Structure and function of benthic habitats – towards a more comprehensive assessment of MSFD descriptor 6 in Swedish coastal waters

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INTRODUCTION

The EU Marine Strategy Framework Directive (MSFD, 2008/56/EG) is the EU legal instrument that should ensure that human activities do not threaten the state of European marine ecosystems, including the seafloor. According to the MSFD, seabed status is assessed in two of the 11 so called descriptors (D1 and D6) and has a significant role in determining environmental status of the marine environment (Commission Decision 2017/848/EU).

In Sweden, the Agency for Marine and Water Management is responsible for producing an initial assessment according to the MSFD and its national implementation (Havsmiljöförordningen). The units D1 (biodiversity) and D6 (seafloor integrity) are compulsory in the assessment. There are five criteria for the assessment of benthic habitats according to D6, of which the most comprehensive is D6C5: *The extent of adverse effects from anthropogenic pressures on the condition of the habitat type, including alteration to its biotic and abiotic structure and its functions (e.g. its typical species composition and their relative abundance, absence of particularly sensitive or fragile species or species providing a key function, size structure of species), does not exceed a specified proportion of the natural extent of the habitat type in the assessment area*. The assessment will be executed in subdivisions of the regional seas. Habitat types should be assessed on a relevant scale within the assessment units.

Despite its importance in the overall assessment, the sea-floor integrity descriptor is one of the less implemented descriptors in the two Swedish sea regions, the Baltic Sea and the North-east Atlantic Ocean as well as across Europe. The lack of implementation for the sea-floor integrity descriptor is mainly attributed to data and knowledge deficiencies as well as methodological difficulties. To date, the Swedish assessment of D6 is incomplete, lacks indicators and is associated with undefined uncertainties. In the latest initial assessment, a robust assessment of benthic habitats is missing, mainly due to lack of data. However, during the past two years there has been a considerable increase in data collection and mapping, both in terms of species and habitats (NMK) as well as on relevant pressures in the coastal zone (Törnqvist et al., 2018). A characteristic feature of Sweden's aquatic habitats is the presence of ca 270 000 islands (Statistics Sweden, 2013) and several sources such as worldatlas.com claims that Sweden has the most islands in the whole world. More than 100 000 of Sweden's islands are located in the marine environment (Statistics Sweden, 2013) and form large archipelago areas in both the Baltic Sea and the North Sea giving Sweden the longest coastline in the EU (28458 km or ca 22 % of the EU total coastline; Table 1).

Table 1. Statistics for the EU Member States with marine areas. Coastline length and marine areas based on data from EEA (EEA_Coastline_20170228.shp) and Flanders Marine Institute (https://doi.org/10.14284/403), data on population and GNP from the year 2018 obtained from data.worldbank.org.

Member State	Coastline length (km)	(%)	Marine area (km^2)	(%)	Population	(%)	GNP sum (USD)	(%)
Belgium	90	0.1%	3492	0.1%	11433256	2.8%	5.97433E+11	3.3%
Bulgaria	455	0.4%	34746	0.6%	7025037	1.7%	1.56693E+11	0.9%
Croatia	5778	4.5%	55648	1.0%	4087843	1.0%	1.14932E+11	0.6%
Cyprus	755	0.6%	98478	1.7%	1189265	0.3%	45802501374	0.2%
Denmark	7995	6.2%	371843	6.6%	5793636	1.4%	3.31503E+11	1.8%
Estonia	2882	2.2%	36473	0.6%	1321977	0.3%	48064476464	0.3%
Finland	25532	19.8%	81849	1.5%	5515525	1.3%	2.73291E+11	1.5%
France	7723	6.0%	345178	6.1%	66977107	16.3%	3.11092E+12	17.0%
Germany	3662	2.8%	56601	1.0%	82905782	20.1%	4.51479E+12	24.6%
Greece	15716	12.2%	483759	8.6%	10731726	2.6%	3.2579E+11	1.8%
Ireland	7261	5.6%	427414	7.6%	4867309	1.2%	4.11092E+11	2.2%
Italy	8761	6.8%	537128	9.5%	60421760	14.7%	2.58594E+12	14.1%
Latvia	513	0.4%	28300	0.5%	1927174	0.5%	59250542695	0.3%
Lithuania	243	0.2%	6818	0.1%	2801543	0.7%	1.00385E+11	0.5%
Malta	233	0.2%	52934	0.9%	484630	0.1%	21100068067	0.1%
Netherlands	1705	1.3%	62277	1.1%	17231624	4.2%	9.91942E+11	5.4%
Poland	937	0.7%	29772	0.5%	37974750	9.2%	1.20592E+12	6.6%
Portugal	3277	2.5%	1728852	30.7%	10283822	2.5%	3.52448E+11	1.9%
Romania	481	0.4%	29754	0.5%	19466145	4.7%	5.65711E+11	3.1%
Slovenia	54	0.0%	215	0.0%	2073894	0.5%	80361841186	0.4%
Spain	6158	4.8%	1008337	17.9%	46796540	11.4%	1.89449E+12	10.3%
Sweden	28458	22.1%	155605	2.8%	10175214	2.5%	5.47507E+11	3.0%
	128670	**100%**	**5635474**	**100%**	**411485559**	**100%**	**1.83354E+13**	**100%**

The complex mosaic of islands and land in the Swedish archipelago areas creates specific challenges for marine status assessments, especially on spatial data resolution and quality, and assessment approaches as well as data resolutions suitable for large homogenous offshore areas are clearly insufficient or even misleading.

The aim of this report is to support the next assessment of benthic habitats by providing suggestions on use of available data, thresholds and aggregation principles to achieve a measurement of adversely affected area per broad habitat type. Additionally, we describe the current gaps of data and knowledge as well as a potential roadmap for the coming years that may enable a comprehensive assessment of D6 in Sweden.

