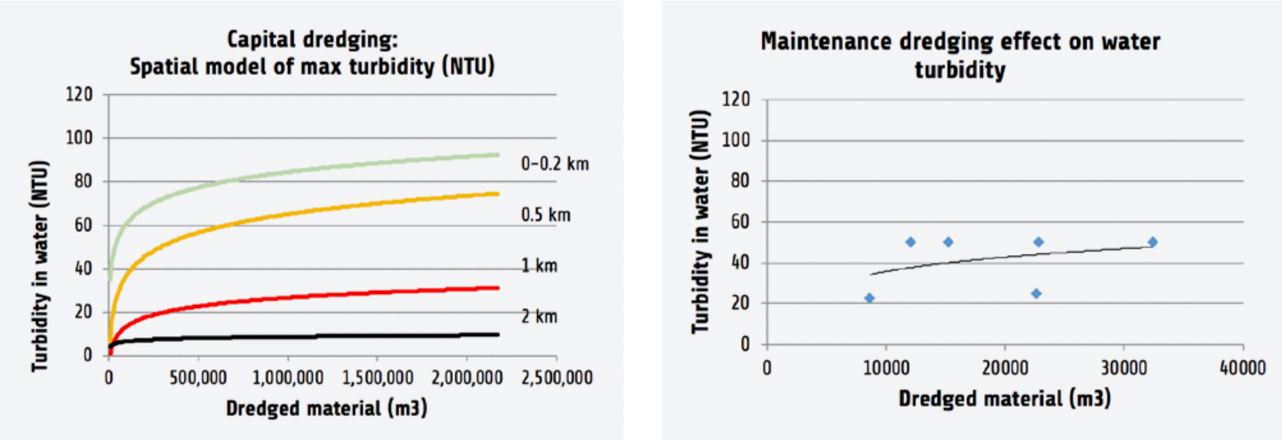

Figure 6. Dependence of water turbidity on dredging activity at different distances from the dredging site. Left panel shows smoothed trendlines from the Vuosaari harbor construction case study and Right panel shows turbidity at the vicinity of a maintenance dredging site in a study by Vatanen *et al.* 2012. The figures were made on the basis of the Catalogue, Annex 2.

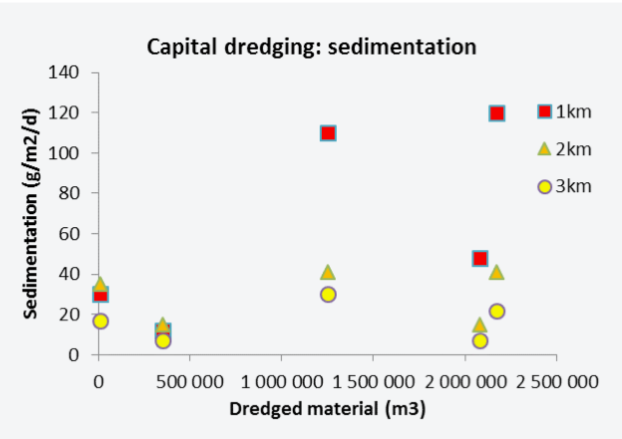

Figure 7. Dependence of sedimentation rate on dredging activity at different distances from the Vuosaari harbor construction case study (see Annex 2 for the data).

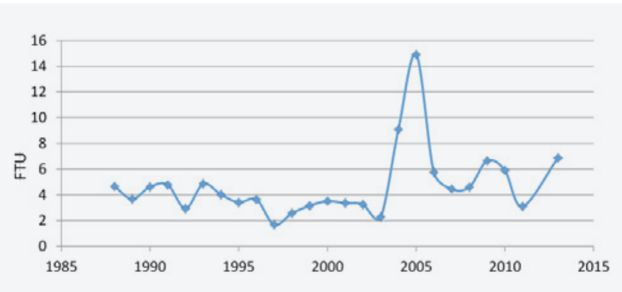

Figure 8. Long-term bottom-water turbidity (FTU) at a monitoring station (st.174) outside the Vuosaari Harbor, Helsinki. The dredging and landfill activities began in 2003–2004, peaking in 2005 and ending by 2008. The elevated by turbidity values after 2008 are likely from shipping traffic outside the harbour area. See Appendix 3, Supporting material 1 for the entire case study.

from the 'core zone', and (3) the turbidity pressure is mostly limited to 2 km distance. Also maintenance dredging of a shipping lane in the SW Finland caused high turbidity, measured just beside the activity, and the amount of turbidity positively correlated with the amount of dredged material (Figure 6, right panel).

Also sedimentation rates depended on the distance from the capital dredging activity site (Figure 7). The dependency was not weaker at longer distances from the site.

A long-term monitoring station adjacent to the harbour construction activity site showed a clear peak in turbidity for the time period of the activity and then a drop after cessation of the dredging and landfill. However, the turbidity did not decrease to the original level, likely because the new shipping route to the new harbour was launched as a result of the dredging and then resuspended sediments maintained elevated turbidity (Figure 8). Turbidity effects decrease rapidly away from the core zone where turbidity up to 500 NTU have been measured at 50-100 m while values close to natural wind-forced turbidity are found at circa 2-3 km distance (see Section 4.2).

Dependency of the macrofauna index (BBI) on the near-bottom suspended solids and turbidity was not very strong in the Gulf of Finland case study (Figure 9). The strength of using the BBI is the already defined GES boundary, which is 0.6 in the normalized scale of the BBI. The results indicate that already relatively low amounts of sedimentation near the dredging site have led to sub-GES status for macrofauna.

In this review, we focused on physical disturbances (siltation, turbidity, sedimentation) and physical loss (substrate removal, altered topography, smothering) of the dredging activities, while the contamination and eutrophication effects were given lower focus. Nutrient reserves of the

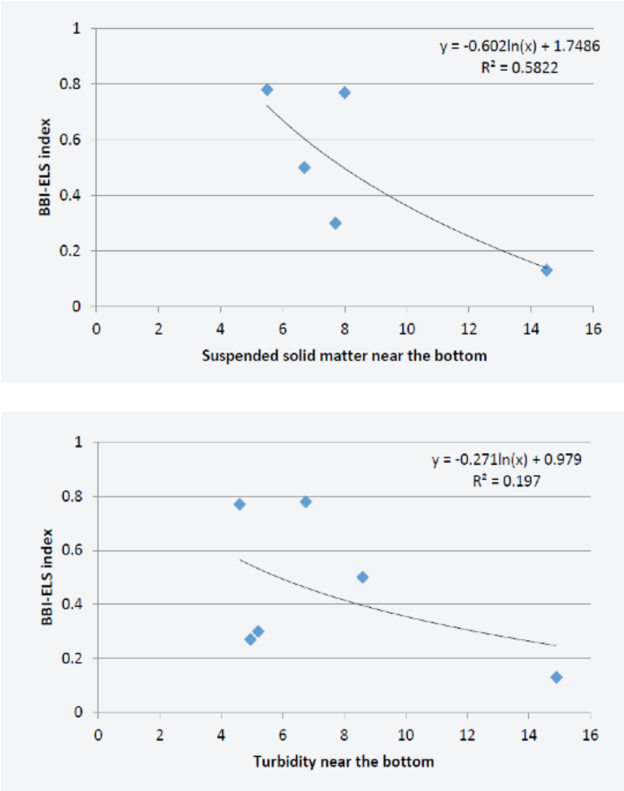

Figure 9. Depency of benthic macrofauna index (BBI) on (top panel) suspended solid matter (mg/l) and (bottom panel) turbidity (NTU) in the near-bottom water close to the dredging site in 2005 and 2008. The GES boundary in BBI is at 0.6.

- Baltic sediment are high due to the long eutrophication process and, similarly, the Baltic sediments contain high amounts of persistent organic pollutants (POPs) and heavy metals. Dredging and other physical contact with sea floor affect resuspension of these substances and, hence, eutrophication and contamination effects are expected. Moreover, these may be stronger in shallow areas, where stratification is weaker and mixing takes place, and in sheltered areas such as inner archipelagos or semi-enclosed bays, where the effect is not diluted.

3.2.2 Disposal of dredged matter

The pressure causes 'physical loss' and 'physical disturbance' (Table 1).

As a result of dredging a vast amount of sediment that needs to be disposed arises. Much of this material is disposed at sea, covering the seafloor at the disposal sites. Often the dredged sediment ranges from mud to silt (Essink 1999), giving rise to increased turbidity and siltation in the area around the disposal sites. As for dredging, the main focus here is on the physical pressures while ecotoxicological effects of potentially contaminated dumped sediments or eutrophication effects due to resuspended nutrients were not analyzed.

