Task 4.2.1 Definition of adversely affected habitats

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1. Introduction

HELCOM is developing a Second Holistic Assessment of the Ecosystem Health of the Baltic Sea through the HOLAS II project that started in late 2014 and will run until mid-2018. The 2nd holistic assessment will assess progress towards reaching a Baltic Sea in a Good Environmental Status and will follow-up the initial HELCOM holistic assessment that was published in 2010 (HELCOM 2010). The Contracting Parties to the Helsinki Convention being EU Member States have decided to use the outcome of HOLAS II for the purpose of their reporting under Article 8 of the Marine Strategy Framework Directive (MSFD) in 2018.

Currently, several projects and activities are being conducted to deliver the first version of the 2nd holistic assessment by mid-2017 which will serve national MSFD consultation purposes. An updated version of the assessment report, including the most recent monitoring data and taking into account the outcome of the consultation process, will be prepared by mid-2018. The SPICE project contributes to the finalization of the holistic assessment, including development and refinement of central components of the report that are also requirements under the MSFD.

The state of marine benthic and pelagic habitats is threatened by several land-based and sea-based human activities. The HELCOM Baltic Sea Pressure Index and Impact Index (BSPII) are methods which can be used to estimate human activities and the cumulative pressures and impacts on marine environment and they have been further developed to fit to the purpose of the HELCOM 2nd Holistic Assessment through the HELCOM TAPAS project. While the existing tool can present spatially resolved maps of activities, cumulative pressures and impacts, it does not have validated linkages to the state of the benthic and pelagic habitats and hence it does not allow estimates of GES. In the Theme 4 of the SPICE project, guidelines are produced for an assessment of benthic and pelagic habitats, possible thresholds will be tested and draft assessments will be produced.

This report presents the findings of the task 4.2.1 “Definition of adversely affected habitats”. Adverse effects refer to tolerance and recoverability of each habitat type, including its structure and functions. A practical definition is proposed on the basis of the pressure - state correlations made under the HELCOM TAPAS and BalticBOOST projects. Habitat-specific thresholds for the amount of pressures causing 'adverse effects' have been explored and proposed by comparing indicators for the habitat structure and function (e.g. the benthic quality index) and the specific and cumulative pressures.

2. Approaches to define adverse effects on habitats

Indicators of good status of benthic or pelagic habitats can include any parameter which can become a limiting factor (e.g. living conditions) or is indicative for a change (e.g. quantity or quality of a specific feature). In the EU Marine Strategy Framework Directive (MSFD), the good environmental status (GES) is closely connected with the ecosystem-based management of human activities, which means that GES indicators describe changes as a result of human activities (or human mitigation measures). The definition of GES can, hence, be interpreted as an anthropogenic change in the marine environment, but the challenge lies in defining the amount of change that threatens GES. This is called as ‘adverse effect’ in the MSFD. The MSFD further describes adverse effects on habitat condition as alterations in its biotic and abiotic structure and its functions (e.g. typical species composition and relative abundances, absence of particularly sensitive or fragile species or species providing a key function, or size structure of species).

In the SPICE WP4, the objective of the task 4.2.1 was to define the term 'adversely affected habitat' and explore potential thresholds in line with the definition. This work will draw from the pressure – state correlations from the TAPAS and BalticBOOST projects but also benefit from additional data and literature analyses with habitat and pressure data.

Adversely affected habitats can be defined from at least the following perspectives:

a) GES status of predominant fauna or flora of the habitat: this approach builds on the available state indicators such as benthic invertebrate indices and macrophyte indicators, which have GES thresholds. These thresholds are already established under other regimes, such the EU Water Framework Directive (WFD), the EU Habitats Directive or HELCOM core indicators. A habitat status can be assessed by the state indicator alone, but also from the pressure point of view. The intensity of pressure causing the adverse effect can, in principle, be found from the pressure – status correlation (e.g. Josefson 2009, Chuševė *et al.* 2016).
b) State of fauna or flora (not established indicators): biological state parameters can show significant reductions in extent, abundance or condition which are caused by increased pressures. As no GES threshold has been established, the link to the pressure must be shown and the adverse effect is defined from that correlation. The state of the habitat can, however, be assessed either from the pressure or state point of view. For example, extent or abundance of sensitive species can be used as a threshold indicating adverse effects and GES or, vice versa, amount of pressures known to kill or deteriorate those species can be used instead.
c) Physical or chemical indicators (with GES threshold) or parameters (without a threshold) reflect the living conditions of the predominant fauna or flora of a habitat. A threshold can be found in values where the conditions start deteriorating. These conditions need to be shown to affect the state indicators and they need to be caused by anthropogenic pressures. An example of this approach is the oxygen concentration which affects different species differently. Also water quality parameters in pelagic habitats are an example of this approach.

In the task 4.2.1, all the three approaches were used. The task outcome suggests potential approaches to assess the state of benthic and pelagic habitats. In each case, the existing indicators are identified and notes for their use in practice are discussed. Special emphasis is given to spatial scales and temporal matching.

3. Potential habitat thresholds based on oxygen concentration

Oxygen is a limiting factor for species and their habitats and therefore specific limits can be searched for the species which characterize habitats and these may be used as quality or quantity indicators for these habitats.

Anoxia means lack of oxygen (0 mg L^{-1}) but there are different definitions for hypoxia. Typically hypoxia is defined as the concentration range between 0 and 2.8 mg L^{-1} (Diaz & Rosenberg 1995, Vaquer-Sunyer and Duarte 2008). There are, however, large biomass differences even within this range. Timmermann *et al.* (2012) has shown that benthic biomass production can increase significantly if oxygen levels are increased from 2 mg l^{-1} to 4 mg l^{-1}.

A global literature review of effects of benthic oxygen concentrations on benthic species shows that the hypoxia threshold may vary between 2-8.5 mg L^{-1} depending on species characteristics (Vaquer-Sunyer & Duarte 2008). According to the study, the global median lethal oxygen concentration is 1.6 mg L^{-1} (0.12 SE), the median sublethal concentration is 2.24 (0.21 SE), and the 90 percentiles for lethal and sublethal concentrations are 4.59 and 5.00 mg L^{-1}, respectively. Crustaceans are the most sensitive species to die, covering the entire range of hypoxia concentrations up to 8.6 mg L^{-1}, whereas the lethal concentration for bivalves ranged between 0.2 and 3.5 (5 and 95 percentiles). Gastropods were even more tolerant (5 and 95 percentiles: 0.5 and 1.7). Sublethal effects were seen for fish in the range (5 and 95 percentiles) 2.0-10.0 mg L^{-1}, for Crustacea in 0-5.5, for Mollusca in 0.5-4.0 and for Polychaeta in 0.3-1.5. The median survival time for 50% of the individuals (LT50) for all organisms tested was found to be 116 ± 28 hours (mean ± SE).

Species living in the Baltic Sea, settle well within these results. Interestingly, some fish species seem to be very sensitive to decrease in oxygen concentration. For instance, cod (*Gadus morhua*) shows sublethal hypoxia effects (increased ventilation) already in 10.2 mg O_2 L^{-1} (Saunders 1963, Davis 1975) and the juvenile flounder has the LT50 of 23 min in acute hypoxia (Tallqvist *et al.* 1999). Table 1 presents the oxygen concentrations for the Baltic Sea species which can be considered as thresholds for the HUB biotopes. For some species no threshold is available, but LT50 values which indicate the survival time for 50% of the population.

Modig and Olafsson (1998) divided Baltic benthic macro- and meiofauna to four groups according to their sensitivity to hypoxia, based on mesocosmos results: 'very sensitive species' (*Monoporeia affinis* and the harpacticoid copepods *Microarthridion littorale* and *Pseudobradya* sp.); 'sensitive species' (the surface-dwelling nematode species *Axonolaimus spinosus* and the groups Turbellaria and Oligochaeta); 'less sensitive species' (*Macoma balthica*, the ostracod species *Paracyprideis fennica*, and the surface-dwelling nematode *Paracanthonchus* spp. and *Calomicrolaimus honestus*), and 'tolerant species' (two ostracod species *Heterocyprideis sorbyana, Candona neglecta*, the kinorhynchs, and the numerically important nematode species *Leptolaimus elegans* and *L. papilliger*).

The index of the benthic invertebrate community (BBI, Perus *et al.* 2007), which is relatively comparable with the Benthic Quality Index (BQI), reacts clearly to hypoxia. According to the SPICE WP4 results, the BBI, Shannon-Wiener diversity (H') and species richness (S) start steeply declining already in 5% probability of having <4 mg O_2 L^{-1}. The decline is slower for the total abundance (number of individuals). The peak BBI, H', S and total abundance are reached between 7-8 mg O_2 L^{-1}.

Table 1a. Sensitivity of benthic species to oxygen concentration. The affected species is linked to a habitat type, if it is considered as a predominant or significant element of the habitat. The threshold (or its range) is justified by literature reference and explanation how the species is affected. For each species a single threshold (or range) is identified.