1. DEFINITION OF SUITABLE SCALES

The spatial scale and resolution at which status assessors frame their analyses is driven by several considerations. In many cases, the selection of scale to be used is among the most important decisions but is based on pragmatic assumptions constrained by legal and practical circumstances. With increasing value being placed on consideration of spatial scales in status assessments, the need to define a scale that balances analytical and ecological realities is imperative. The scale of assessment is often defined based on ownership boundaries, ecological, or habitat boundaries and/or physical and hydrogeological boundaries (e.g., watersheds or water bodies). Defining the spatial scale based on the scale of ecological effects on a population offers an opportunity to improve the ecological relevance and defining the scale based on effects from individual activities allows opportunities to assess the potential for (site specific) measures targeting relevant individual pressures. To relate the question of spatial scale for the assessment to the Swedish MSFD descriptor 6 contexts, the reporting requirements are on the scale of sea regional area (Baltic Sea and North Sea). While a specific activity may be detrimental to the ecological function of an enclosed bay, it alone will not affect the status on a sea level scale. In order to improve the environmental status on the reporting requirement scale, it is necessary to both identify many individual activities as well as carry out appropriate measures to reduce the combined impact.

Projects and initiatives such as HELCOM SPICE, HELCOM BOOST, HELCOM Baltic Sea Impact Index, HELCOM HOLAS, EcApRHA, BENTHIS and SYMPHONY have all addressed the issue of scale in seafloor assessments of the Swedish marine environment. However, at a rather broad scale both in terms of spatial resolution and ecosystem components, especially regarding coastal ecosystem. We here focus on coastal habitats and physical pressures on their associated species and biotopes. There is thus a need to downscale the pressure-response relationships to ecologically relevant levels (meter scale rather than km scale) and use the large amounts of high-resolution spatial data produced in Sweden during the last years.

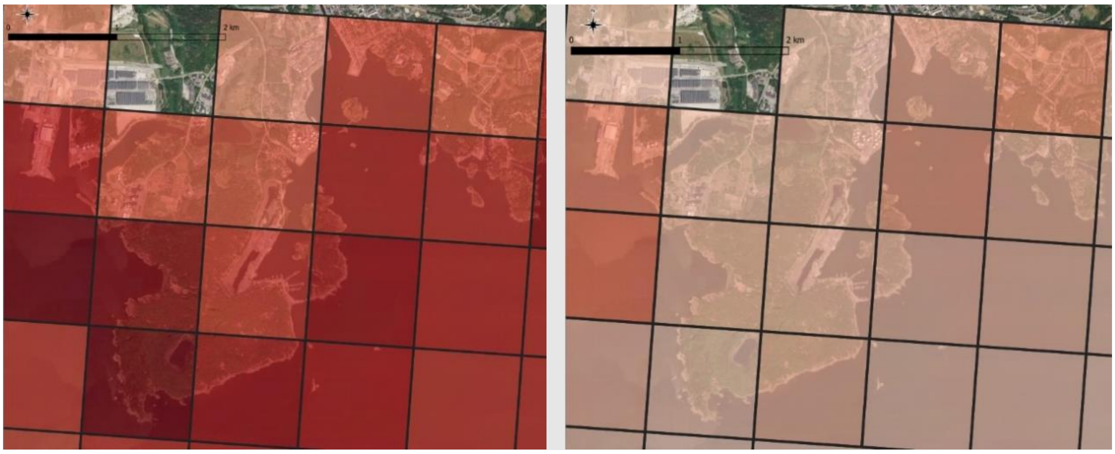

Figure 1. The spatial scale used for the 2018 HELCOM assessment showing Karlshamn harbor in the Baltic Proper and its assessed Baltic Sea impact index (BSII) values between 26-64 in red tones to the left, darker hues mean higher impact. Baltic Sea Pressure index (BSPI) is shown to the right with low index values also for the cell covering the heavily industrialized oil harbour. Background satellite image map ©2020 TerraMetrics.

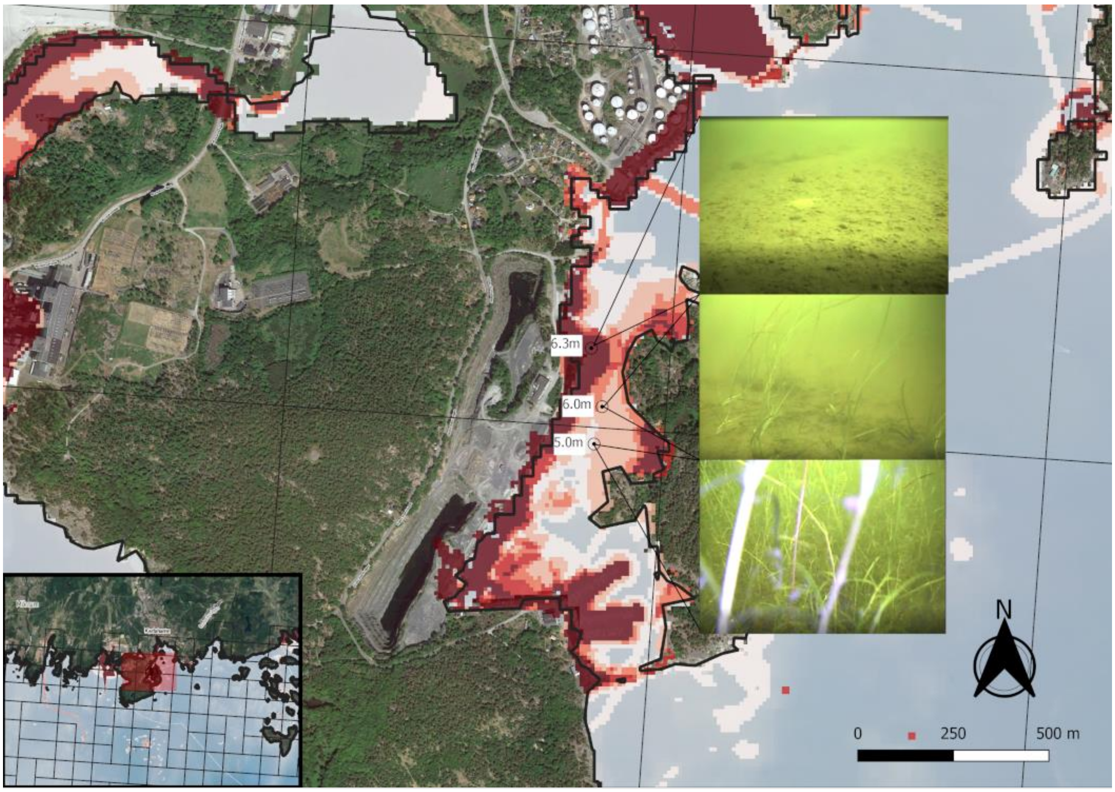

Figure 2. Physical disturbance index according to Törnqvist et al., (2018) with its assessed impact values between 1-5 in white to red for Karlshamn marina in the Baltic Proper (central part of Figure 1). Images from three underwater video inventory points were available within a 250 m radius, showing how Zostera marina *coverage varies from 0-100% due to variation in depth as well as physical pressure intensity. Grid lines show cells used in the HELCOM BSII. Background satellite image map ©2020 TerraMetrics.*