Disposal of dredged matter causes two main physical pressures to the seafloor. First, at the disposal site the seafloor is covered with the dredged matter, smothering benthic organisms and changing sediment characteristics in most cases. This is considered as a loss of the habitat (see Section 4.1). However, the effect is strongly affected by the environmental characteristics of the disposal site. In a depositional site, the disposed matter is steadily covered by natural sedimentation (if the disposal activity has ceased). The re-establishment of the macrozoobenthic community often takes a few years if analyzed by univariate indices but at least 5 years when analyzed by multivariate analyses of the species composition (Bolam *et al.* 2006; Barrio Froján *et al.* 2011). At dispersive sites the dumped material will remain exposed and be redistributed along the seafloor, as is commonly the case with dumping sites in tidal high-energy sandy seafloor environments (e.g. Stronkhorst *et al.* 2003; Wienberg and Hebbeln 2004; Du Four and Van Lancker 2008; Marmin *et al.* 2016). The magnitude of change in the macrozoobenthic community will depend on how closely the dumped material mounds resemble the natural seafloor in terms of e.g. grain size, organic content and consistency (e.g. Bolam *et al.* 2006; Powilleit *et al.* 2006; Barrio Froján *et al.*, 2011). An assessment scheme has recently been proposed to estimate the seafloor integrity in the Baltic Sea (Virtasalo *et al.* 2018).

Second, increased turbidity during the disposal or as resuspension of the dumped material cause increased siltation on the site itself and in the areas around the disposal site. The impacts of disposal of sediment depend on the seafloor habitat type, type and amount of disposed material and distance to the disposal site. Burial of benthic organisms causes mortality, but there are species-specific differences in survival and ability to re-surface in different types of disposed sediments and burial depths (Olenin 1992, Powilleit *et al.* 2009). Generally there are higher survival rates with coarser grain size. For example, at hard substrates fauna is killed already with 1-2 cm sediment cover (Essink 1999), but mortality of Macoma balthica was only 58% when experimentally covered with 40 cm till and 86 % died under 35 cm of sand/till-mixture (Powilleit *et al.* 2009). Macrozoobenthic species richness, population density and biomass decrease considerably after disposal (Newell *et al.* 1998), but recovery is quite fast; less than 5 years in many studies (e.g. Boyd *et al.* 2000, Dalfsen & Essink 2001, Orviku *et al.* 2008, Frenzel *et al.* 2009, Vatanen *et al.* 2010). The borderline between physical damage (at least some of the fauna can survive or recover) and physical loss (due to permanent change of sediment characteristics and subsequent community structure) is hard to evaluate. However, in this report physical loss is generally attributed

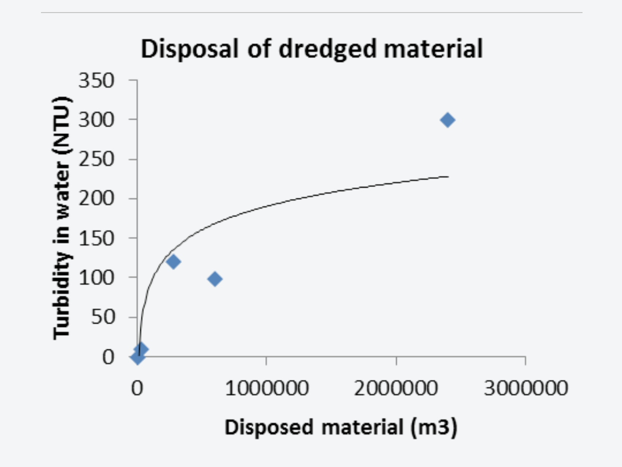

Figure 10. Dependency of water turbidity on the amount of disposed dredged matter at the vicinity of a disposal site in the harbor construction case study in the Gulf of Finland (Appendix 3, Supporting material 1).

- to the disposal core zone due to the application of a precautionary approach in areas covering only small amounts of broad scale habitats. In cases where better data are available and where a smaller spatial scale is relevant, a finer distinction of damage and loss can be appropriate.

Disposal of dredged matter increase the sedimentation in the areas surrounding the disposal sites (Figure 10). In sheltered areas sedimentation can increase threefold, whereas in exposed areas effects are not seen (Vatanen & Piispanen 2012). Sedimentation is largest close to the disposal site (up to 600 mg/m2/day at a distance of 0.15 km) and gradually decreases with increased distance, although still visible at 3 km distance (Vatanen & Piispanen 2012). Water turbidity also increases, but the effect is short-term; depending on the background turbidity the increase lasts only for 2 h to 1 day (Vatanen & Piispanen 2012). The effects of sedimentation are seen as for example mortality and changes in the population structure of benthic organisms, e.g. resulting in a Macoma balthica population with only large individuals (Vatanen *et al.* 2010), reduced herring spawning (50% mortality at 1 km distance from disposal site; Syväranta & Leinikki 2014) and reduced coverage and lacking colonization in bladderwrack at a distance of 2 km from the disposal site (Syväranta *et al.* 2013).

3.2.3 Sand and gravel extraction

The pressure causes 'physical loss' and 'physical disturbance' (Table 1).

Extraction of sand and gravel from the seafloor is as an activity comparable to dredging; sediment is removed from the seafloor for use of the sand and gravel fractions e.g. for construction, coastal protection, beach nourishment and land fill purposes. Thus, the effects of sand and gravel extraction are similar also to those of dredging; removal of substrate, changing the seabed topography, resuspension and sedimentation in nearby areas. A big difference is, however, the active sieving of the wanted grain size and discharging the unwanted matter overboard. This results in a change in the sea-floor grain size. Sedimentation is usually restricted to a smaller area (predominantly within 0.15 km; Newell *et al.* 1998) than caused by dredging, as the grain size of the extracted substrate generally is larger, but fine sands can be transported >10 km (Phua *et al.* 2004). Even if the extraction does not extend to underlaying till or clay layers, grainsize composition, water depth and hydrological features are most often permanently changed. Phua *et al.* (2004) have made a review of the techniques used for this activity.

At sand and gravel extraction sites the mortality of benthic organisms is more or less complete (Boyd *et al.* 2002, 2003, Barrio Frojan *et al.* 2008), as their habitat is removed, whereas the impact is smaller in adjacent areas (50% morality at 0.4-1 km distance; Vatanen et al 2010). Recovery of the benthic communities in the impact areas is slow; in high intensity extraction areas recovery in species richness and abundance last >10 years in the North Sea (Newell *et al.* 1998, Wan Hussin et al 2012). Finally, even when the extraction does not extend to underlaying till or clay layers, grainsize composition, water depth and hydrological features are most often permanently changed.

Specifically, the case studies Mecklenburg Bight and Plantagenetgrund (see Appendix 3, Supporting material 2 and 3 for full reports) showed that, in regard to extraction of sand and gravel, the definition of physical loss can be applied to the extensive activities in both areas. In both areas mostly fossil sand deposits, that cannot be regenerated, are being exploited. In the process, the sea floor is deepened, topography altered and the granulometric composition is changed permanently, even if the deposit is not exploited to the underlying clay or till layer. This effect is much more pronounced in the Baltic Sea than in the North Sea, where tide driven currents often move the targeted sediments, and has not been properly appreciated in former assessments. Because of the large amount (by 2004 the deposits in Germany had been exploited by 31 %, Schwarzer 2006) and the scale (ca. 8 % of sublittoral sand in Mecklenburg Bight is targeted by extraction) of this activity, a closer look is needed both for the assessments and during the development of Environmental Targets. According to the two case studies, physical loss of benthic habitats is, however, of lower importance for broad-scale benthic habitats (EUNIS 2) than more detailed habitats (EUNIS 6). The sand extraction focuses on certain grain size of sandy and gravelly seabed and therefore more detailed habitat classification is necessary for the analysis. The biotopes on the level of HUB 6 (HELCOM Underwater Biotope; comparable with EUNIS 6) were, in contrast, highly threatened by the sand extraction activities. A good practice seems to be the U.K. data and GPS loggers which provide exact information about the locations and amounts of the activity and allow for estimating also recovery of the benthic fauna.

The HELCOM Recommendation 19-1 'Marine sediment extraction in the Baltic Sea area' describes techniques which, if applied, help to minimize the negative effects of sand and gravel extraction. To our knowledge, there is no regional review of the use such techniques in the Baltic Sea.

3.2.4 Shipping and ferry traffic

The pressure causes 'physical disturbance' (Table 1).