Threshold (mg O_2 L^{-1})	**Affected species**	**Literature reference and arguments**	**Affected broad habitat type**	**HUB habitat code**
2.8 mg L^{-1}	*Macoma balthica*	Constant hypoxia (0.5-0.8mg L^{-1}) reduced the number of individuals significantly, but weekly pulses of hypoxic (0.5-0.8 mg L^{-1}) water did not increase mortality (Modig & Olafsson 1998)	Infralittoral muddy habitats, Infralittoral sandy habitats, Circalittoral muddy habitats, Offshore circalittoral muddy habitats, Circalittoral sandy habitats, Offshore circalittoral sandy habitats	AA.H3L1, AA.J3L1, AA.J3L9, AB.H3L1, AB.J3L1
2.96 mg L^{-1} (sublethal effects)	*Zostera marina*	Pedersen *et al.* 2004	Infralittoral muddy habitats, Infralittoral coarse sediment habitats, Infralittoral sandy habitats, Infralittoral mixed sediment habitats	AA.H1B7, AA.I1B7, AA.J1B7, AA.M1B7
0.57 mg L^{-1} (sublethal effects)	*Cyanea capillata*	Rutherford and Thuesen 2005	Photic habitat above halocline	AD.N5
0.57 mg L^{-1} (sublethal effects)	*Mya arenaria*	Jorgensen 1980; Mya arenaria LT50 (under 2 mg O2 L^{-1}) is 504 hours (Theede 1969).	Infralittoral sandy habitats, Circralittoral sandy habitats	AA.J3L4, AA.J3L9, AB.J3L4, AB.J3L9
0.57 mg L^{-1} (sublethal effects)	*Abra alba*	Jorgensen 1980;	Infralittoral muddy habitats	AA.H3L8
0.57 mg L^{-1} (sublethal effects)	*Cerastoderma edule*	Jorgensen 1980; C. edule LT50 (under 2 mg O2 L^{-1})102 hours (Theede 1969).	Infralittoral sand, Circalittoral sand	AA.J3L2, AA.J3L9, AB.J3L9
0.57 mg L^{-1} (sublethal effects)	*Hydrobia ulvae*	Jorgensen 1980	Infralittoral rocky habitats, Infralittoral hard clay habitats, Infralittoral coarse sediment habitats, Infralittoral sandy habitats, Infralittoral mixed sediment habitats, Circalittoral rocky habitats	AA.A1V, AA.I2W, AA.B1V, AA.K, AA.M2W, AB.A1V, AB.A2T
1.43 mg L^{-1} (sublethal effects)	*Carcinus maenas*	Renaud 1986	All types of infralittoral habitats	All AA-HUB biotopes
2.9 mg L $^{-1}$ (for survival)	*Harmothoe sarsi*	Field sampling (Witek 1993)	Circalittoral muddy habitats, Offshore circalittoral muddy habitats,	AB.H3L1
3.90 mg L^{-1} (sublethal effects)	*Monoporeia affinis (Pontoporeia femorata* was more	Experiment, >80% survival >2 mg L^{-1}, after 24 d (Johansson 1997, Goedkoop & Johnson 2001). Weekly pulses of hypoxic (0.5-0.8 mg L^{-1}) water killed (Modig & Olafsson 1998)	Infralittoral muddy habitats, Circalittoral muddy habitats, Offshore circalittoral muddy habitats, Circalittoral sandy habitats, Offshore circalittoral	AA.H3N1, AB.H3N1, AB.J3N1

	sensitive but no threshold was found)		sandy habitats. Salinity up to 18 (Cedervall 1977)	
<1 – 2 mg L^{-1}	*Gmelinoides fasciatus*	Berezina *et al.* 2013	Gulf of Finland sediments in up to 2 (but likely 5) salinity (Berezina 2007)	
??	*Halicryptus spinulosus*	Survived 2 months in hypoxia (0.5-0.8 mg L^{-1}), but with high mortality; older individuals are more tolerant (Modig & Olafson 1998).	Infralittoral muddy habitats, Infralittoral sandy habitats, Circalittoral muddy habitats, Offshore circalittoral muddy habitats, Circalittoral sandy habitats, Offshore circalittoral sandy habitats.	AA.H3, AA.J1, AB.H3, AB.J1
??	Ostracoda, Nematoda, Oligochaeta and Turbellaria	Survived 2 months in hypoxia (0.5-0.8 mg L^{-1}), but with high mortality (Modig & Olafson 1998).		
1.25 mg L^{-1} (sublethal effects)	*Saduria entomon*	Johansson 1997	Circalittoral sandy habitats	AB.J3N1
2.58 mg L^{-1} (sublethal effects)	*Crangon crangon*	Sandberg *et al.* 1996	Infralittoral sandy habitats	AA.J
4.5 mg L^{-1} (sublethal effects)	*Salmo salar*	Kutty and Saunders 1973		
3.22 mg L^{-1} (sublethal effects)	*Esox lucius*	Siefert *et al.* 1973		
0.52-2.78 mg L^{-1} (LT50)	*Gadus morhua*	Schurmann and Steffensen 1992, Plante *et al.*1998,		
2.65 mg L^{-1} (LT50)	*Rhithropanopeus harrisii*	Stickle *et al.* 1989		
	Hediste diversicolor	LT50 (under 2 mg O_2 L^{-1}) of 14 hours, 105 hours and 120/192 hours for postlarval, juvenile and adult stages respectively (Henriksson 1969, Theede 1969, Gamenick *et al.* 1996)	Infralittoral sand, Circalittoral sand, Offshore circalittoral sand	AA.J3M4, AB.J3M4
	Capitella capitata	LT50 (under 2 mg O_2 L^{-1})of 312 hours (Rosenberg 1972)	Infralittoral muddy habitats	AA.H3M, AA.H3M5
	Arenicola marina	LT50 (under 2 mg O_2 L^{-1})of 398 hours (Groenendaal *et al.* 1980)	Infralittoral sandy habitats	AA.J3M2

	Scolops armiger	LT50 (under 2 mg O_2 L^{-1})of 46 or 120 hours (Henriksson 1969, Schöttler and Grieshaber 1988)	Infralittoral muddy habitats, Circalittoral muddy habitats, Offshore circalittoral muddy habitats	AA.H3M, AA.H3M5, AB.H3M1,
	Corophium volutator	LT50 (under 2 mg O_2 L^{-1})of 4-42 hours (Gamble 1970, Gamenick *et al.* 1996)	Infralittoral muddy habitats	AA.H3N2
	Idotea baltica	LT50 (under 2 mg O_2 L^{-1})of 2-6 hours (Vetter *et al.* 1999)	Infralittoral rocky habitats	AA.A1C1, AA.A1C4
	Gammarus oceanicus	LT50 (under 2 mg O_2 L^{-1})of 15 hours (Theede *et al.* 1969)	Infralittoral rocky habitats	AA.A1C1, AA.A1C2, AA.A1C3, AA.A1C4, AA.A1C5
	Chironomus plumosus-t.	LT50 (O_2 deficiency) of 200 days (Nagell 1978)	Infralittoral muddy habitats	AA.H3C1
	Marenzelleria viridis	LT50 (O_2 deficiency) 4-11 hours for larvae, 23 hours for juveniles and 100-300 hours for adults (depending on salinity) (Fritzsche and Von Oertzen 1995). High tolerance to low oxygen and anoxia (Schiedek 1997).	Infralittoral muddy habitats, Circalittoral muddy habitats, Offshore circalittoral muddy habitats	AA.H3M, AA.H3M3, AB.H3M, AB.H3M3

Table 1b. Sensitivity of benthic species to hydrogen sulphide. The affected species is linked to a habitat type, if it is considered as a predominant or significant element of the habitat. The threshold (or its range) is justified by literature reference and explanation how the species is affected. For each species a single threshold (or range) is identified.

Threshold	**Affected species**	**Literature reference and arguments**	**Affected broad habitat type**	**HUB**
~1000 umol L^{-1} (in sediment)	*Harmothoe sarsi*	Janas & Szaniwaska 1996	Circalittoral muddy habitats, Offshore circalittoral muddy habitats,	AB.H3L1
~20 umol L^{-1} (in sediment)	Saduria entomon	Janas & Szaniwaska 1996	Circalittoral sandy habitats	AB.J3N1
max. 1224 umol L^{-1} (in sediment)	*Pontoporeia femorata*	Janas & Szaniwaska 1996	Infralittoral muddy habitats, Circalittoral muddy habitats, Offshore circalittoral muddy habitats, Circalittoral sandy habitats, Offshore circalittoral sandy habitats. Salinity up to 18 (Cedervall 1977)	AA.H3N1, AB.H3N1, AB.J3N1
~20 umol L^{-1} (in sediment)	*Corophium volutator*	Janas & Szaniwaska 1996	Infralittoral muddy habitats	AA.H3N2
max. 500 or max 1224 umol L^{-1} (in sediment)	*Macoma balthica*	Jahn *et al.* 1993, Janas & Szaniwaska 1996	Infralittoral muddy habitats, Infralittoral sandy habitats, Circalittoral muddy habitats, Offshore circalittoral muddy habitats, Circalittoral sandy habitats, Offshore circalittoral sandy habitats	AA.H3L1, AA.J3L1, AA.J3L9, AB.H3L1, AB.J3L1
max 305 umol L^{-1} (in sediment)	*Mya arenaria*	Janas & Szaniwaska 1996	Infralittoral sandy habitats, Circralittoral sandy habitats	AA.J3L4, AA.J3L9, AB.J3L4, AB.J3L9