Examples of spatial data that are openly available and have been used in assessments of Swedish marine waters include the Broad Habitat Types mapped by the EU Seamap project (see Figure 4), activities and pressures compiled by the work related to the HELCOM Baltic Sea Impact Index (BSII) as well as the similar project SYMPHONY. The resolution of these spatial data is coarse in comparison to what is ecologically relevant in coastal areas (see Figure 1 and 3 for examples). Furthermore, when aggregating combined effects to larger grid cells it is important to consider how this should be made as average effects within a larger grid cell may be very small while on the other hand using the maximum value gives large overestimations of possible impact.

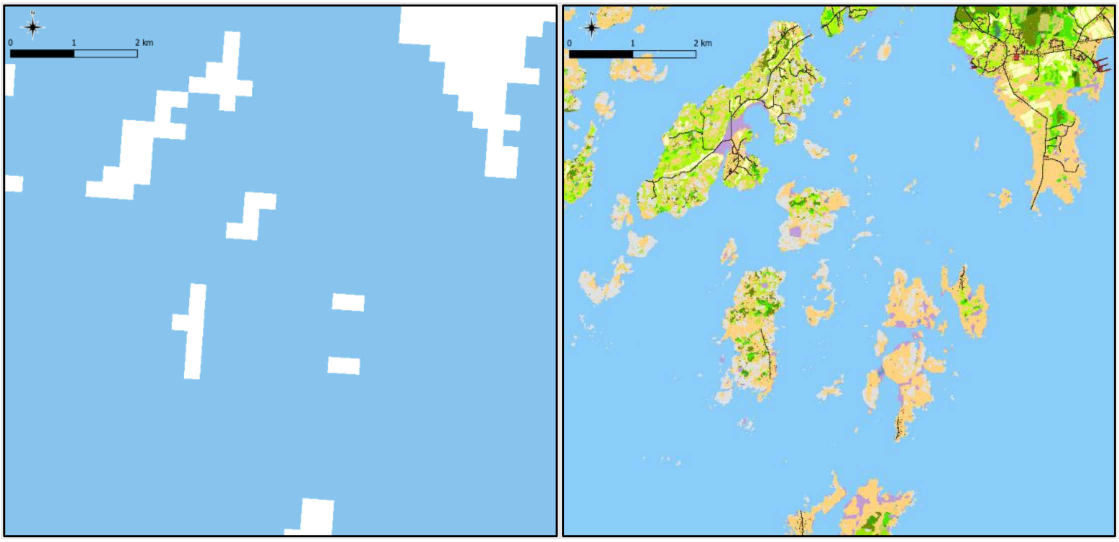

Figure 3. Example from Blekinge archipelago near Torhamn of areas classified as marine (blue) on a 250 m resolution in the SYMPHONY-project (left) and at 10 m map resolution in the Nationella Marktäckedata project (right). For a typical archipelago area in Sweden, 250 m resolution is not enough to depict reality at an adequate level of detail.

The Swedish national project for land cover mapping Nationella Marktäckedata (NMD) has in May 2019 finalized a first version of standardized information on land cover and its use on a national scale at 10m cell resolution, which is a great step forward beyond CORINE land cover. Using a 10m cell size resolution brings the data down to ecologically relevant scale. Even 10m is an ecological generalization, especially in the Swedish part of the Baltic Sea where abundant areas with glacial deposits (till) occur. In these areas finer sediments often co-occur with rocks and boulders, creating a mosaic landscape of soft and hard substrate relatively uncommon in other European sea areas. Sweden's long and complex coastline is also challenging. Furthermore, due to legislation concerning national security, high-resolution bathymetric and substrate data (i.e. finer cell resolution than approximately 500 m) is classified information in Sweden and any analyses including such data as well as any results in form of spatial maps needs permits from several national authorities in order to be allowed for distribution.

Based on discussions in various national and international forums[1], there seems to be an overall agreement that the analysis of benthic habitats should, if possible, be based on map data in 10 m resolution. For national or regional assessment this is probably the finest scale that presently can be used from a practical (computational) view, but if finer data is available this could possibly be used if the aggregation principles allow for it. With coarser data on pressures and physical parameters, there is a risk that the information is no longer ecologically relevant, as it gets smeared out over too large areas compared to the distribution of environmental habitats and associated biota (see Figures 1-2).

[1] Workshop/dialog om SGU:s nya substratmodeller, Oct 2 2019,; HELCOM workshop on benthic habitat mapping, Nov 12-13 2019; Third Meeting of the HELCOM Expert Network on Benthic Habitats, Nov 14-15 2019.

For the Swedish assessment, the 25 Water Framework Directive coastal water bodies (HVMFS 2017:20) and the 12 offshore waters (HVMFS 2014:14) constitute units on a scale that we deem possibly relevant for status assessment of benthic habitats according to the MSFD, equivalent to the use of ICES C-squares or other grid systems. The water bodies are delineated based on generalizations of environmental parameters such as salinity, bathymetry, hydrographic conditions, morphology, wave exposure and ice conditions, and thus partly reflect strong gradients in natural conditions relevant also for the MSFD assessment. The environmental status of the waterbodies could then be aggregated to HELCOM assessment units, marine spatial planning areas or nationally, to reflect overall status of the broad habitat types contained within the waterbodies. To allow for sustainable use, not all water bodies may need to be in good status, but the overall status of a BHT across all water bodies in an aggregated assessment unit must be good. The water bodies (or their equivalent) are hereon referred to as the Minimum Assessment Unit (MAU), as opposed to the aggregated assessment units used in reporting (AU).