Ship and ferry traffic causes disturbance to benthic habitats in at least three ways: propeller induced currents causing abrasion, resuspension and siltation of sediments, waves causing stress in littoral habitats and at anchoring sites anchor dragging causes physical disturbance. Common for these effects are that they mainly occur in shallow areas and that effects are local, concentrated along shipping lanes and in the vicinity of harbours. Increased turbidity caused by ship traffic has been observed at 30 m depth (Vatanen *et al.* 2010). Traffic by mid-sized ferries increased the turbidity by 55% in small inlets (Eriksson *et al.* 2004). Erosion of the sea-floor can be substantial along heavily trafficked shipping lanes. Up to 1 m of sediment loss due to abrasion has been observed (Rytkönen *et al.* 2001). Water flows of 40-60 cm s-1 have been measured in the Finnish Archipelago Sea on shore waters 0.5 km from a ship route (Rytkönen *et al.* 2001). According to the measurements, the highest concentrations of suspended solids exceeded 8 mg L-1 several times a day. The passing ships caused periodic (3-4 sec) waves of 20-40 cm height and also a decrease of water level of ca. 20 cm (caused by a deep-water sucking current) which produced oscillating water level for ca. 60-80 sec. While the Finnish measurements differentiated big ferry ships from smaller ones in wave height, the water flows were of same magnitude in both size classes. Similar magnitudes of water flows and wave heights were measured also in the Stockholm archipelago at the distance of 150-300 m from the passing ships at speed 14-17 knots (Daleke *et al.* 1989). According to the Swedish measurements, higher ship speeds (up to 22 knots) caused higher waves (80-85 cm) and drop of water level (up to 30 cm), whereas the water flows were between 0.57-1.29 (waves) and 0.39-1.77 m s-1 (water level decrease). Rytkönen *et al.* (2001) modelled water flows based on their measurements and estimated that even 2 m s-1 flows take place in shallow water near the bottom. Even slower flows move coarse sediments such as sand and gravel. In the measurements, turbidity was high 1 m above the seabed and consisted also of coarse grain size. In shallow areas benthic vegetation is affected by shipping, both measured in coverage and species richness (Eriksson *et al.* 2004). Shipping also negatively affects fish dependant on the benthic habitat for spawning or as nursery grounds (even 90% reductions, e.g. Vahteri & Vuorinen 2001, Sandström *et al.* 2005). Impacts of anchor dragging have not been quantified.

3.2.5 Wind turbine construction and operation

The pressure causes 'physical loss', 'physical disturbance' and 'changes to hydrological conditions' (Table 1-2).

Information on wind farm construction is available on http://www.4coffshore.com. About 1.000 turbines and converter stations have been built in the Baltic Sea or are in advanced stages of building or planning. The information often includes the type of foundation, length of cables and burial depth. However, type and extent of scour protection, which is necessary for the assessment of habitat loss, is missing. The pressures on seafloor integrity during the construction phase are commonly separated between the construction phase and the operational phase. During the construction phase, the pressures are diverse but depend on the technique used. Generally, the activities and pressures include drilling and relocation of land masses at the site before covering the area by the turbine and its scour protection (abrasion, smothering, sealing). In the surrounding area siltation and turbidity take place following the prevailing currents. The area of loss is on one hand determined by the scour protection, most often a layer of sand topped by rocks. An average of 20 m around the pilings is a sufficient generalisation for this impact (OSPAR 2008). Power cables connect the turbines to each other and to the mainland (see cables below). In the operational phase, the seabed disturbances are limited to increased maintenance shipping and hydrographical secondary effects caused by averted currents. Reported information mentions that 300 m erosion/abrasion effects take place around the turbines. Theoretically, wind parks are supposed to be dismantled after use, and this has happened for two small parks in Sweden and Denmark already. During deconstruction impacts comparable to the construction phase are to be expected.

3.2.6 Placement of cables and pipelines

The pressure causes 'physical loss' and 'physical disturbance' (Table 1).

Power and communication cables and pipelines (water, gas, other) are typically laid by first digging a trench, laying the cable inside and then covering the trench with sediment extracted elsewhere. Most often the sediment composition then differs considerably from surrounding habitats, so that the cable track is visible in a side scan sonar for decades (Schwarzer 2014). Clay and till have to be cut by a milling machine leading to larger amounts of fine sediments in the plume. Less invasive methods like vibrating or hydrodrilling are not often used in the Baltic due to the less uniform content of seafloor layer (pers. comm.). On hard bottoms, cables are often covered with a protective layer of steel or concrete casings. The loss of habitats by smothering and sealing can be generalized to a 2 m wide band (OSPAR 2008), but the damage by siltation depends on sediment composition, currents, etc. and is much more difficult to assess. This is likely of lesser magnitude compared to the siltation from dredging and disposal activities. According to the two case studies in German waters, the areal extent of physically lost seabed due to cable and pipeline laying is comparatively low (typically less than 0,1 % of broad scale habitats' extent). It is possible (though more costly) to use the same sediment for filling up cable and pipeline trenches. For example, the Nordstream I deposited the sediment and used it to refill the trenches after inserting the pipeline in the trench.

Pipeline construction is basically similar to cable laying, even though the dimensions of moved material should be bigger. In case of the big gas pipelines the seabed is disturbed through ploughing, explosions, burial and relocations of sediment masses. The main purpose is to level off the seabed to support the pipeline. There is no information of the possible hydrographical secondary effects of the operational pipeline (as around turbines, see above), but this can be assumed.

3.2.7 Marinas and motor boating

The pressure causes 'physical loss' and 'physical disturbance' (Table 1).

Motor boating causes in principle the same physical impact to benthic habitats as shipping but in a smaller scale. Depending on the size of the boat, or more precisely the power of the engine, the depth to which the impact is restricted varies. For example, a 10 hp engine causes resuspension from bottoms down to 1.5 m, whereas the impact of a 50 hp engine reaches 4.5 m depth (Degerman & Rosenberg 1981). As a consequence, turbidity increases in areas where boating takes place (Eriksson *et al.* 2004). Benthic vegetation is affected by boating and in the busiest boating areas vegetation cover can be totally lost (Oulasvirta & Leinikki 2003). In marinas, decreases in vegetation cover and species richness have been observed (Eriksson *et al.* 2004). Impacts of boating on benthic fauna are weak, however changes in species composition on hard substrates have been found in anchoring sites in natural bayments (Oulasvirta & Leinikki 2003). Fish spawning sites are also affected by boating. For example, a reduction by 89% in pike young of the year was observed in inlets with a marina (Sandström *et al.* 2005). Maintenance of boating channels by small-scale dredging in shallow inlets has large impacts on benthic vegetation and especially charophytes (Munsterhjelm 2005, Torn *et al.* 2010).

3.2.8 Links between the fishing and the physical disturbance of seabed

The pressure causes 'physical disturbance' (Table 1).

The fishing case studies were made on the basis of the BalticBOOST FIT tool (Work Package 3.2). The FIT tool follows the method by Eigaard *et al.* (2016) where both surface and subsurface abrasion by each specific gear are calculated according to each bottom type as well as for separate gear parts. In this report, the analyses of fishing impacts have been combined by gears, as the sum product of the individual gears' impact and the effort with each gear. This has simplified the case study analyses. Therefore the results in this report cannot be, at the moment, targeted to different gear types, but more detailed future analyses with the FIT tool could be used to separate gear types which will allow more detailed analyses. The fishery case studies are described in Section 2.3 and the entire reports are in Appendix 3, Supporting material 4-6.

The Swedish case study analysed the impacts of demersal fishing on benthic fauna abundance and species richness, the Benthic Quality Index (BQI) as well as the W statistic (biomass per individual for the whole sample). The benthic fauna parameters strongly depend on hydrographic parameters which can partly be explained by water depth. Therefore water depth was included as a factor in the analysis. The results showed that statistically significant and timewise consistent impacts occurred only in the test area east of Gotland, Central Baltic Proper. Fishing intensity and its impacts were much higher in the Gotland area than in the other test areas. According to the results in 2010 and 2012, species richness of benthic macrofauna was clearly lower in areas under heavy fishing than in less fished or not fished areas (Figure 11). However, collinearity between depth and fishing intensity was high in Scania in 2012 and in Blekinge in 2010 and 2012 and therefore it is not possible to discern whether it is depth or fishing intensity that is the most important predictor variable. Therefore, fishing intensity might be more important in Blekinge and Scania than what has been shown in this study. Collinearity in Blekinge and Scania is largely caused by the fact that there are no monitoring stations without fishing at greater depths where fishing mainly