max 305 umol L^{-1} (in sediment)	*Halicryptus spinulosus*	Janas & Szaniwaska 1996	Infralittoral muddy habitats, Infralittoral sandy habitats, Circalittoral muddy habitats, Offshore circalittoral muddy habitats, Circalittoral sandy habitats, Offshore circalittoral sandy habitats.	AA.H3, AA.J1, AB.H3, AB.J1
<50 umol L^{-1} (in sediment)	*Hediste diversicolor*	Miron and Kristensen (1993)	Infralittoral sand, Circalittoral sand, Offshore circalittoral sand	AA.J3M4, AB.J3M4
<50 umol L^{-1} (in sediment)	*Alitta virens*	Miron and Kristensen (1993)	Infralittoral sand	AA.J3M4,
50-2000 umol L^{-1} (in sediment)	*Alitta succinea*	Miron and Kristensen (1993)	Infralittoral sand	AA.J3M4,
max 340 umol L^{-1} (in sediment)	*Arenicola marina*	Völkel and Grieshaber (1992)	Infralittoral sandy habitats	AA.J3M2

4. Benthic invertebrate indices

The HELCOM monitoring of benthic macrozoobenthos targets at soft-bottom habitats which are easily sampled by grabs. The benthic invertebrates are an obvious indicator for the state of the soft-bottom habitats and the various indicators for benthos have extensively been tested in the Baltic Sea.

Each HELCOM Contracting Party has established legal or scientific thresholds for benthic invertebrate indices under the EU WFD. The most indices follow the basic structure where species are given sensitivity scores and their abundance and species composition affect the outcome. Many of the indices correlate negatively with the increasing pressures, most often eutrophication (Rosenberg *et al.* 2004, Perus *et al.* 2007, Leonardsson *et al.* 2009) but also the cumulative pressures (Lauringson *et al.* 2013) and physical pressures (Korpinen *et al.* 2017).

Table 2 presents some results from literature about the pressures correlating with the benthic indices. The table also suggests possible thresholds in pressures and links the benthic indices to the habitats where they may be representative.

Table 2. Sensitivity of benthic species to oxygen concentration. The affected species is linked to a habitat type, if it is considered as a predominant or significant element of the habitat. The threshold (or its range) is justified by literature reference and explanation how the species is affected. For each species a single threshold (or range) is identified. As most of the sampling is done in muddy seabed, the affected habitat is listed as the muddy substrate.

Benthic index (and literature reference)	**Linkage to pressures (and literature reference)**	**Possible threshold and its justification**	**Affected broad habitat type**	**HUB**
BBI (Perus *et al.* 2007)	Turbidity (Korpinen *et al.* 2017)	8 NTU: the threshold is based on limited amount of measurements from a dredging site.	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BBI (Perus *et al.* 2007)	Suspended solid matter (Korpinen *et al.* 2017)	7 mg/l: the threshold is based on limited amount of measurements from a dredging site.	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BBI (Perus *et al.* 2007)	Distance from a dredging site (Korpinen *et al.* 2017)	600 m: after this distance the invertebrate community showed acceptable status above the GES threshold.	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BBI (Perus *et al.* 2007)	Oxygen saturation (Perus *et al.* 2007)	Below 80% oxygen saturation the BBI indicates disturbed status.	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BBI (Perus *et al.* 2007)	Sediment organic content (Perus *et al.* 2007)	Above 10% organic content the BBI indicates disturbed status.	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BBI (Perus *et al.* 2007)	Total nitrogen (SPICE WP4 results)	BBI, H' and S start declining in >250 µg TN L^{-1}	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BBI (Perus *et al.* 2007)	Total phosphorus (SPICE WP4 results)	BBI and H' start declining in >25 µg TP L^{-1}	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
ZKI	Baltic Sea Pressure Index	Significant linear correlation but no threshold (Lauringson *et al.* 2013)	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BQI	Eutrophication (Chuševė *et al.* 2016)	2.6 µg Chl *a* L^{-1} most accurate threshold for detecting BQI below WFD G/M-border	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BQI, DKI	Urban effluents (Josefson *et al.* 2009)	10 km (Aarhus Bight), 20 km (Oslofjord): Distance at which the increase in benthic indices levelled off.	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3
BQI, DKI	Hypoxia (Josefson *et al.* 2009)	489 days (BQI) and 517 days (DKI) to recover from defaunation after hypoxic events in Gullmarsfjord.	Infralittoral muddy habitats, Circalittoral muddy habitats	AA.H3, AB.H3

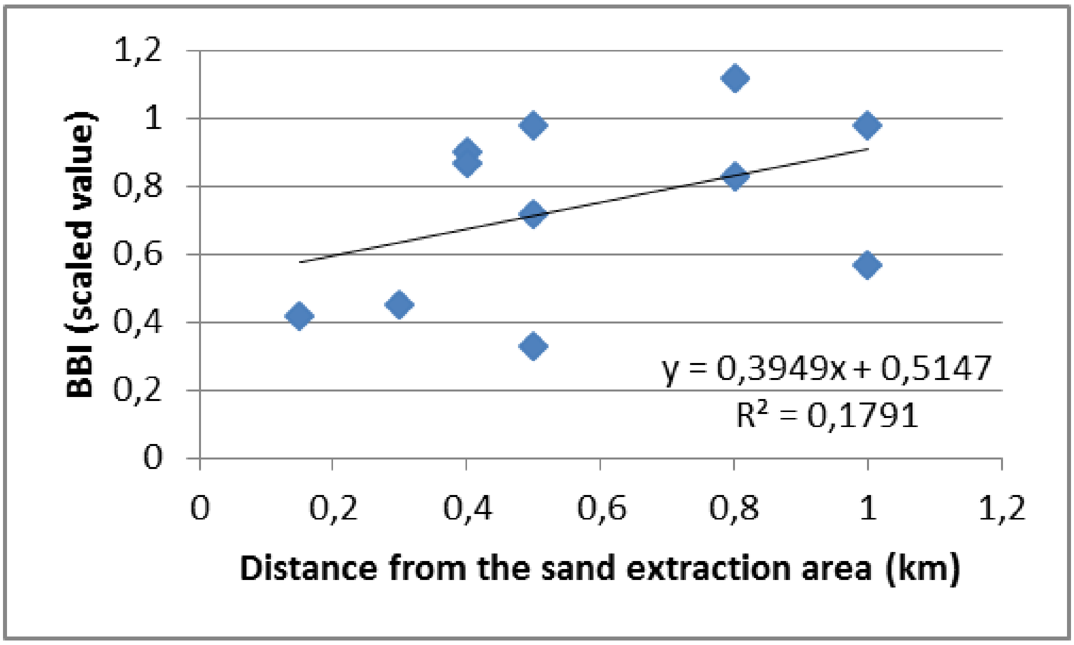

Figure 1. Dependency of benthic fauna index (BBI) on the distance away from the sand extraction site (km) in the Vuosaari Harbour construction site. The GES boundary in BBI is at 0.6. Source: Korpinen et al. 2017.

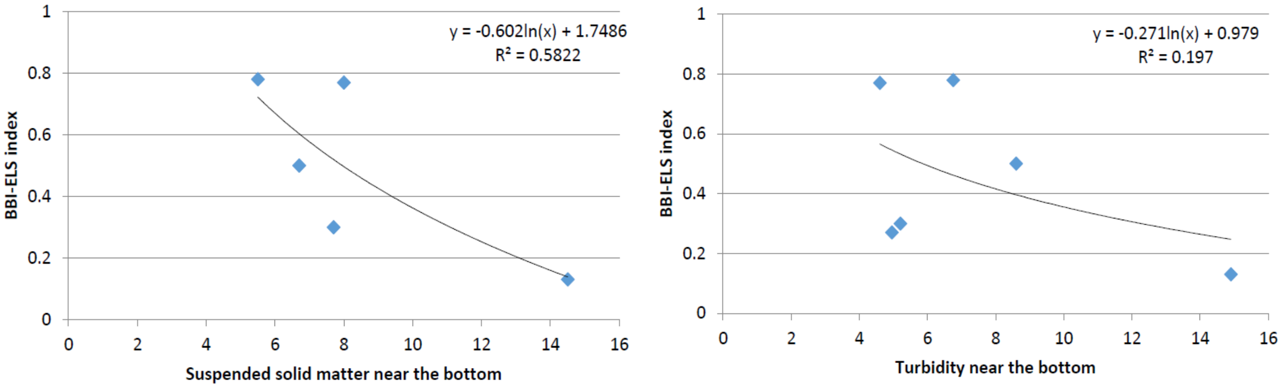

Figure 2. Dependency of benthic macrofauna index (BBI) on (left panel) suspended solid matter (mg/l) and (right panel) turbidity (NTU) in the near-bottom water close to the dredging site in 2005 and 2008. The GES boundary in BBI is at 0.6. Source: Korpinen et al. 2017.