2. DEFINITION OF RELEVANT PRESSURES

Relevant pressures

The pressure intensity on benthic habitats varies greatly across different areas of Sweden and habitat sensitivity also vary along environmental gradients. To achieve a relevant assessment of impacts, ecosystem components and their associated structure and function as well as the pressures affecting them need to overlap in space and time, and the ecosystem components monitored need to respond to these pressures. With mismatching scales in space, time, or information depth, the response might easily be masked due to random noise.

An extensive compilation and analysis of coastal activities and their resulting pressures have been made by Törnqvist et al., (2018). The aim of the compilation was to create useful, homogenous, and fair information with full spatial cover on physical activities and associated pressures and their impact on the seafloor. This work resulted in a map of physical disturbance of the seafloor, in 10 m resolution (5 disturbance classes). To date this is the most relevant disturbance layer we have access to, as it is produced on a scale that is relevant for the biological processes that are likely to be impacted by said pressures. The analysis includes identification and mapping of relevant physical pressures, definition of buffer zones and classification of degree of impact on hydrological conditions, morphological conditions, and connectivity. Note that pressures related to off-shore activities such as bottom trawling are also of very high relevance for the assessment of seafloor integrity but are not the focus of this report as we here concentrate on pressures from coastal activities, which likely have not been adequately addressed in previous status assessments of Swedish marine waters.

In this report we have tested the relevance of the impact on morphological conditions for benthic organisms.

We use the morphological impact layer from Törnqvist et al., (2018) to assess status according to D6C3 for all Swedish coastal waterbodies. The status classification was then checked against the prevailing pressures in each water body.

3. DEFINITION OF SUITABLE BIOTOPES, KEY SPECIES OR INDICATORS TO BE USED IN ASSESSMENT

Seafloor integrity status according to the MSFD is to be assessed as proportion of seafloor per broad habitat type that is not adversely affected by human-induced pressures. Currently, compiled information is lacking for most steps in the assessment, from the actual distribution of habitats to sensitivities of ecosystem components to pressures, and high-resolution spatial information of the activities causing these pressures. There is also a need to suggest biotope complexes, species groups or other ecosystem components to represent the status for a given broad habitat type, and a framework for using those sub-types to account for status at a broad habitat type scale. In this report we test the response of several ecosystem components to physical disturbance pressures, both based on data as is and on modelled distributions of species and biotopes

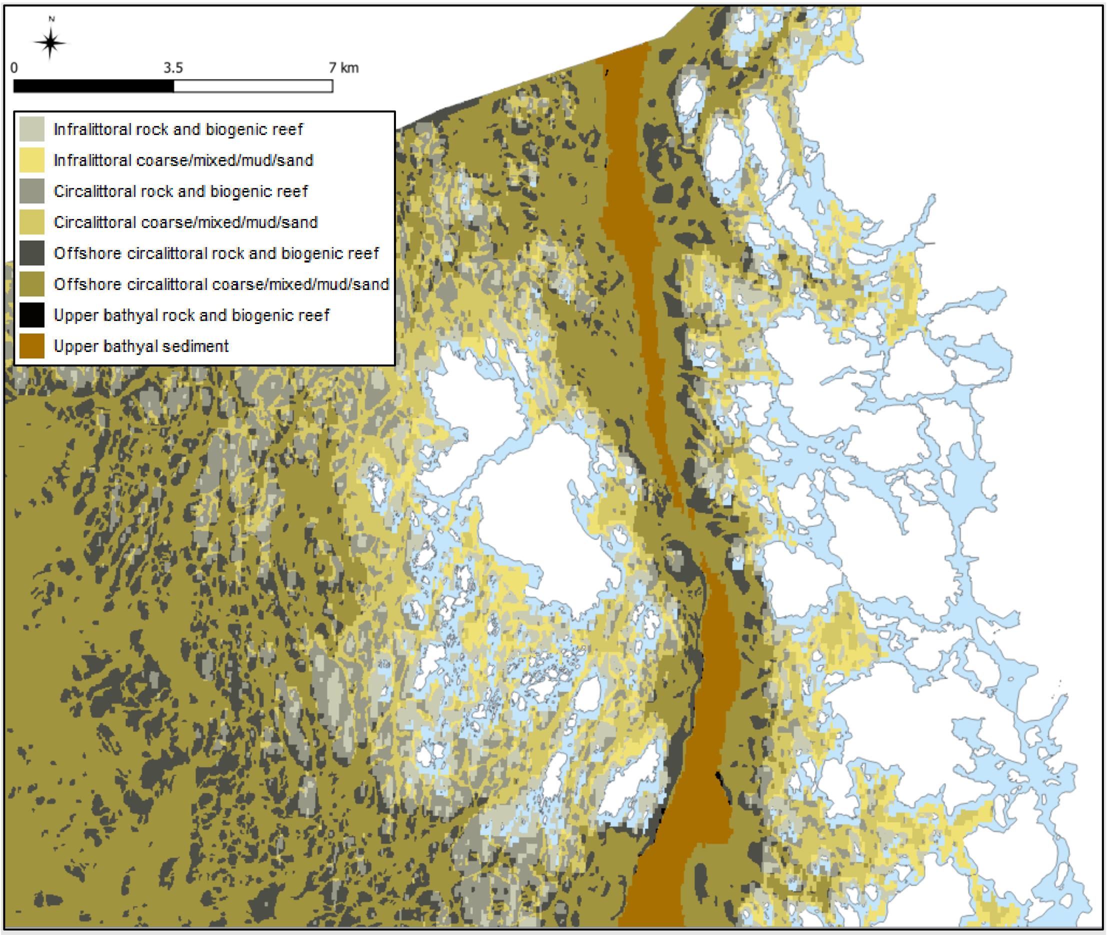

Figure 4. Example of broad habitat types/substrates for the Koster national park area and Strömstad archipelago according to data available from EMODnet. Blue areas are marine waters where information is unavailable, covering most of the archipelago, including the areas under most anthropogenic physical pressure as well as being ecologically sensitive areas.