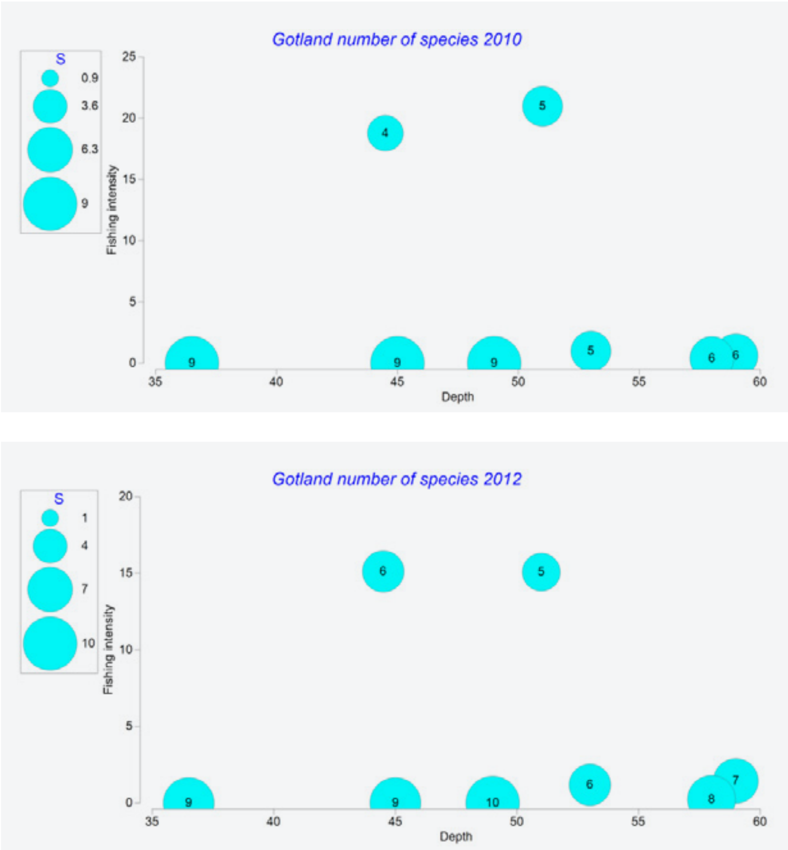

Figure 11. Number of species in macrofauna community in the test site east of Gotland, Central Baltic Proper in 2010 and 2012. The number of species is indicated both as the size of the circle and as number inside it, and shown along the axes of depth and fishing intensity. For further details see Appendix 3, Supporting material 5.

occurs, therefore the confirmed fishing impact in these areas would require re-design of the benthic monitoring programme to co-occur in areas of demersal fishing.

The case study in the Femern Belt found from multivariate analyses of variance with mixed statistical models that there is a small but statistically significant negative correlation between fishing intensity and three benthic state parameters: number of species and density in the benthic invertebrate community as well as the average individual weight herein. The results indicate that biodiversity, density and mean weight are rather strong indicators of impacts of fishery on the benthic invertebrate community, while benthic invertebrate biomass seems not to be a strong indicator on community level. The latter naturally also influences the mean individual weight as indicator. It is evident that there are strong and significant interaction effects and that the fishing pressure has different impacts on the biodiversity and density in different habitats dependent on the season of the year. Consequently, the results show that the impact depends also on season (as fishing intensity, hydrographical factors and benthic community all vary seasonally) and habitat type, as fauna on coarse substrates are affected more than the ones on sandy substrates, and the muddy communities are least impacted. Overall, the results indicate that the impacts of fishing pressure on the benthic community biodiversity and density and mean weight is in the same order of magnitude as the influence of natural hydrographical factors, especially near bottom maximum current speed and minimum oxygen concentration. Furthermore, it seems necessary to consider the positive correlation and impact of density on biodiversity when evaluating impacts of fishing pressure and other factors on biodiversity.

In general, there cannot be identified any robust threshold levels of fishing pressure for changes in benthic invertebrate community density, biodiversity and biomass (Figs. 12a and 12b).

The third fishing case study – the longevity approach – estimated fishing effects on seabed for the whole Baltic Sea. The analysis revealed that of the 18 benthic fauna communities (see Annex 3), three were particularly impacted in terms of proportion of community biomass (Table 3). The most impacted communities were found from the Kattegat and SW Baltic Sea (Figure 13). Looking at all the communities, already low fishing intensity caused relatively high impacts on the benthic communities (Figure 14). The case study should, however, be considered as an interim analysis, because the species data was not yet sufficient to cover all the Baltic species and their longevity estimates and also the assumption of 100% mortality needs to be improved with more development. However, with better data on species distribution and species life history the approach may provide useful impact estimates also for other pressures than fishery only.

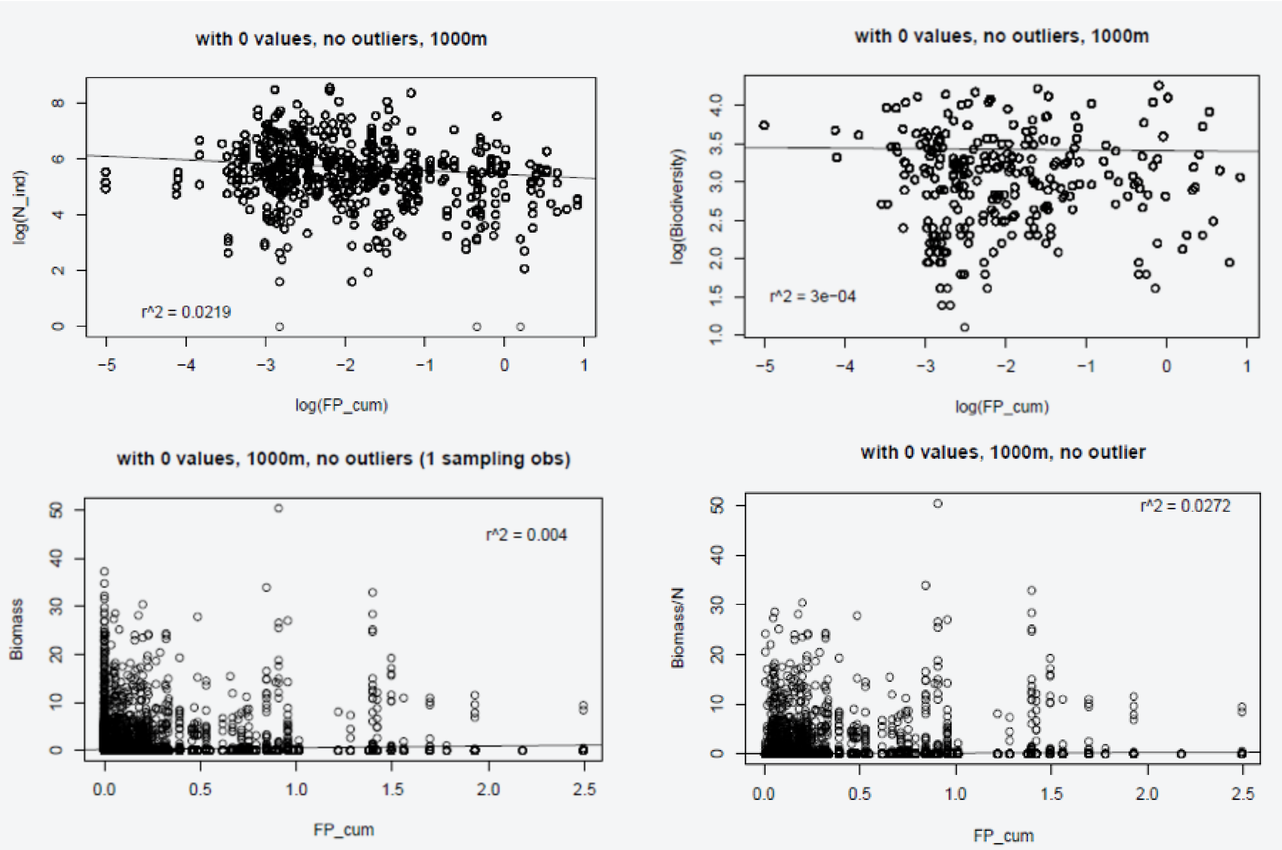

Figure 12a. Correlation between benthic invertebrate community density (N) and fishing pressure (FP) on a continuous scale for samples covering stations respectively with and without zero fishing pressure. Shown as both natural and log-log plots. For further information see Appendix 3, Supporting material 4.