5. Sensitive and tolerant macrophyte species

Macrophytes can be used as indicator species for infralittoral biotopes. Abundance of sensitive or tolerant species or an index aggregating such a result can be used to define thresholds for the EUNIS 6 level (also HUB 6 level) biotopes.

The use of sensitive and tolerant species is, however, not straightforward as sensitive species may be sensitive to different pressures. For example, charophytes, are favoured by naturally high sediment nutrient concentrations, low phosphorus concentrations in water (but high nitrogen concentration!) and low turbidity – natural conditions of flads and other enclosed bays (Rosqvist 2010, Rosqvist *et al.* 2010). Charophytes are however very sensitive to changes in water circulation and dredging (Rosqvist 2010). Other sensitive species, such as perennial macroalgae, are sensitive to sedimentation, reduced water transparency and high nutrient concentrations in water (Eriksson & Johansson 2005). Keeping this limitation in different pressure responses in mind, the SPICE WP4 made analyses and reviewed scientific literature to find evidence for any thresholds for the state of benthic biotopes.

SPICE WP4 tested the macrophyte indices MI_C (macrophyte community index) and MI_A (macrophyte abundance index) (Hansen & Snickars 2014). Both the indices use indicative species which are classified as 'sensitive' or 'tolerant'. The former uses only the species presence/absence while the latter also uses the species abundance. The indices have been used for at least 100 years in macrophyte or pollution studies and they seem to be suitable both to temporal changes (Ruuskanen 2017) and spatial differences of pressures (Hansen & Snickars 2014). The indices are scaled between -100 (very sensitive) and 100 (very tolerant). Based on water quality and boating pressures (incl. dredging and piers), Hansen and Snickars (2014) suggested that the good environmental status is set for the MI_C at 20 in enclosed bays and at -10 in semi-enclosed and open bays.

In SPICE the indices were used with the Finnish macrophyte inventory data from a couple of thousand sites and with the Swedish macrophyte inventory data from some hundreds of sites. The indices were calculated and tested against both physical and eutrophication pressures. The analyses were made with three approaches: (1) the generalized additive model (GAM), (2) the Zonation software and (3) the multivariate methods (canonical correspondence analysis and principal component analysis). In the Zonation analysis, the pressures were analyzed as distances between the macrophytes and the pressure source.

The results showed that the eutrophication pressures explained most of the macrophyte community variance and physical pressures seemed to have only minor effect on them. In general, the explanatory power of the pressures was weak and it was suspected that the environmental variability was very high along the strong latitudinal and coast-offshore gradients. However, it was possible to suggest some pressure thresholds based on the SPICE analyses and literature reviews. In addition, distance thresholds from pressures were suggested from the analyses and compared with the BalticBOOST literature review (Korpinen *et al.* 2017). The multivariate analyses confirmed the general results but did not suggest any detailed thresholds. Table 3 summarizes thresholds from the analyses, Table 5 summarizes distance thresholds to pressures and Figures 3-4 present the multivariate analyses.

Table 3. Pressure thresholds depicted from the analyses of sensitive and tolerant macrophyte species in the Northern Baltic Sea.

Pressure threshold	**Literature reference**	**Threshold justification**	**Affected habitat**
Total phosphorus 15-25 µg L^{-1} (in the Northern Baltic Proper, Ålan Sea and Archipelago Sea)	Hansen & Snickars 2014	Macrophyte communities in the northern Baltic Proper coastal bays included sensitive species in TP <25 µg L^{-1}. High sensitivity (Mic = -80) was found at concentration 15 µg L^{-1}, which is also the TP threshold in WFD.	Infralittoral mud (in enclosed bays): AA.H1B4, AA.H1B5, AA.H1B6
Total phosphorus 15-30 µg L^{-1} (in the Northern Baltic Proper, Ålan Sea and Archipelago Sea)	Hansen & Snickars 2014	As above, but sensitive species were also found in higher TP concentrations, such as 30 µg L^{-1}.	Infralittoral mud (semi-enclosed and open bays): AA.H1B4, AA.H1B5, AA.H1B6)
Turbidity <2.5 NTU (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	Hansen & Snickars 2014	Macrophyte communities show higher variation in semi-enclosed and open than enclosed bays, but typically sensitive species are more common in turbidities below 2.5 NTU.	Enclosed, semi-enclosed and open bays: AA.H1B
Suspended matter (in the Northern Baltic Proper, Ålan Sea and Archipelago Sea)	Appelgren & Mattila 2005	Charophyte-dominated enclosed and semi-enclosed bays are characterized by low turbidity: 2-3 mg L^{-1} suspended mater. Vascular plant meadows in bays have higher turbidity regime: ~5-6 mg L^{-1}.	Infralittoral mud (in enclosed bays): AA.H1B4, AA.H1B5, AA.H1B6
Boating activity is minor, no dredging and only a couple of piers (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	Hansen & Snickars 2014	Dredging, more than 2-5 piers per hectare and > 700m from a ferry route caused decline of sensitive species in bays.	Enclosed, semi-enclosed and open bays: AA.H1B
Harbour effects is very small (Finland's coast)	SPICE WP4	Blue mussel cover (%) and eelgrass cover are clearly highest at very small harbor effects.	All infralittoal habitats
Water transparency at least 6 m (Finland's coast)	SPICE WP4	Number of sensitive species starts decreasing in Secchi depths <6 m.	All infralittoal habitats
Water transparency at least 3 m (Finland's coast)	SPICE WP4	Tolerant species start prospering in Secchi depths <3 m.	All infralittoal habitats
Water transparency at least 6 m (Finland's coast)	SPICE WP4	Blue mussel cover decreases linearly in Secchi depths <6 m.	Infralittoral rocky habitats: AA.B1E1
Water transparency at least 4.5 m (Finland's coast)	SPICE WP4	Eelgrass cover decreases in Secchi <4.5 m.	Infralittoral sandy habitats: AA.J1B7
Water transparency at least 3.5 m (Finland's coast)	SPICE WP4	Bladderwrack cover decreases in Secchi <3.5 m.	Infralittoral rocky habitats: AA.A1C1

Table 3. Pressure thresholds depicted from the analyses of sensitive and tolerant macrophyte species in the Northern Baltic Sea.

Pressure threshold	**Literature reference**	**Threshold justification**	**Affected habitat**
Total nitrogen: 350 µg L^{-1} (Finland's coast)	SPICE WP4	Eelgrass cover decreases in TN > 350 µg L^{-1}. Blue mussel cover decreases in TN >400 µg L^{-1}.	Infralittoral sandy habitats: AA.J1B7
Total nitrogen: 450 µg L^{-1} (Finland's coast)	SPICE WP4	Tolerant macrophytes start prospering >450 µg L^{-1}.	All infralittoal habitats
Total nitrogen: 200-300 µg L^{-1} (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	Rosqvist *et al.* 2010	Vascular plant meadows in shallow bays (or 'juvenile flads') are characterized by lower TN concentrations in water.	Infralittoral mud (semi-enclosed and open bays): AA.H1B4, AA.H1B5, AA.H1B6)
Total nitrogen: 400-500 µg L^{-1} (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	Rosqvist *et al.* 2010	Charophyte-dominated enclosed bays (or 'flads' or 'gloe-flads') are characterized by high TN concentrations in water.	Infralittoral mud (in enclosed bays): AA.H1B4, AA.H1B5, AA.H1B6
Turbidity: 1-2 NTU (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	Rosqvist *et al.* 2010	Low turbidity values are found from charophyte dominated flads or gloe-flads.	Infralittoral mud (in enclosed bays): AA.H1B4, AA.H1B5, AA.H1B6
Turbidity: 3-4 NTU (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	Rosqvist *et al.* 2010	High turbidity values are found from vascular plant meadows in shallow bays or 'juvenile flads'.	Infralittoral mud (semi-enclosed and open bays): AA.H1B4, AA.H1B5, AA.H1B6)
Total phosphorus (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	SPICE WP4	Cover of sensitive macrophyte species starts declining in >25 µg L^{-1}	All infralittoral habitats
Total phosphorus (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	SPICE WP4	Blue mussel cover decreases in TP >25 µg L^{-1}. Eelgrass cover decreases in TP >35 µg L^{-1}.	Infralittoral rocky habitats: AA.B1E1
Total phosphorus (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	SPICE WP4	Semi-high TP concentration in water (20-35 µg L^{-1}) is characteristics for the vascular plant meadows in shallow bays	Infralittoral mud (semi-enclosed and open bays): AA.H1B4, AA.H1B5, AA.H1B6)
Total phosphorus (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	SPICE WP4	Low TP concentration in water (15-20 µg L^{-1}) is characteristics for the charophyte-dominated biotopes in enclosed or semi-enclosed bays. High sediment P and N concentrations are also characteristic.	Enclosed, semi-enclosed and open bays: AA.H1B
Humus: 2-2 mg CDOM L^{-1} (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	SPICE WP4	Tolerant macrophytes start prospering >2 mg CDOM $L^{-1}$and sensitive species decline in >2-3 mg CDOM L^{-1}. Benthic invertebrate community index BBI and Shannon-Wiener diversity decline in >2 mg CDOM L^{-1}.	Infralittoral rocky habitats: AA.B1E1

Table 3. Pressure thresholds depicted from the analyses of sensitive and tolerant macrophyte species in the Northern Baltic Sea.