On a HELCOM level, experts have concluded that vegetated hard substrate, vegetated sand/soft, hard substrate with epifauna and sand/soft with infauna (equivalent to HUB level 4) are habitats that should be assessed in the respect of potential measures[2]. This allows for use of more specific national indicators to assess status and sufficiency of measures for these habitats. For the Swedish west coast, sand/soft substrate with epifauna might need to be added.

Within the above categories, several different plausible species and biotopes exist, of which some respond more to physical pressures than others. We tested the response of submerged rooted plants to a gradient in physical pressure (morphological condition). As response variable we used a combination of different species of vascular plants (in Blekinge) or eelgrass meadows (along the Swedish Skagerrak coast), to evaluate potential impacts on benthic species from physical pressures.

4. TEST OF INDICATORS

As several pressures as well as natural gradients in temperature and salinity covary in space, defining indicators that properly respond to status, let alone single pressures, is a complex task. In this report, we try to quantify pressure effects on benthic habitats by creating scenarios of changing pressure, in a pilot area in Blekinge county. We also test the HELCOM pre-core indicator "Cumulative impact on benthic biotopes" (Berg et al., 2018) on *Zostera marina* habitats on the Swedish west coast as well as on submerged rooted plants in the pilot area in Blekinge.

Eelgrass (Zostera marina) on the Swedish Skagerrak coast

Seagrasses are photosynthesising marine flowering plants that grow in soft sediment coastal areas throughout most of the world. Their distribution in depth is limited by light availability, which can be impaired through increased eutrophication and sedimentation in the coastal zone. Other physical pressures such as dredging and the disturbance and fragmentation of habitat through boat mooring buoys and anchoring can also impact the habitat at different spatial and temporal scales (Sagerman et al., 2019).

Around the Swedish Skagerrak coast, eelgrass (*Zostera marina*) is the species most found which can form large, continuous underwater meadows. Eelgrass habitats are important for many different functions and roles within the environment such as sediment stabilisation, carbon sequestration, as well as a habitat for marine organisms (Nordlund et al., 2016), including juvenile and sub-adult stages of economically important fish, such as Atlantic cod. However, like many other habitats around the world, seagrass is declining globally (Waycott et al., 2009), with an average worldwide loss of eelgrass of 1.4% annually (Short et al., 2010). The loss of eelgrass on the Swedish west coast has been reported as severe with an average loss of 60% between 1980 and 2000, with up to 80% disappearing in some areas during this time (Baden et al., 2003).

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[2] HELCOM SOM-workshop, part of the third Meeting of the HELCOM Expert Network on Benthic Habitats, Nov 14 2019

The loss of eelgrass on the Swedish west coast has been thought to be heavily coupled to the substantial loss of larger predatory fish due to fishing pressures as well as increased eutrophication. This has caused a shift in trophic food web structure in the seagrass meadows, leading to an abundance of meso-predatory fish (e.g. sticklebacks) and increased filamentous algae growth on the blades of the seagrass (Baden et al., 2012). Recently, heavy investment has been made into trying to restore seagrass meadows in the Swedish Skagerrak through projects such as seed transplanting.

In this report, eelgrass distribution was based upon data collection from the report 'eelgrass distribution in the Västra Götalands county 2008' (Bertelli and Unsworth, 2013; Envall, 2012). These data were based on an analysis of satellite recordings (from SPOT-5) and related to collected biological reference data. Here we only used the 'best qualitative estimation of eelgrass' (according to Envall 2012) from the survey, i.e., pixel values of 7-10. Data were used at a 10 m resolution. Many of these areas have also been subsequently confirmed with the presence of eelgrass through field surveys (e.g. (Staveley et al., 2017). Of note, a large area of the Koster Islands in the northern part of the Swedish Skagerrak were not included in the eelgrass distribution layer from 2008. Therefore, no water bodies in this region were included here due to lack of information. However, eelgrass has been observed in some shallow, sheltered sites throughout this archipelago (*pers. com.* T. Staveley). In addition, water bodies where eelgrass coverage was only modelled for part of the water body area were not included in the analysis.

As the physical disturbance layer (Törnqvist et al., 2018) already incorporates several pressures and take their magnitudes into account, we do not assess the pressures according to the indicator description (Berg et al., 2018). The analysis below is thus a simplification, in the sense that the impact is determined on an already combined pressure layer, not sensitivity of the biotopes to each pressure individually. If the underlying activities and pressures are made public, the analysis could be rerun following indicator description more closely. In this exercise we start at the chapter *The intersection process for impact determination*, where pressure magnitude and biotope sensitivity are intersected according to a matrix.

The physical disturbance layer was divided into 5 classes, where 5 is the highest risk of impact on morphological conditions. In the intersection matrix (

Table 2), classes 1 and 2 were grouped as "very low" while 5 was equivalent to "high".

Sensitivity of the eelgrass was split into 2 categories (

Table 2) based on the wave exposure of the region (data: SWN_EUNIS_NMD, 10 m resolution). Two distinct exposure limits were used based on the potential physical pressures attributed to exposure:

1. High exposure areas (SWN_EUNIS_NMD value >5) were assigned a low sensitivity
2. Low exposure areas (SWN_EUNIS_NMD value ≤ 4) were assigned a moderate sensitivity.

These assignments were based on information on physical pressures from MarLin[3] (e.g. smothering and siltation rates, disturbance of substratum, changes in suspended solids) as well as ecological knowledge of the eelgrass habitat and region.

Table 2 Intersection matrix to combine magnitude of pressure and biotope sensitivity to potential impact on the benthic biotopes (adopted from Berg et al., 2018).

		Magnitude of pressure			
		5	4	3	1-2
Sensitivity	moderate (low exposure)	H	M3	M1	L
	low (high exposure)	M2	M1	L	VL

In the indicator description, the limit for "adversely affected" is set between low and moderate impact of a pressure (red line in

Table 2), which is dependent on the sensitivity of biotopes in combination with magnitude of the pressure in question.