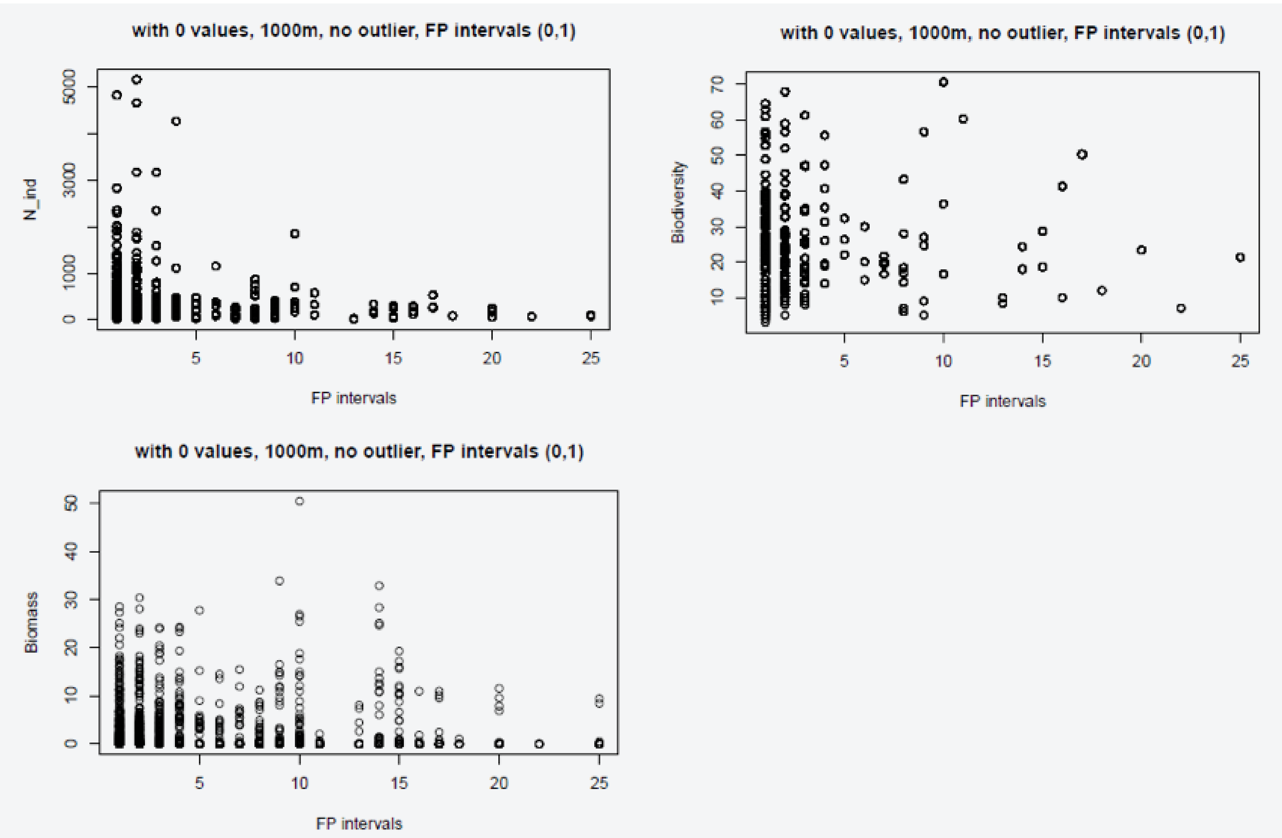

Figure 12b. Correlation between benthic invertebrate community density (N), biodiversity (BD), biomass (B) and fishing pressure (FP) where averages for N, BD and B are estimated for FP in discrete steps of 0,1 (discrete scale) for samples also covering stations with zero fishing pressure. At the scale of the FP-axis then 1 correspond to FP=0,0-0,1, 2 corresponds to FP=0,1-0,2, etc, i.e. 10 corresponds to FP=0,9-1,0. For further information see Appendix 3, Supporting material 4.

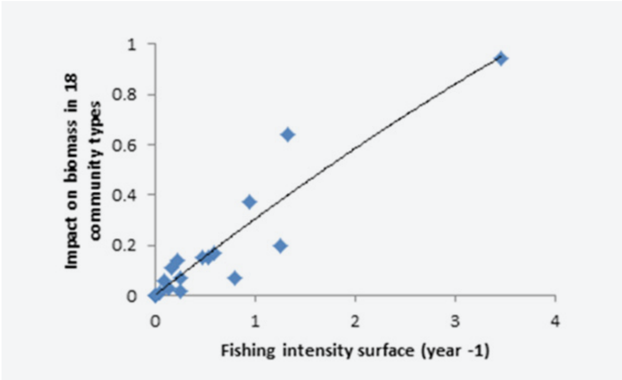

Figure 13. Spatial distribution of the three most impacted benthic community types according to the longevity approach (left panel) and the total intensity of bottom fishing (right panel). Impacts on other communities are given in Supporting material.

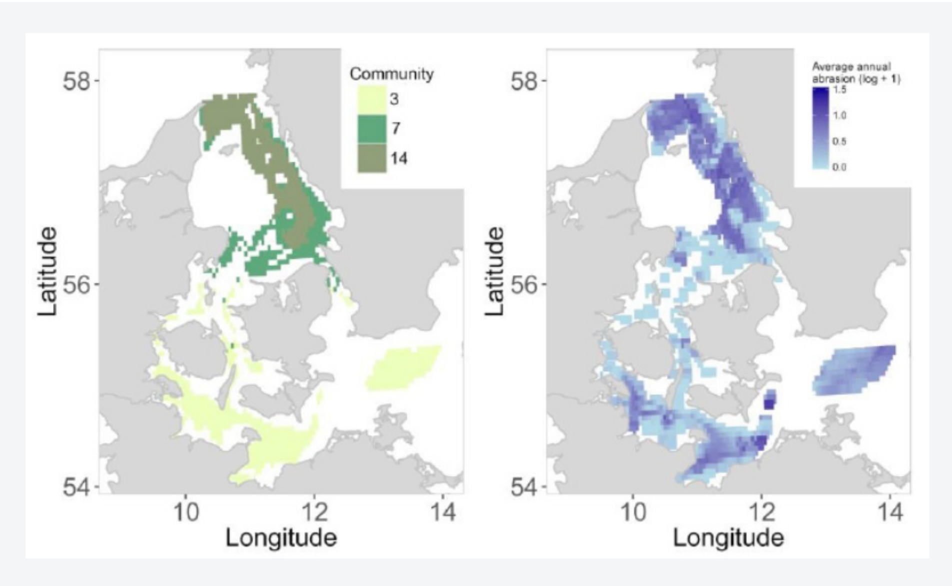

Figure 14. Impact of bottom-trawling fishing on benthic biomass in 18 benthic communities. The fishing intensity is an average value over all occurrences of that community type in the Baltic Sea and the impact on biomass is modelled for each community type in the Baltic Sea scale. The dependency indicates that relatively high impacts on benthic communities are reached already at rather low fishing intensity. For further information see Appendix 3, Supporting material 6.

Table 3. Predicted impact of mobile-bottom contacting gears by the longevity of species. Both surface and sub-surface abrasion impacts were estimated. The bottom fishing intensity columns show the average annual intensity between 2009 and 2013 (for surface and sub-surface abrasion), averaged across all grid cells per community type. The communities are described in Annex 3.

Community	Total impact	Surface impact	Sub-surface impact	Fishing intensity (surface)	Fishing intensity (sub-surface)	Longevity at 75% of biomass (surface)	Longevity at 75% of biomass (sub-surface)
1	0.07	0.07	0.05	0.79	0.12	5.52	9.78
2	0.15	0.17	0.10	0.53	0.05	9.96	> 20
3	0.64	0.69	0.60	1.33	0.14	7.4	> 20
4	0.02	0.02	NA	0.26	0.04	2.4	NA
5	0.15	0.15	0.03	0.48	0.07	5.84	3.6
6	0.06	0.06	0.04	0.09	0.05	5.36	8.96
7	0.37	0.44	0.33	0.94	0.16	14.52	15.06
8	0.01	0.02	0.00	0.05	0.01	5.76	8.1
9	0.00	0.00	0.00	0.00	0.00	> 20	> 20
10	0.14	0.15	0.09	0.22	0.03	> 20	> 20
11	0.03	0.06	0.01	0.13	0.01	6.34	15.1
12	0.00	0.00	0.00	0.01	0.00	7.28	15.4
13	0.07	0.08	0.01	0.26	0.05	6.56	3.6
14	0.94	0.96	0.83	3.45	0.67	12.56	19.38
15	0.20	0.21	0.19	1.25	0.26	9.38	12.08
16	0.11	0.17	0.07	0.16	0.01	> 20	> 20
17	0.00	0.00	0.00	0.00	0.00	6.96	> 20
18	0.17	0.18	0.13	0.59	0.10	6.6	17.74

3.3. Recovery of benthic habitats from a physical disturbance pressure

The literature review recorded also observed recoveries of the benthic features (species and habitat parameters). Typical recovery times were between 1-10 years depending on the feature and energy of the habitat (sheltered/ exposed). Also intensity (amounts and duration) of an activity affects the recovery; high dredging intensities have resulted in 15 years of recovery, twice longer than normally (reviewed in ICES 2016). Table 4 gives a synthesis of the recoverability of habitats. The table presents also recovery values for water column turbidity, which is much faster than in benthic habitats. In the table, the habitat recoverability is a combined value of different features. Also the features with longest recovery times are mentioned. All the recovery values are given in Annex 2.

Table 4. Recoverability of benthic broad habitat types from the physical disturbance pressure. The values comprise a synthesis of several studies. Note also that hydrographic conditions affect the recovery time.

Broad benthic habitat type	Typical recovery time in years	Features of longest recovery times
Infralittoral hard bottom	Disposal, dredging, sand extraction: >5 years	Herring spawning, Vegetation
Infralittoral mud bottom	Disposal and dredging: 5-10y (in exposed areas faster)	Vegetation
Infralittoral sand bottom	Sand extraction: >6y at the site, 2 y at 0.5-1km.	Benthic fauna
Circalittoral hard bottom		
Circalittoral mud bottom	Disposal of dredged matter: 4y at the site;	
Capital dredging: 4-6 y at the site (1 y on exposed sites).	Benthic fauna	
Circalittoral sand bottom	Sand extraction: >6y at the site, 2y at 0.5-1km.	Benthic fauna
Pelagic habitats	1 day – 1 week	Turbidity

4. Practical application of results

4.1. Definitions of the physical pressures and the activities causing them

The observations made from the linkage framework, the literature review and the case studies, made it clear that it was necessary to make more detailed definitions of the three physical pressures 'physical loss', 'physical disturbance' and 'changes of hydrological conditions' to seabed and to clarify which pressure belongs to each category. As already seen in Figure 1 and Tables 1-2, several human activities can cause the three pressures. In this section, we aim to give practical definitions to the three physical pressures.