Pressure threshold	**Literature reference**	**Threshold justification**	**Affected habitat**
Openness of flads: not artificially opened (in the Northern Baltic Proper, Åland Sea and Archipelago Sea)	Rosqvist 2010	Artificial opening of flad mouths exposes the charophyte meadows to wave exposure which causes a regime shift to other plant community type.	Infralittoral mud (in enclosed bays): AA.H1B4, AA.H1B5, AA.H1B6

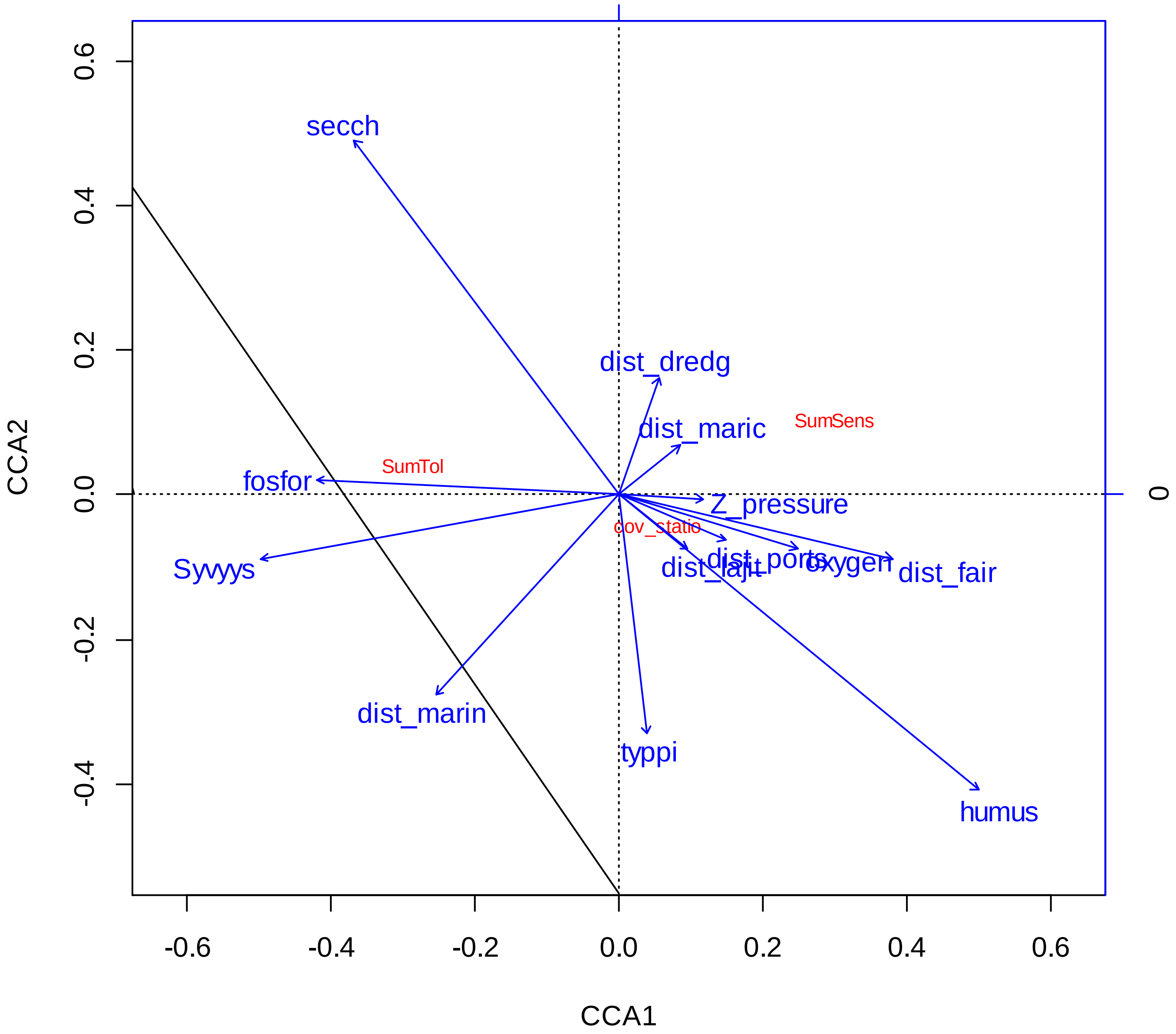

Figure 3. Output of the canonical correspondence analysis (CCA) where the sum cover of sensitive, tolerant and non-categorized species (red text) settle into the ordination graph along the environmental and human activity variables.

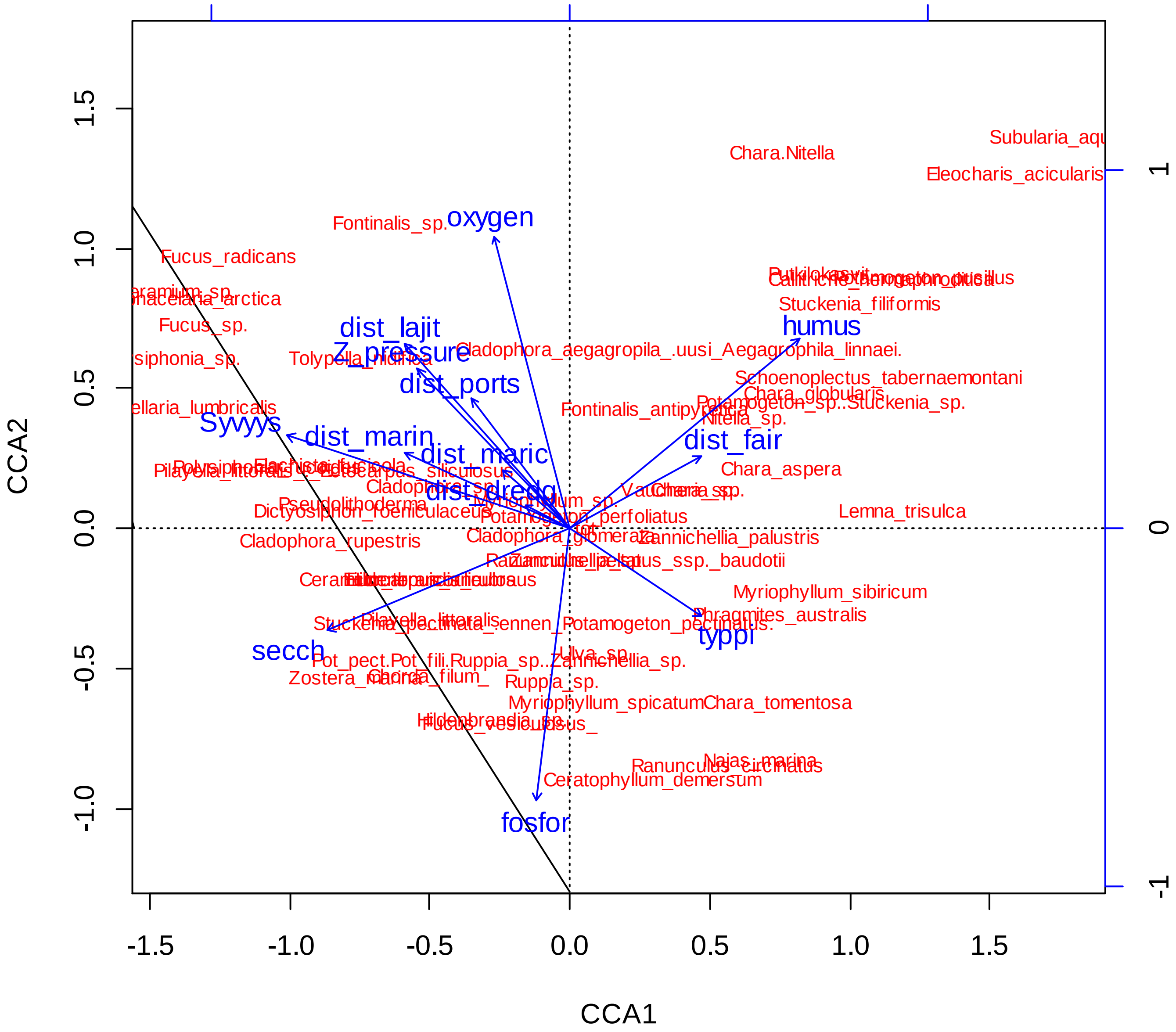

Figure 4. Output of the canonical correspondence analysis (CCA) where species (red text) settle into the ordination graph along the environmental and human activity variables.