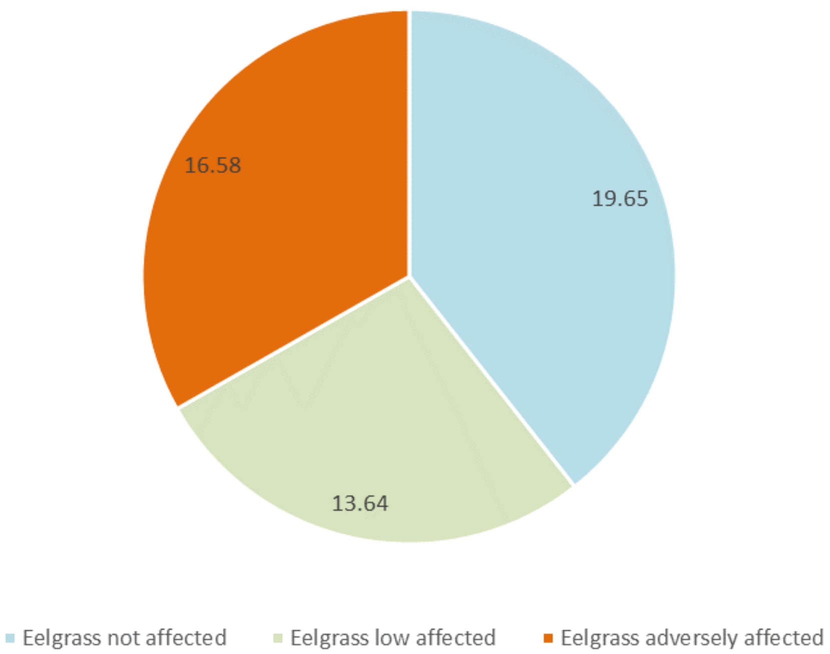

Figure 5. Area of eelgrass (km²) not affected, low affected and adversely affected by physical pressures (based on 85 water bodies).

[3] https://www.marlin.ac.uk/

The amount of eelgrass was calculated and aggregated for 85 water bodies (i.e., those with available data for the whole water body) based upon sensitivity and impact on the Swedish west coast. The above pie chart (Figure 5) shows the amount (km^2) of eelgrass that is classed as adversely affected (orange; H, M1-M3) low affected (green; L, VL) and not affected (blue; not categorised in the pressure index). “Not affected” in this case only refers to “not coinciding with the pressure classes”, as historical impacts are not accounted for it does not necessarily indicate a pristine state. A third (33%) of the eelgrass area throughout the assessed water bodies was classed as adversely affected, while 27% classed as low affected and the remaining area of eelgrass (39%) was not affected (in other words the pressure index layer did not overlap with the eelgrass distribution).

In the indicator report, the criteria for GES to be met is that both 25 % or less of the biotope area is significantly impacted (moderate or higher degree of impact) and 10 % of the biotope area is permanently without impact. We used these thresholds to classify each water body as impacted or not, based on the amount of eelgrass classified as adversely affected and permanently without impact.

The area of broad habitat types per water body was provided by SGU. Based on a non-public fine-scale map of seafloor surface substrate, the area per water body of different substrate types (i.e., soft, sand, coarse and hard) split into the euphotic and aphotic zones were calculated for most water bodies.

The impact assessment is thus not based on exact geographical overlap between the eelgrass meadows and the BHTs euphotic sand and euphotic soft substrate. As eelgrass occurs on both substrates, without spatial substrate information it is not possible to distinguish between the two. Rather, the eelgrass calculations above were used as an indicator for determining the impact status of soft and sand substrate alike in the euphotic zones for each water body. Therefore, if the criteria were not met in a particular water body (based on the eelgrass), that would mean that the total area of euphotic soft and sand sediment in that water body would also be classified as potentially impacted. The total area of euphotic sand and soft substrate impacted and not impacted respectively was then summed for all water bodies on the Swedish Skagerrak coast.

The pie chart below (Figure 6) shows the aggregated amount (km^2) of euphotic soft and sand sediment that meets the criteria (green) and that doesn’t meet the criteria (orange) for the Swedish Skagerrak coast. Approximately 60% of the total area of assessed euphotic sand and soft water bodies are classified as not impacted. Note: only 57 water bodies could be assessed from the original 85 due to substrate data availability.

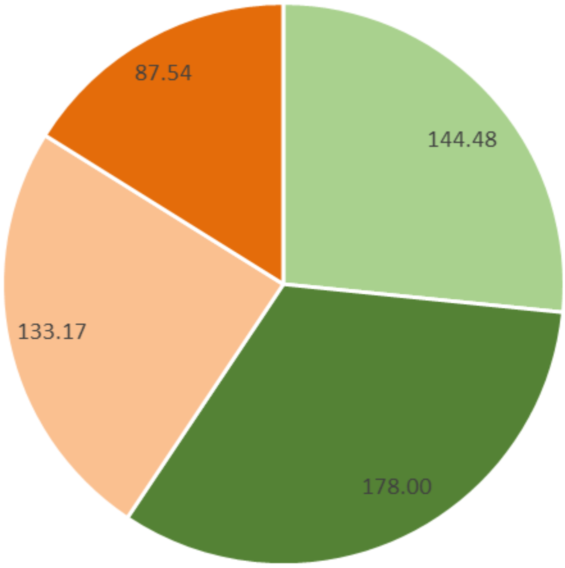

Figure 6. Area of sea floor (km²) that passed or failed the criteria for potential impact, for both soft and sand sediment (57 water bodies). Light green: Soft, not adversely affected. Dark green: Sand, not adversely affected. Light orange: Soft, adversely affected. Dark orange: Sand, adversely affected.