4.1.1 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'. Moreover, the revised COM DEC defines this 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'.

These definitions allow a rather clear picture of the pressure but do not mention, for instance, biotic components in the seabed or human activities causing the pressure. In this project, a simplified definition was used, because the regional data does not allow for more detailed analysis of individual sites. A more detailed definition is discussed in the end of this section. For the purposes of the BalticBOOST project, we defined – as a result of the literature study, that:

— all **dredging and sand and gravel extraction** activities where seabed substrate is removed cause physical loss of the activity site, because the 'seabed morphology' has changed and it lasts usually more than 12 years to see recovery of the morphology; in case of maintenance dredging, the seabed is not even allowed to recover; the area of the activity is defined in the GIS data;
— **disposal of dredged matter** and other dumps like artificial reefs and matter from mariculture piling on seabed cause physical loss of the buried habitat as the 'seabed substrate' has changed; if the deposited material is similar to the buried seabed, the recovery may take place, but in other cases, the original seabed will not recover; the area of the activity is defined in the GIS data;
— all **built structures**, such as wind turbines, platforms, artificial reefs, telecommunication and electricity cables, pipelines, piers, sea walls, groynes, breakwaters and dam, cover seabed area and thus cause physical loss; the area of structures is either given in the GIS data or estimated on the basis of technical information (e.g. area of wind turbines);
— also, **marinas and harbours** cause physical loss as they have, in addition to built structures, continuous propeller currents which change the seabed characteristics.
— **land claim** – where marine area is filled with land material and turned as dry land – causes physical loss of the seabed; the area of activity is given in the GIS data.

The physical loss pressure can be assessed as the total area lost (square kilometres).

Sand extraction, dredging, disposal of dredged matter, mariculture, all kinds of waste dumps and all construction activities all cause siltation in water column, in addition to the seabed area considered as lost. These activities cause also physical disturbance and therefore the BalticBOOST project defined loss from these activities according to the following:

— the core zone of the activity (extraction/ dredging/ disposal/ construction site) is considered 'lost' because the seabed morphology (topography, bathymetry) or substrate type (grain size, substrate type) has been changed for at least 12 years;
— the core zone may be lost forever, if the site is emptied of the particular substrate (e.g. extracting specific grain size) or covered by a new substrate (depositing dredged matter over a different substrate type or extracted a specific grain size and leaving the rest on the seabed);

It is clear that this definition has several exceptions and open questions for practical assessment purposes. First, it is clear that local environmental conditions affect the recovery potential in many ways. As discussed in chapter 3.2.2 the water movements at site affect natural sedimentation or stability of new substrates. Secondly, the new substrate (an artificial hard surface, disposal mound, a new substrate underneath the extracted substrate) will also become a habitat, but its value may be different than the indigeneous value of the site. Virtasalo *et al.* (2018) discuss the term 'potential ecological value' in this context. Thirdly, it is a matter of definition how the 'change in seabed morphology' is defined for the assessment. Literal interpretation means that every change in topography is considered as 'loss' even if the surface substrate has not been changed (e.g. sand extraction when indigenous substrate is left to the pit). Fourth, the scale of an activity influences on the physical loss; a small-scale change in the seabed substrate or morphology does not necessarily affect the habitat functionality (which is a possible measure of physical loss).

With the above consideration it is obvious that physical loss is very difficult to estimate on regional scale. The more detailed and reliable assessments need to be carried out at local level and then contribute to the HELCOM level assessments.

In case of physical loss, it is necessary to consider also the potential to reverse the loss in the longer perspective, i.e. remove an obstacle (e.g. wind turbine or sea wall), compensate for the loss by building a new habitat (e.g. an artificial reef), or restore a habitat (e.g. restore a sill to an semi enclosed bay). Also the current assessment methodology cannot separate between different techniques even though it is known that some cause more impacts to seabed. The GES assessment does not currently cover these aspects but environmental targets can be defined more accurately and also support more realistic GES assessments in future.

4.1.2 Physical disturbance

Physical disturbance to seabed is listed in the revised MSFD Annex III and is further defined in the revised COM DEC as 'Physical disturbance shall be understood as a change to the seabed which can be restored if the activity causing the disturbance pressure ceases'. Because recovery time leading to the physical loss was defined >12 years, one can assume that disturbance can be refined on the basis of the recovery of <12 years.

The pressure is understood to include the following more specific pressure types:

- **siltation/sedimentation:** this pressure is caused by sediment particles resuspended to the water column and re-settlement to new areas as a result of seabed disturbance. This can take place either as a result of physical modification of the seabed (e.g. construction, bottom trawling), propeller currents causing resuspension, lifting sediments to a barge (sand extraction, dredging), sieving the sand/gravel on the barge, depositing material to a seabed (disposal of dredged matter, land fill) or spreading abiotic or biotic matter (mariculture, riverine discharges, discharges from waste water treatment plants and industry. It is caused outside the core area of all the activities causing 'physical loss' (in case of structures only during the construction phase)). If the sedimentation is heavier, it is often called smothering (the difference between smothering and burial may be continuous and depend on the impacts it is causing);
- **turbidity:** this pressure is caused by sediment particles resuspended to the water column where it affects the light penetration to seabed; it is caused by the same activities as in siltation/sedimentation;
- **abrasion:** this pressure is caused by activities which cause seabed surface to erode; such activities are different types of demersal fishing (different types of bottom trawling, such as otter trawls, seines, dredges), anchoring and mooring by ships as well as erosion effects by shipping and boating in shallow or narrow routes.

Pressures and impacts from an activity depend strongly on the hydrography of the site. Exposed areas will have weaker siltation/sedimentation/turbidity effects than sheltered areas, whereas abrasion may even be stronger on those areas, but generalizations are difficult.

Seasonality of a feature (habitat or species) affects the impact: impacts can be high on a sensitive season, whereas pressures acting on other seasons may cause negligible impacts. The data is, however, often annual, and therefore the seasonality can be difficult to observe. This is, however, a critical aspect in planning of construction projects and should be also included in environmental targets and GES assessments.

Temporal extents of the activities vary greatly. A long lasting or a frequent pressure can cause higher impacts than single occurrences of that pressure. In this respect also the significance of the impact depends on the recovery of the benthic feature; frequent pressures restrict recovery.

The borderline between physical disturbance (where at least some of the fauna can survive or recover) and physical loss (due to permanent change of sediment characteristics and subsequent community structure) is hard to evaluate. In cases where better data are available and where a smaller spatial scale is relevant, a finer distinction of disturbance and loss can be appropriate.

4.1.3 Changes to hydrological conditions

Changes to hydrological conditions affect seabed indirectly by changing water flows that cause abrasion, erosion and resuspension near built structures such as wind turbines, platforms, piers, breakwaters and groynes. Permanent hydrographical alterations due to construction of wind turbines, platforms or other obstacles take place in the vicinity of the object. If these cause changes in water flows, they may exert abrasion, erosion, resuspension and sedimentation to the seabed, but these are difficult to assess and approximations are needed. Some literature-based estimates are given in this report and in the catalogue (Annex 2).

4.2. Spatial extent of physical disturbance

The physical disturbance pressure has spatial extent which is not regularly monitored. In this report, the literature review was used to estimate these spatial extents which can be added to the pressure GIS layers.

Environmental monitoring programmes rarely have spatial components that cover effect distances from activities. These distances are usually included in environmental impact assessments but these are seldom made available for national or regional assessments. For the BalticBOOST purposes, it was necessary to develop estimates of the spatial extent of different pressures. These estimates will form an important component in the process to judge whether an activity and its pressures cause significant harm to the benthic habitats (and hence whether environmental targets are needed to be established). The BalticBOOST WP 3.1 included the spatial extents of pressures to the literature study and the case studies. Also in WP 3.2 spatial extents were added to the analyses of the impacts of fishing gears on seabed. The summary results of the spatial extents are presented in Table 5 and the detailed background information is given the catalogue (Annex 2).

Another aspect of spatial extent is the distribution of the human activities. While non-fishery activities are typically local, demersal fishing is spatially widespread. For the former, the highest pressure and impacts occur close to the site and the pressure diminishes at increasing distances from the source. This spatial decrease of the pressure needs to be incorporated into the GIS data layers of the pressure. According to the results, the decreasing gradient was not linear but steeply decreasing at short distance (usually 0.1-0.5 km) after which it slowly decreased on the way of a couple of kilometres. Figure 15 exemplifies this in the Gulf of Finland case study. In case of demersal fishing the main pressure is the abrasion which is only local whereas some resuspended sediments will spread from the trawl track. No estimates were available of the resuspension/sedimentation amounts or the spread of the plume and hence a careful assumption may be 0.1 km.