6. Sedimentation and turbidity effects on macroalgae

Macroalgae require hard substrates without sediment cover to recruit, settle and prosper. Isaeus *et al.* (2004) tested this with *Fucus serratus* and found clear negative effect of sedimentation in the field and lab experiments. In the field, *F. serratus* stands had 0.2 g dw fine sediment (<0.25 mm) per dm^2 while neighbouring areas without *F. serratus* had 2.4 g dw dm^{-2}. Fucoids are known to sweep sediments from their neighborhood, but the difference gives, however, an indication of the situation of space where *F. serratus* does not prosper. In the lab experiment, the study used 26 g dw fine sediment per dm^2 which efficiently prevented all *F. serratus* settlement. Already a 3-mm layer of very fine sediment has been shown to reduce the settlement, but bigger grain size slightly improved the settlement in the 3-mm layer (Chapman & Fletcher, 2002).

7. Macrophyte indicators under the EU Water Framework Directive status assessments

The status assessments of good ecological status of the three biological quality elements under the EU WFD are based on indicators for macrophytes, macrozoobenthos and phytoplankton. Although the ecological status is not a measure of eutrophication, the indicators in the Baltic Sea have been usually tested (successfully) against it.

Macrophyte growth depends on light availability. This dependency has been shown in several indicator studies and typically also other eutrophication related parameters significantly affect the condition of macrophyte zones. It is not always clear which mechanisms operate behind the observed correlations, but, in addition to the decrease in water transparency, there may be increased sedimentation, decrease in oxygen and altered competition for space. Blomqvist *et al.* (2014) analyzed the responses of several macrophyte species (their depth distribution) and the cumulative algal cover to changes in water quality parameters (Secchi depth and concentrations of chlorophyll a, total nitrogen and phophorus). They found several statistically significant correlations, which show that the depth distribution and cumulative cover are valid indicators for assessing eutrophication effects. Hence, there are good arguments also to use either the macrophyte indicators or the water quality indicators to measure the state of benthic biotopes (which are characterized by macrophytes).

Cover of macroalgae correlates negatively with chlorophyll-*a* and total nitrogen and positively with Secchi depth in Denmark (Carstensen *et al.* 2014). A clear drop in total and cumulative cover takes place in total nitrogen (TN) concentration of 420 and 308 ug L^{-1}, respectively. The cumulative cover of late-successional species responded similarly as the cumulative cover of all species. The HELCOM TN thresholds for sub-basins in Denmark are ~230-290, but it is natural that the macroalgae cover may even benefit from these larger TN concentrations.

Blomqvist *et al.* (2014) showed significant negative correlation between macroalgal cumulative cover and planktonic chlrophyll a in Sweden. The HELCOM chlorophyll-a threshold for the Northern Baltic Proper is 0.23 ug L^{-1}, which would give the cumulative cover of ca. 30-40 %, which can be assumed as an acceptable macroalgae cover for a habitat. The same threshold for the angiosperms gives a lower cumulative cover (~10 %). In case of opportunistic macroalgae, the correlation was positive and above the chlrophyll-a threshold of 0.23 ug L^{-1} the cumulative cover is over 50 %.

The Secchi depth correlated positively with the cumulative cover of macroalgae; with 6-8 m Secchi depth the cumulative cover was ~40-60 % in the Swedish material (Blomqvist *et al.* 2014).

In conclusion, the WFD macroalgae indicators can be used as proxies for the status of respective habitats and possible thresholds could be derived from the respective HELCOM thresholds for TN, chlorophyll-a and Secchi depth.

8. Adverse effects in pelagic habitats

There are no definitions of pelagic habitats in the Baltic Sea. The HELCOM State of the Baltic Sea report considered the pelagic habitat as a single habitat type that was assessed in sub-basins with a division to offshore and coastal areas (HELCOM 2017). The HELCOM assessment was based on three indicators: cyanobacterial bloom index, zooplankton and phytoplankton chlorophyll *a*.

In principle the same approach could be used for pelagic habitats as for benthic habitats: the definition of adverse effects can be approached from the state point of view, pressure point of view and from the aspect of limiting living conditions (see Chapter 1).

The following <u>state indicators or parameters</u> could be used for the pelagic habitats:

(1) *Indicators of phytoplankton community or taxonomic groups*: the set of HELCOM core indicators does not include any phytoplankton indicator, but some indicators have been developed as candidate indicators. An indicator of changes in the community was developed based on temporal changes of phytoplankton groups (Lehtinen *et al.* 2017). Another indicator focuses on changes in seasonal communities (Jaanus *et al.* 2016) and a third one indicated the diatom-dinoflagellate ratio (HELCOM 2017).
(2) *Zooplankton total stock and mean size:* this indicator is the HELCOM core indicator and indicates changes in the zooplankton community composition.
(3) *Cyanobacterial bloom index:* this indicator has been tested as a core indicator in the HELCOM State of the Baltic Sea report. It is based on the spatial extent of cyanobacterial blooms (from satellites) and the biomass of the blooms (from sample-based monitoring).
(4) *Planktonic chlorophyll a:* the indicator is a core indicator and is used to describe the direct effect of eutrophication.

The <u>pressure perspective</u> is not clear for the pelagic habitats, but nutrients can be considered as a pressure if they are present in excess. Four nutrient indicators are available in HELCOM:

(5) *Total nitrogen:* a core indicator,
(6) *Total phosphorus:* a core indicator,
(7) *Dissolved inorganic nitrogen:* a core indicator,
(8) *Dissolved inorganic phosphorus:* a core indicator.

<u>The limiting factors for living conditions</u> could be described by the light availability for plankton:

(9) *Water transparency with Secchi depth:* a core indicator,
(10) *Turbidity:* this is not a core indicator and may be more applicable in coastal waters where physical disturbance of seabed and riverine plumes elevate turbidity.

Eight of the ten indicators have quantitative GES thresholds in place which allows them to be used to define what an adverse effect for pelagic habitats is. These thresholds are specific for coastal and offshore waters and for sub-basins with different salinity regimes which could be also considered as separate pelagic habitats. Both the coast-offshore gradient and the salinity have strong influence on planktonic communities.

The phytoplankton indicators have typically the difficulty of showing that their changes depend on anthropogenic pressures. This is especially true for community indices where tens of species are aggregated to an index. Lehtinen *et al.* (2017) showed that it has been possible to define a GES indicator of the changes in phytoplankton species composition; the changes of selected taxonomic groups were correlated with the pressures of the pelagic habitat. However, no quantitative thresholds were proposed, but GES was defined on the basis of temporal changes.

Turbidity has not been suggested as a core indicator, but the BalticBOOST project included it in a literature review near a large port construction site in Helsinki (Figure 5). According to the results even relatively small amounts of dredged matter caused highly elevated turbidity values within 2 km from the site (~10 NTU) and even higher beside the dredging area (>90 NTU). Elevated values were found as far as 4-10 km from the site but these were difficult to differentiate from the natural resuspension in the area. The turbidity values depend on the coastal area's exposure to waves, and elevated turbidity values may be a common feature in soft bottom habitats on exposed coasts. Rosqvist *et al.* (2010) showed that the turbidity in water column differed greatly between flads (~1 NTU) and open bays (1.5-4 NTU).

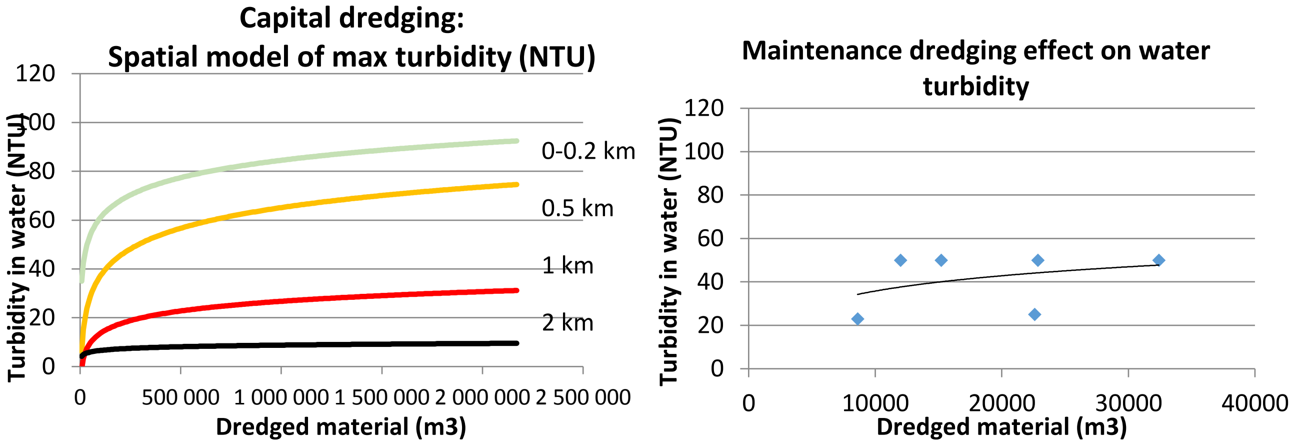

Figure 5. Dependence of water turbidity on dredging activity at different distances from the dredging site. Left panel shows smoothed trendlines from the Vuosaari harbor construction case study and Right panel shows turbidity at the vicinity of a maintenance dredging site in a study by Vatanen et al. 2012.