Changes in the assessment of potential impact depend heavily on the cut-off values for each part of the assessment criteria. Such as where the exposure limits (i.e., sensitivity) and to what degree the impacts of pressure are set relating to each BHT. Shifting these could have drastic implications of whether the water body passes or fails, and implications of setting the right criteria should be considered for future evaluations. Since the eelgrass distribution survey was conducted in 2008 some areas will have changed in eelgrass distribution, where the coverage has decreased, for example around the Kungälvs archipelago and Byfjorden near Uddevalla (*pers.com.* Anders Olsson). There may also be over-estimation of eelgrass distribution in some areas where eelgrass was modelled to be present but, does not exist in reality to the given extent (e.g., Fiskebäckskil harbour area). Some water bodies included in this assessment, that have known to have suffered large declines of eelgrass since the 1960s (Baden et al., 2003), have both met and not met the criteria set out in this report. For example, both Sälö fjord and Älgöfjorden, in the Kungsälv area, have lost a substantial amount of eelgrass, however Sälö fjord meets the criteria while Älgöfjoden does not. This raises the question of the historical impact upon the eelgrass and that even though a water body maybe classed as not adversely affected in this assessment, the underlying information shows that much of the habitat has already been adversely affected or lost due to previous impacts.

Vascular plants around the coast of Blekinge and northeast Scania

Information regarding the distribution of vascular plants layer was retrieved from the MARMONI[4] project where vascular plant information was modelled based upon in-situ vegetation surveys and biological, physio-chemical and environmental parameters. In this report, the distribution was based upon a lower threshold of 25% cover of vascular plants. This limit was deemed suitable as the BHT serves as a functional habitat. Habitat cover lower than 25% may not perform the same functional roles in the ecosystem as that of a higher % cover. In this area, 36 water bodies were analysed where vascular plant information was present. Water bodies where vascular plant distribution was only modelled for part of the water body area were not included in the analysis.

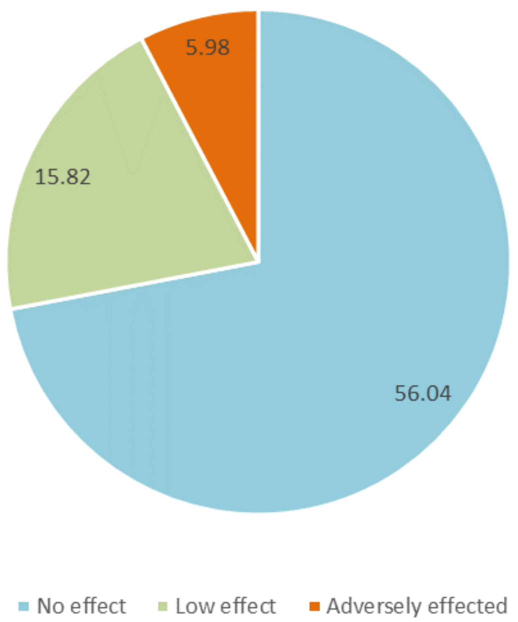

Figure 7. Area (km²) of vascular plants not affected, low affected and adversely affected by physical pressures (based upon 36 water bodies)

The number of square kilometres of vascular plants has been calculated and aggregated for 36 water bodies (i.e. those with available data) based upon sensitivity and physical impact from Blekinge and northeast Scania's coast. The above pie chart (Figure 7) shows the amount (km^2) of vascular plants that were classed as adversely affected (orange; H, M1-M3) low affected (green; L, VL) and not affected (blue; not categorised in the pressure index).

In the indicator report, the criteria for GES to be met is that both 25 % or less of the biotope area is significantly impacted (moderate or higher degree of impact) and 10 % of the biotope area is permanently without impact. We used these thresholds to classify each

[4] http://marmoni.balticseaportal.net

water body as impacted or not, based on the area of vascular plants classified as adversely affected and permanently without impact.

From the investigated 36 water bodies, the vascular plant biotope met these criteria in all but 3 water bodies.

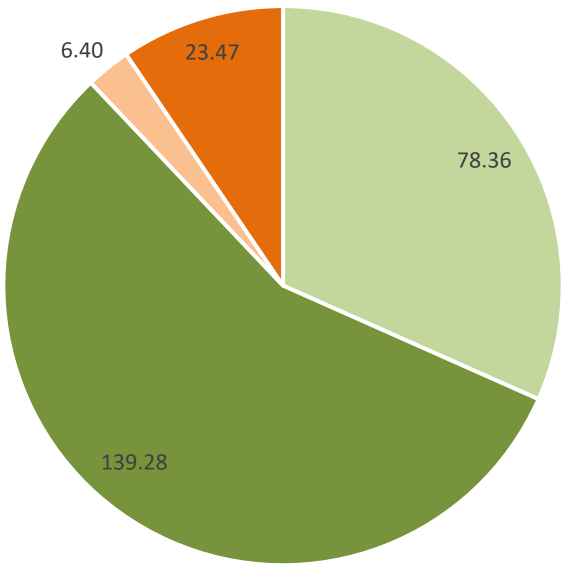

Figure 8. Area of sea floor (km2) that passed or failed the criteria for potential impact, for both soft and sand sediment (23 water bodies). Light green: Soft, not adversely affected. Dark green: Sand, not adversely affected. Light orange: Soft, adversely affected. Dark orange: Sand, adversely affected.

The impact assessment of vascular plants was then used as an indicator for determining the impact status of soft and sand sediment in the euphotic zones in a water body. Therefore, if the vascular plants in a particular water body did not meet the criteria, the total area of euphotic soft and sand sediment in that water body would be considered adversely affected. Substrate data was not available in all water bodies in this region, therefore only 23 (out of 36) could be analysed further with regard to substrate type. The pie chart above (Figure 8) shows the aggregated amount (km^2) of euphotic soft and sand sediment that meets the criteria (green) or not (orange) for the study area. Of the 23 water bodies that remained, two were left that did not meet the criteria. Of these two, one (water body 584) was represented by a very small proportion of vascular plants throughout the water body, however the areal extent of the water body was relatively large (see map below).

In addition, it is worth noting that some water bodies contain a very low proportion of vascular plants. As an example, if the cut-off point was set to <1% vascular plant distribution of the total area of euphotic sand and soft habitat, then 4 water bodies would be excluded from the analysis (see Figure 9). However, this poses the question on the relevance and appropriateness of including water bodies that have a low proportion of BHT, which can result in potentially large areas of a benthic substrate being classified as adversely affected. The pie chart below (Figure 10) shows the same information as the previous above (Figure 8), however with the 4 water bodies that had <1% vascular plants removed. As these 4 water bodies represented such large areas it is clear to see the implications of this particular cut-off boundary on the total area or proportion of water bodies that can be classified as impacted or not. As some of these water bodies have high exposure these may not be suitable to include in assessments.