Table 5. Spatial extents of physical disturbance from their source. The extents are estimated to the distance where impacts are considered negligible. Note that hydrographic conditions affect the distances and these estimates are usually applicable in exposed or semi-exposed areas. For further details, see the catalogue in Annex 2.

Activity	Pressure extent (km)
Capital dredging	4 km (fish), 3 km (benthos), 3 km (vegetation), 3 km (water turbidity)
Maintenance dredging	4 km (fish), 3 km (benthos), 3 km (vegetation), 3 km (water turbidity)
Sand extraction	5 km (water turbidity), 4 km (fish), 3 km (vegetation), 2 km (benthos)
Disposal of dredged matter	4 km (fish), 3 km (benthos), 3 km (vegetation), 2 km (water turbidity)
Shipping and ferry traffic	1 km (fish), 1 km (water turbidity, 30 m in depth), 0.5 km (vegetation), 0.3 km abrasion (substrate change)
Boating	0.5 km (water turbidity, 4 m in depth),
Marinas	0.5 km (fish), 0.5 km (vegetation)
Bottom fishing (siltation)	0.1 km
Wind turbines (operational)	0.1 km (abrasion effect)
Bottom fishing (abrasion)	local

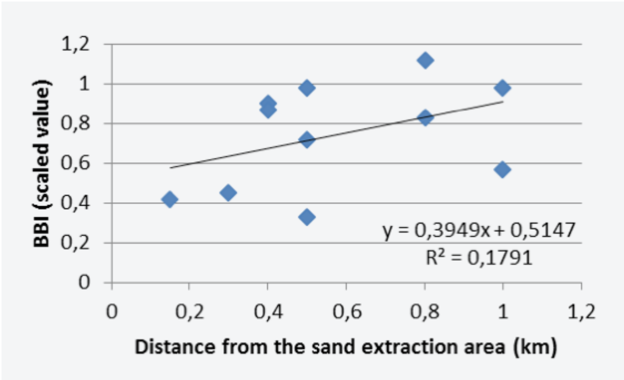

Figure 15. Dependency of benthic fauna index (BBI) on the distance away from the sand extraction site (km) in the Vuosaari Harbour construction site. The case study results are also presented in Appendix 1, Supporting material 3.

Table 6. Estimates of high pressures on some state parameters. The results are guidelines only and cannot directly be related to maximum allowable pressures. The pressure amounts are measured at 0.2–0.9 km distance from the activity but the amounts still depend on local environmental factors. The numbers are generally from semi-exposed coast, unless stated otherwise.

	Physical disturbance causing adverse impacts
Fucus colonization	0,1 g/m² (dw) sediment cause poor colonization: only 5% of propagules grow (Berger *et al.* 2003), 0.2 cm burial, 10 g/m² per day sedimentation inhibits colonization (Vatanen *et al.* 2012)
Fucus growth	7 g/m² 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/m²/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% mortality at 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/m²/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 (Figure 7)

4.3. Are there thresholds for adverse effects?

The concept of environmental targets, as presented in Section 2.4, includes the concept 'maximum allowable pressure' (MAP). The MAP concept should be in line with the GES criteria of the revised COM DEC which ask for a threshold to define 'adverse effects'. The MAP concept is thus centred on the pressure, but the MAP threshold should be defined on the basis of magnitude and coverage of effects and recovery from effects. Based on the literature study and the summaries in Chapter 3, one can estimate MAP thresholds for pressures (Table 6) for certain ecosystem components. In many cases, the levels are so strict that no activity could be carried out which is not a feasible solution for the use of marine waters. For instance, the turbidity value in Table 6 is 5-8 NTU which would indicate, according to Figure 6, a dredging amount of <10 000 m³ as the maximum level of dredging, which is a very low number for this activity compared with the dredged amounts listed in Annex 2. The reported impacts at that level of pressure are already adverse (Table 6), but maintenance dredging of < 10 000 m³ would not be sufficient for maintenance of shipping lanes. The 2nd workshop of the project recommended that the MAP concept should be expanded to spatial zones rather than magnitudes only.

4.4. Ranking the impacts of human activities causing physical disturbance on seabed

The physical disturbance pressure is too broad in definition to be assessed directly as there is no single parameter to be used as the metric. Therefore indirect methods are needed. The HELCOM TAPAS project has suggested that the physical disturbance is calculated by summing up normalized human activity data in each assessment unit (e.g. a grid cell). When developing a spatial layer of physical disturbance, this means that each activity data layer is normalized between 0-1 in the assessment area. However, as it is realistic to assume that some activities cause lower pressure magnitudes than others, some of the normalized data layers also need to be weighted. The weight factors for this can be derived from a ranking of human activities based on literature-derived information of pressures and impacts caused by the human activities. Description of the spatial assessment of pressures and cumulative effects is given in the Supplementary report to the State of the Baltic Sea Report (HELCOM 2017).

In the BalticBOOST WP 3.1, the human activities causing physical disturbance were ranked according to their reported impacts (e.g. mortality) and pressure levels (e.g. level of sedimentation, turbidity or abrasion). The background and approach were presented in Section 2.5.

Rankings of human activities in different contexts depend strongly on their purpose and therefore they are seldom comparable. In some rankings, the impacts are assessed in relation to real data of the frequency and occurrences of the activities in the region, whereas in BalticBOOST, the ranking has been made to support the implementation of the Baltic Sea Impact Index in which distribution and extent of pressures is already reflected through spatial maps representing these features (HELCOM 2017). Thus, the BalticBOOST ranking is only meant the compare the magnitude of impact from different pressures and activities. Therefore the BalticBOOST ranking cannot be used to indicate which activities or pressures are causing the highest threats to the Baltic Sea at the moment.

Table 7 gives arguments for the ranks of activities according to their impacts. Based on this information as well as below information on activities the activities were placed to six categories: high, moderate to high, moderate, low to moderate, low and no pressures and impacts). The proposed ranking is a sum of many studies.

The catalogue of the non-fishery human activities allowed ranking them according to the amounts of pressures they cause (e.g. sedimentation rates, turbidity levels) and impacts on the benthic habitats. The physical disturbance caused by demersal fishing was included after conclusions of the Second HELCOM BalticBOOST workshop on the development of joint principles to define environmental targets for pressures affecting the seabed habitats (28-29 November 2016, Helsinki). Arguments for the ranking of fishing activities in relation to other activities were not included in the catalogue but include reductions in population size, species richness, vegetation coverage and reproduction. Even though strictly numeric criteria are difficult to give, the category 'high impact' should typically include most of the population or extent lost (at least temporarily) while 'low impact' includes lesser reductions, like 10-15%.

The activities causing physical disturbance are compared below. The comparison does not consider spatial extent or frequency as these are available in the GIS data products. Otherwise those factors would be double-counted. The comparison, however, includes impacts on benthic features as well as recoverability.

Dredging (capital and maintenance): Due to high sedimentation on adjacent seabed and high turbidity of the water column, impacts on benthic fauna, vegetation and fish spawning are high. The activity usually lasts some weeks and in very large construction projects even months. Recovery from the disturbance takes place within 4-6 or even 10 years, but this is faster on exposed sites (see Table 4).

Disposal of dredged material: Due to high sedimentation on adjacent seabed and high turbidity of the water column, impacts on benthic fauna, vegetation and fish spawning are high. As the barges empty the load from the surface, the spread of the matter can be wide (depending on grain size) and the effect dilutes away from the site. The disposal sites are often fixed and the activity is repeated over years and therefore resuspension of the disposed matter is continuous. Recovery from the disturbance takes place within 4-10 years (see Table 4).

Extraction of sand and gravel: While the activity causes severe loss of seabed, if no environmentally friendly techniques are applied in order to decrease and minimize the negative effects, the physical disturbance over adjacent areas is not as high as in the two previous activities. The main difference is in the bigger grain size, which settles quickly to the sea floor. In new deposits, the initial siltation effects are high when the finer surface matter is disturbed. Another source of siltation is the sieving process, when the wanted grain size is sieved from the rest of the matter, which is then discharged to the surface water. The overall impact is considered moderate to high. Recovery from the disturbance at the adjacent sedimentation areas takes place within 4- >5 years (see Table 4).

Shipping and ferry traffic: Shipping and ferry traffic cause moderate to high impacts on seabed, but these are limited to shallow waters only and are spatially more restricted than the previously described activities. The main impacts are strong abrasion of the seabed due to the deep water flows along the seabed, turbidity of the water and sedimentation over vegetation and fish fry. Higher impacts take place in sheltered inlets and bays. The recovery could be fast, but as the shipping routes are rather fixed in shallow water areas, the pressure is more or less on-going and no reported recovery times were available.

Wind turbines: The physical disturbance pressure from the construction phase is generally moderate due to limited dredging and use of coarse sediment matter for the scour protection. Concrete data is lacking from the hydrographical secondary effects (e.g. abrasion of sediments) but these have not been reported to be strong. Recovery from the sedimentation is likely relatively fast (within 1-2 years) but the abrasion effect is continuous.