9. Bottom-trawling fishery

In the SPICE WP4, the analyses did not include bottom trawling fishery because that was already analyzed in the BalticBOOST project and thorough studies have been made in the BENTHIS project and by ICES (ICES 2017). The BalticBOOST analyses found out that spatial overlap of bottom-trawling fisheries and environmental monitoring was only minor and therefore the conclusions were weak. However, in the Gotland area where the trawling intensity was high, the benthic species richness was clearly negatively affected by the trawling. Similar results were found from sea areas in Blekinge and Scania, but there the uncertainty in the results was higher. In Danish Femern Belt, the study concluded that a minor but significant negative correlation existed between trawling and three benthos parameters (number of species and density in the benthic invertebrate community as well as the average individual weight). It is good to note that the studies were made in already fished areas and thus no analysis was made for the effect of fishing on non-fished areas.

The BalticBOOST results also showed that fauna on coarse substrates are affected more than the ones on sandy substrates, and the muddy communities are least impacted. The BalticBOOST analyses included also estimates for damage in benthic invertebrate communities. This showed that already low bottom trawling pressure disturb the communities. Despite the dependencies found in the BalticBOOST approaches, no threshold values were found along the pressure gradient. Nonetheless, the project suggested that environmental targets could also be considered from spatial point of view: how wide area an activity can cover over the seabed or over a specific habitat type? This was particularly exemplified with the bottom trawling case study, where it was estimated that the widely expanding low trawling intensities can have high impacts on benthic communities, while the benefit from the fishing perspective is not high compared to the good fishing areas.

In the scientific literature, effects of bottom-trawling fishery on the state of benthic habitats have been repeatedly shown by several studies (e.g. a meta-analysis by Hiddink *et al.* 2017). One way of defining an impact is establishing where the effects of fishing disturbance go beyond the natural variation of a habitat in the absence of pressure (ICES 2017). As the methods for estimating adverse effects from this activity are well developed elsewhere (e.g. the BENTHIS project, OSPAR BH3 indicator, ICES 2017), here we only summarize some key aspects. The WGBENTH report (ICES 2017) presents a number of indicator results for the EUNIS 3 habitats, but these still lack thresholds for adverse effects.

Garcia *et al.* (2006) state that the effects of fishing are much more severe at the beginning of the exploitation of an area. This was confirmed in the meta-analysis by Hiddink *et al.* (2017), who showed that the decrease of relative abundance of benthic fauna (proportion of benthic biomass of the carrying capacity) followed a logarithmic function; the first trawling events caused greatest decreases in biomass.

The thresholds for bottom trawling are also habitat specific. Benthic communities on gravel substrate are more sensitive to trawling than those on sandy and muddy terrains (Collie *et al.* 2000, Hiddink *et al.* 2017).

Another way of defining adverse effects is in relation to recovery i.e. whether a habitat can recover within a reasonable timescale. Foden *et al.* (2010) estimated the effect from the recovery point of view; they reviewed literature for habitat recovery time from trawling. Table 3 shows the results for the UK marine areas. In their assessment for the 2007 bottom trawling intensity in UK waters, Foden *et al.* (2010) concluded that, in general, sandy and muddy habitats likely recovered in time before the next trawling event, but the gravel, reef and muddy sand habitats did not have time to recover before new trawling. However, if looking at specific gear types, scallop dredging was too disturbing for the sandy habitats to recover in time. They further estimated that circa 90 % of the sandy and muddy area was able to recover before new fishing event, whereas only 20 % of the reef area was able to recover. The study did not, however, consider the long-term effects of repeated trawling, which have been shown to modify the community structure (Hinz *et al.* 2009).

Hiddink *et al.* (2017) estimated the recovery times for different trawl types in relation to the proportion of depleted habitat; recovery from towed dredges is very long (10-15 years) already at low depletion (<50%), the recovery from otter trawls takes considerably less time (1-7 years) depending on depletion %, and the recovery from beam trawls is always relatively quick (< 2 years). It is good to note that these estimates do not separate between habitat types, as in Foden *et al.* (2010).

Table 4. Recovery times in days for five seabed substrates and three bottom trawling gear types. Source: Foden *et al.* 2010.

	Beam trawl	Otter trawl	Scallop dredge
Sand	182	0	2922
Gravel	no data	365	2922

Muddy sand	236	213	589
Reef	no data	2922	1175
Mud	no data	8	no data

Based on the results in several studies, one can attempt to form a definition for adverse effects from ‘mobile bottom contacting gears’ (MBCG).

- Habitat area not touched by MBCGs is obviously in GES (as regards MBCGs).
- Disturbed habitat area seems to be adversely affected even after the first trawling for a certain period of time (i.e. the recovery time) which depends on habitat type. Even though benthic diversity or biomass could be high in some trawled habitats, the sensitive species are adversely affected. This might be more visible in the more detailed EUNIS levels (e.g. level 6) where species or communities define the habitat.
- The recovery time should be defined on the basis of sensitive species of each habitat type.

After the ‘adverse effect’ has been defined, one should define how widely a habitat can be adversely affected and still be in GES. For that kind of ‘extent threshold’, the SPICE cannot suggest any scientific support.

10. Distance thresholds for habitat disturbances

Benthic and pelagic habitats are spatially defined and therefore their status is not only an issue of condition but also of an area. According to the rationale in the MSFD assessment of benthic and pelagic habitats, one should define how widely a habitat is being disturbed or lost (European Commission 2017). In the SPICE WP4, this was tested by analyzing the distance when a state parameter was seen to respond to a pressure. The results are preliminary and limited to a few benthic parameters only in the northern Baltic Sea (Swedish and Finnish coasts).

The results indicate that the pressure impact distances may vary from 0.5 km to circa 25 km depending on pressure type. In many cases the analyses did not reveal any changes in the response parameter and hence distances were not defined. The distance thresholds are listed in Table 5.

The BalticBOOST project made a literature review of the impact distances from human activities (Korpinen *et al.* 2017). Table 6 analyzes the SPICE results against Table 5 results. The SPICE effect distances seem to agree relatively well with the BalticBOOST results, but the variation is relatively high in many cases; probably as a result of local differences in wave exposure, sea bed characteristics, currents as well as the intensity of the pressure and the differences how it was produced.

The SPICE distance thresholds were defined on the basis of benthic vegetation and fauna in soft and hard substrates. Table 5 shows the results separately for the response parameters, but in many cases the results do not target to separate habitats. The physical disturbance pressures have different effects on hard, coarse, sandy, muddy or mixed substrates and these should be remembered when defining the distance thresholds. Based on the literature, one can however make a couple of ‘rules of thumb’:

- hard and coarse substrate habitats are more sensitive to sedimentation (e.g. Eriksson & Johansson 2005) and

- charophyte meadows in flads are sensitive to increased water currents (due to widening the mouth of the bay) and sedimentation and phosphorus inputs (e.g. Rosqvist *et al.* 2010, Rosqvist 2010).

Based on Table 6, it is relatively safe to conclude distance thresholds for a number of activities and pressures. The thresholds can be used to define adverse effects, but the distance thresholds are generalizations from several studies and therefore they may be more applicable in generalized assessments, e.g. covering wide habitat areas.

Table 5. Effect distances from pressures to habitat characteristics.

	Harbours	Nutrient input	Guest harbours	Jetties	Potentially polluted areas	Environmentally hazardous	Shoreline exploitation	Leisure traffic	Shipping lanes	Dredging	Disposal o dredge matter	Mariculture
Sensitive phanerogam species	1 km	-	-	-	3 km	2 km	0.5 km	0.5 km	-			
Number of sensitive species	10 km	-	7 km	-	-	10 km	-	0.5 km	3 km			
Number of tolerant phanerogams	-	-	5 km	1 km	2 km (or 8 km)	12 km	1 km	0.5 km	1 km			
Number of tolerant species	10 km		7 km	1 km	1 km	12 km	1 km	0.5 km	2 km			
BMIa	20 km	-	7 km	2 km	3 km	12 km	1 km (or 4 km)	0.2 km	4 km (or 10 km)			
BMIc	20 km	-	5 km	2 km	4 km	10 km	1 km (or 4 km)	0.2 km	4 km (or 10 km)			
Charophyte cover	-	-	3-5 km	-	-	-	4 km	-	1 km	4 km	-	4 km
Eelgrass cover	-	-	-	-	-	-	0.5 km	-	1 km	-	1.5 km	
Bladderwrack cover	-	-	-	-	-	-	-	-	-	5 km	-	
Cumulative cover of algae	10 km	-	8 km	2.5 km	4 km	11 km	4 km	0.7 km	1 km (or 7 km)			
Cumulative cover of phanerogams	-	-	5 km	1 km	-	-	2 km	0.4 km	2 km			
Cumulative cover of sensitive phanerogams	-	-	-	-	-	-	-	-	-			
Cumulative cover of sensitive species	11 km	-	8 km	1 km	4 km	10 km	4 km	0.4 km	1 km (or 3 km)			
Cumulative cover of tolerant phanerogams	20 km	-	-	-	-	-	-	0.1 km	2 km			
Cumulative cover of tolerant species	11 km	-	11 km	-	-	11 km	0.5 km (or 4 km)	0.1 km	2 km			

Cumulative cover	11 km	-	8 km	1 km	5 km	10 km	4 km	0.1 km	2 km			
Macrophyte Index - Abundance	25 km	-	4 km (or 24 km)	2 km	10 km	12 km	0.5 km (or 4 km)	0.1 km	3 km			
Macrophyte Index – Community for phanerogams	24 km	-	-	1 km	-	-	7 km	0.1 km	5 km			
Macrophyte Index – Community for tolerant species			4 km						2 km		2.5 km	
Macrophyte Index – Abundance for tolerant species			5-7 km				1 km				3-4 km	
Macrophyte Index – Abundance for sensitive species			3 km						3 km	10 km		9 km
Macrophyte Index – Community for sensitive species			2.5 km				1 km		3 km	4 km	10 km	8 km
Macrophyte Index – Community	15 km	-	4 km (or 17 km)	2 km	7 km	11 km	5 km	0.1 km	5 km			
Mytilus coverage	12 km	-	-	-	-	13 km	2-4 km	-	4-10 km	4-10 km	1-2 km	
Benthic invertebrate community (BBI, S, H’, total abundance)	-	-							1.7 km		(10 km)	4 km
Brackish-water Benthic Index (BBI)		10 km								0.6 km		

Table 6. Synthesis of the effect distances and comparison with the BalticBOOST literature review.

Activity / Pressure	SPICE result	BalticBOOST result
Dredging (capital and maintenance)	typically 4-5 km (up to 10 km for sensitive species)	3 km for benthos, vegetation and turbidity and-4 km for fish
Sand and gravel extraction	no result	2 km for benthos, 3 km for vegetation, 4 km for fish and 5 km for turbidity
Disposal of dredged matter	typically 1-4 km (up to 10 km for sensitive species)	2 km for turbidity, 3 km for vegetation and benthos and 4 km for fish
Shipping and ferry traffic	typically 1-5 km (up to 10 km)	0.3-1 km
Harbours	typically 10-25 km	no results
Leisure boating	0.1-0.7 km	0.5 km
Marinas	2.5- 8 km (up to 11 km)	0.5 km for fish nursery and vegetation
Mariculture (fish farms)	4-9 km	no results
Shoreline exploitation	0.5-5 km	no results
Jetties, breakwaters, etc	1-2.5 km	no results
Potentially polluted areas	2-5 km (up to 7-10 km)	no results
Environmentally hazardous business	2-13 km	no results
Wind turbines (operational)	no results	0.1 km (abrasion effect)
Mobile bottom contacting gears	no results	0.1 km for sedimentation; local for abrasion

11. Recovery times as the thresholds for habitat assessments

The habitat recovery is also a factor which can be used (in combination with adverse effects) to define assessment thresholds. A short-term effect may not leave any lasting impact on the organisms or the abiotic features of the habitat. Therefore one could define a threshold for the combination of the duration of the pressure and the resilience of the system. This may be easiest to measure on terms of the recovery times. Fishing related recovery times were discussed above and this chapter focuses on non-fishery pressures.

The BalticBOOST project reviewed recovery times from physical pressures and it was noted that consistent patterns in recovery are hard to find. The recovery time is affected by at least the following factors:

- the substrate characteristics of the site before and after the disturbance (e.g. a sediment disposal changes the seabed substrate and recovery depends on natural sedimentation or natural relocation of the new substrate on a dispersive seabed);

- the topography of the site before and after the disturbance (e.g. an extraction pit will fill up or a sediment mound will smooth down and the duration depends on the amounts of material and the seabed exposure to waves and currents);
- the wave or current exposure of the site: sediment resuspension (i.e. turbidity) will settle down quicker in a sheltered location, sediment plumes will spread further in an exposed location, resuspension of the settled fine matter will be more common and last longer in exposed sites;
- the isolation from the sea (e.g. in coastal lagoons and flads) may be altered due to dredging and its recovery time (if allowed) depends on sediment dispersal and currents.

New substrates are not discussed here, as it is controversial whether they actually recover, even though they can host new and rich community.

Recovery times from aggregate extraction can take fairly long time. It was estimated that in the high-energy environment in North Sea the recovery takes 7.3 ± 2.39 years (mean and SEM) in sand and 9.0 ± 2.1 yr in gravel seabeds (Foden *et al.* 2010). In more sheltered Baltic Sea areas, Virtasalo *et al.* (submitted) estimated that the recovery of a mud/till seabed had not taken place after 7 years after cessation of sediment disposal even if natural sediment had slowly started to accumulate. According to the same study, sediment disposal onto a dispersive seabed site caused slow relocation of the sediment and no natural sedimentation takes place (thus, recovery will probably take place once all the disposed sediment has moved away).

Hypoxia causes partial or total defaunation of seabed communities. Recovery after total defaunation lasted about 2 years in Oslofjord (Josefson *et al*. 2009). Frequent hypoxic events in the Gulf of Finland have prevented the benthic communities from recovering beyond the early successive state (Finnish Environment Institute monitoirng data) and this may lead to gradual decrease of the ecosystem functions in the area (Villnäs *et al.* 2013).

12. Challenges and recommendation in defining adverse effects

The SPICE WP4 results have been based on project's own analyses as well as on literature syntheses. The relationship between physical disturbances and the state of the biotopes is a complex analysis where local environmental conditions are important to take into account and different responses of habitat classes may require separate analyses.

To support further development of habitat assessments, the following observations were made:

i. Challenge: Environmental variability in spatial analyses of pressure-state links is typically strong. In case of the physical disturbance pressure, this is especially true for coast-offshore gradients and exposure gradients. This was also found in the BalticBOOST literature study where >420 state-pressure links were analyzed from >120 published reports (Korpinen *et al.* 2017). Recommendation: Limit the analysis to similar environmental conditions or take those into the model.

ii. Challenge: The data sets of pressures, their effects and the environmental monitoring rarely meet in space. In the northern Baltic Sea, where bottom-trawling is not practiced, it was observed that the spatial disturbance effects from other types of human activities are too small to be appropriately noticed in the state assessments. As shown above, the benthic invertebrate indices showed good status already 600 m from a dredging site (in a semi-open coastal area); such a small scale is not easily captured in any spatial analysis. The SPICE WP 4 analysis was made with the Finnish physical disturbance data which is most data intensive data set of that pressure in the Baltic Sea (including also the small-scale dredging, which can be carried out without a permit). This data was analyzed against the Finnish underwater biotope inventory programme VELMU which has covered tens of thousands of species sampling sites. Even with this data set, the links between physical disturbance and habitat status were found weak. Recommendation: Analyze the pressure responses with spatially and temporally limited data and ensure that the pressure and status data meet within the recovery time in order to see any effects.

iii. Challenge: The temporal effect of the physical disturbance is typically short. This is particularly the case in exposed areas which are usually monitored in the marine status monitoring. In MSFD the biotopes are assessed in the temporal scale of 6-years, but the biotope analyses should be made in the temporal scale of less than a year (probably within a growing season) in order to see any effects. In the current pressure databases in the Baltic Sea, the pressure timing is not recorded in sufficient detail. For larger construction projects, the activity days can be recorded, but this is typically found only in paper reports. Recommendation: Ensure that the data set is suitable for the analysis. All non-dated pressure or status data causes possible noise in the results.

iv. Challenge: The adverse effects of bottom-trawling on the benthic biotopes are shown by tens of studies worldwide. In the Baltic Sea, this was analyzed in the BalticBOOST project, where the previously mentioned difficulty in spatio-temporal data analysis was also observed. The benthic sampling was predominantly placed on shallower waters than the bottom trawling areas, which made any analyses of adverse effects limited. There were, however, areas in Gotland, and possibly elsewhere, where high bottom-trawling intensity resulted in poorer status of benthic invertebrate fauna. A specific analysis in the Femern Belt area showed also that several benthos parameters were negatively affected by the bottom-trawling, though the effect was relatively weak. However, the limited data covered most likely only areas which have been frequently fished. Therefore the effect of bottom-trawling on habitat quality (and especially on its sensitive features) was not included. Recommendation: Use literature evidence for the effects on sensitive species and their recovery times and model the effect.

As the assessment of habitats is supposed to be made in sub-basin scale (i.e. sub-divisions in the Commission Decision on GES criteria, 2017/847/EU), the analysis would require large spatial data sets of pressures and several types of habitats (or more detailed HUB biotopes), and usually also a time period of 6 years. At the moment, the definition of adverse effects and thresholds possibly derived from it has been linked to a limited number of habitats, which are better known than others. This report has shown that the adverse effects cannot be shown for the ‘broad habitat types’ but require more detailed habitat classification. On the level of broad habitats, the sensitive species and their responses to pressures are different.

Using the SPICE approach to integrate the more detailed HUB classes into broad habitats, it is possible to meet the requirements of the MSFD GES assessment. The SPICE integration rule does not require that all HUBs are assessed but a subset can be used. Obviously, this decreases the confidence of the assessment result but may be considered as the first step. The SPICE integration rule also allows qualitative or semi-quantitative assessment approaches where numeric thresholds are not required.

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