Cables and pipelines: The digging of cable or pipeline trenches causes some sedimentation and may be higher in shallow and sheltered areas, but generally these impacts are smaller than in dredging activities and depend also strongly on the substrate type. The impact of power and communication cables and smaller pipelines can be considered low to moderate whereas big gas pipelines cause moderate to high impacts. Concrete data on the impacts of (and recovery from) cables and smaller pipes is not available.

Boating and marinas: Impacts of marinas in shallow are moderate to high areas due to the loss of benthic vegetation and fish recruitment. This impact takes place only in summer time when boats concentrate on these areas more or less continuously and therefore the habitats cannot recover. Boating itself causes only low impacts along the boating routes in shallow waters.

Demersal fishing: As the project case studies did not separate between different bottom-touching fishing gears (but the FIT tool is capable of doing so), these cannot be separated in this ranking. The dominant fishing method in the case study and the Baltic Sea impacting the benthic habitats is demersal otterboard trawling. All the three case studies (using different approaches) showed reduction of benthic fauna due to the fishing activity with hauled gears. While sedimentation may have some impact, the main impact is the abrasion which causes direct mortality, bycatch of larger features and abrasion of the seafloor (both surface and sub-surface). The pressure cannot be considered as 'physical loss' as there is no evidence that the change of sea-floor morphology is changed for longer than 12 years, but the impact is still moderate to high disturbance because the seabed morphology is altered and mortality takes place. The impact is not considered as 'high', because the local dredging and disposal impacts seem to cause higher reduction in benthic fauna, even if the extent is more local. According to the longevity case study, some community types were more heavily impacted than others, but the reason for that is in more detailed biotope classification, i.e. differences in community composition. Also, there was made assumption of total mortality of all species when impacted once by fishery in this case study which is not the case for several abundant benthic invertebrate species such as the large mussels *Mytilus edulis* and *Arctica islandica*. At this moment, such a detailed result cannot be included in the ranking analysis of this report, but should be further developed.

In all the cases described above, sedimentation impacts are serious on hard bottom fauna and flora. Sedimentation (measured as burial depth) of only a couple of centimetres causes mortality on hard bottom fauna whereas in sandy and muddy bottoms greater sedimentation is possible (see Section 3.2). Therefore impacts are considered one category higher in hard-bottom habitats. In sandy habitats the same is true if the sedimentation is caused by muddy matter. As the demersal fishing does not take place on hard bottoms and the sedimentation pressure is likely limited in spatial extent, the impact is considered only 'low'. Based on these arguments, Table 7 presents ranking of activities causing physical disturbance pressure per broad habitat type

Table 7. Ranking of human activities causing physical disturbance on the basis of their pressures and impacts. The activities are categorized into six categories on the basis of the magnitude of pressures and severity of impacts they cause. The ranking is made by expert judgment on the basis of the literature synthesis (Annex 2) and it is made for six types of habitats due to the differences in impacts.

	Activity causing physical disturbance					
Rank	**Hard bottom**	**Sandy bottom**	**Muddy bottom**	**Water column**	**Fish reproduction area ***	**Vegetated habitats ***
High	Maintenance and capital dredging[1], Sediment disposal, Sand and gravel extraction[2]	Maintenance and capital dredging[1], Sediment disposal	Maintenance and capital dredging[1], Sediment disposal	Maintenance and capital dredging[1], Sediment disposal	Maintenance and capital dredging[1], Sediment disposal	Maintenance and capital dredging[1], Sediment disposal, Placement of gas pipelines
Moderate to high	Shipping and ferry traffic[4], Marinas, Placement of gas pipelines	Sand and gravel extraction, Shipping and ferry traffic[4], Marinas, Demersal fishing, Placement of gas pipelines	Sand and gravel extraction[5], Shipping and ferry traffic[4], Demersal fishing, Placement of gas pipelines, Marinas	Sand and gravel extraction, Shipping and ferry traffic[4]	Sand and gravel extraction, Shipping and ferry traffic[4], Marinas, Demersal fishing, Placement of gas pipelines	Sand and gravel extraction, Marinas, Shipping and ferry traffic[4], Demersal fishing, Wind turbine construction
Moderate	Wind turbine construction	Wind turbine construction	Wind turbine construction	Marinas	Wind turbine construction, Placement of cables and small pipelines, Boating	Wind turbine construction, Placement of cables and small pipelines, Boating
Low to moderate	Placement of cables and small pipelines			Placement of gas pipelines		
Low	Boating[4], Wind turbines in operation; Demersal fishing[3]	Placement of cables and small pipelines, Boating, Wind turbines in operation	Placement of cables and small pipelines, Boating, Wind turbines in operation	Wind turbine construction, Wind turbines in operation, Boating, Demersal fishing; Placement of cables and small pipelines	Wind turbines in operation	Wind turbines in operation
No impact						

*) Fish reproduction habitat is often the same as the vegetated habitat, but it is here considered wider, including also unvegetated gravel and sand habitats.
1) As maintenance dredging is a routine activity in harbours, it is not always included in the reported dredging data. For that reason the maintenance dredging category should include harbor areas.
2) The activity was considered one category higher on hard bottoms.
3) Demersal fishing does not take place on hard bottoms and therefore the siltation disturbance to nearby hard bottoms areas is considered only low impacts.
4) Effects from shipping, ferry traffic and boating depend also on depth; a model to take the depth into account is used when mapping pressure from these activities.
5) Sand and gravel extraction do not take place in muddy bottoms and therefore the disturbance on nearby muddy areas is considered as low impact.

5. Conclusions and perspectives for future work

In the BalticBOOST project, human activities and associated pressures were analyzed on the basis of a literature review and six case studies. The project results did not assess the impacts of pressures on benthic habitats but provided background information which can be used for such assessment. In the context of the project, the main objective of the report was to support development of guidelines for environmental targets which are presented separately as WP 3.1 Deliverable 2. The results can also support other processes.

The main results of this report is the overview of knowledge on impacts of pressures and the proposal for practical application of results which can support the further development of assessments of pressures on benthic habitats. Based on the literature survey the project has illustrated how widely pressures extend from different human activities, how long it takes for different benthic features to recover from the pressures and how the pressures from different activities relate to each other. These results support the development process to make environmental targets for pressures affecting seabed but they also support the assessment of benthic habitats under the revised COM DEC. The criterion D6C1 requires an assessment of the area of seabed physically lost and the spatial extent results of this report support that spatial analysis. The criterion D6C2 requires an assessment of seabed area being physically disturbed and the results of this project support also this analysis. The criterion D6C3 requires an assessment of benthic habitats being adversely affected and this is supported – in addition to the extent results – also by the recovery results and by the results of the impacts of the activities and pressures. Although it was not possible to propose concrete values for 'maximum allowable pressures', the literature review and the case studies gave valuable information of the impacts. The work to define such 'thresholds' will continue and can benefit from the BalticBOOST findings.

The results of this project work indicate that impacts from human activities can be high and their underestimation may cause unintended effects in the marine ecosystem. For instance, the analysis of physical loss in the Mecklenburg Bight case study showed that very different assessment results under the criterion D6C1 can be expected if analysed against the EUNIS 2 habitats or EUNIS 6 habitats. In the latter case, the sand extraction activities revealed potential threats to specific biotope types.

The project work did not include any impact analyses of contamination, eutrophication, hypoxia, invasive species, litter, heat or noise, which all are known to cause impacts on benthic features. Full assessments of the state of benthic habitats require such information as also shown by the revised GES criteria D6C4 and D6C5.

The results of this report will support the assessment of impacts of human activities and pressures of the upcoming HELCOM 'State of the Baltic Sea' report (HOLAS II). As outlined in the beginning of this report, the assessment of impacts on benthic habitats is a complex task and requires information of spatial and temporal variables as well as relative significances of the human activities producing the pressures and impacts. All results can be used in making the GIS data layers of the pressures which are the basis of the benthic assessment, including e.g. the spatial extent of pressures. After compiling the GIS layers and linking those to habitats GIS layers with the associated sensitivity scores, it will be possible to identify the geographical distribution of benthic impacts and where high impacts from the human activities particularly take place.

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Annexes

Annex 2.
Catalogue of the reported pressures and benthic impacts caused by human activities

This catalogue of human activities, pressures and impacts has been produced in the EU-cofunded project BalticBOOST.

The project is coordinated by the HELCOM Secretariat and the Catalogue was prepared by the work package 3.1 of the project by Finnish Environment Intitute (SYKE) and Institute of Oceanography in Warnemuende (IOW).

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The data in the catalogue is not free to use without consultation with the HELCOM Secretariat, SYKE or IOW.

The catalogue also includes a synthesis of the results.

The catalogue is available for download as a MS Excel file:

http://www.helcom.fi/Documents/4-4_Annex_2_Catalogue_pressures.xlsx