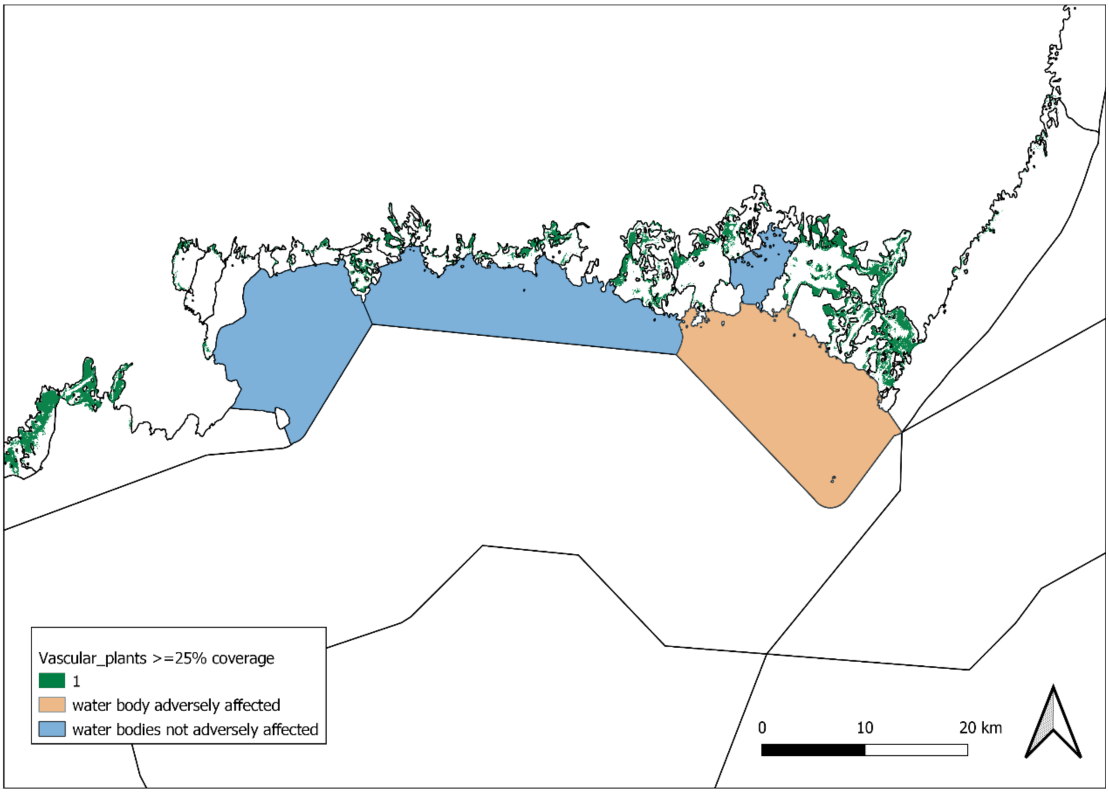

Figure 9. Prediction of >25 % coverage of vascular plants (green areas). The 4 colored water bodies do not meet the criteria of at least 1 % vascular plant distribution of the total area of euphotic sand and soft habitat, and were thus excluded from further analysis. Of those, three water bodies would have passed the criteria (blue) and one failed (orange).

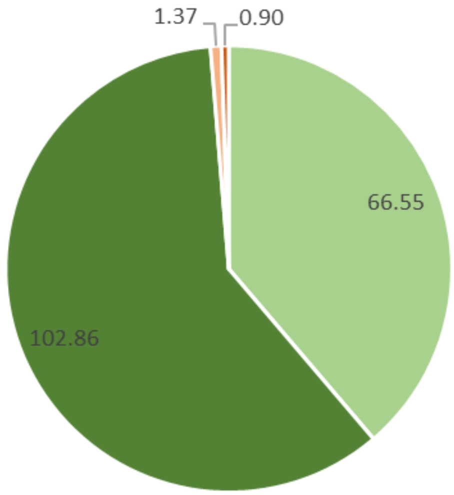

Figure 10. Area of sea floor (km²) that passed or failed the criteria, for both soft and sand sediment (>1% vp in wb) (19 water bodies). Dark green: Sand, not adversely affected. Light orange: Soft, adversely affected. Dark orange: Sand, adversely affected.

The effects of high disturbance on vascular plants in Blekinge could be different to that of eelgrass on the west coast. Perhaps due to a shift in community structure as well of habitat loss. While in eelgrass high disturbance will most likely lead to direct habitat loss, in the Blekinge archipelago, Sago pondweed *Stuckenia pectinata* is a common species which is relatively tolerant to physical disturbance and likely would increase its relative abundance with pressure.

5. AGGREGATION OF ASSESSMENT

Status assessment needs to be executed on a spatial and thematic scale that is ecologically relevant and where it is possible to identify pressure-response relationships. For overall assessment of GES, the fine-scale status estimates of species or biotopes need to be aggregated to broad habitat types in assessment units. As spatial and temporal aggregation and integration of different variables inevitably causes loss of information, the rules need to be transparent.

In this report we used *Zostera marina* beds on the west coast and submerged rooted plants in the pilot area in Blekinge as indicators of impact status of both infralittoral sand and mud alike. As most biological components representative for sand also (to smaller or larger extent) also occupy mud, and vice versa, the impact assessment per water body cannot be separated for the two BHTs at this point. However, as the proportion of habitat per waterbody is available, it is possible to estimate the total area of each BHT that is adversely affected.

For each water body, we calculated impact from physical disturbance on *Zostera* beds on the Swedish west coast and submerged rooted plants in Blekinge, as far as possible following the assessment scheme in the HELCOM indicator “Cumulative impact on benthic biotopes” (Berg et al., 2018). We used physical disturbance according to Törnqvist et al., (2018), which already accounts for cumulative pressure. Thus, the analysis is based on two sensitivity levels of *Zostera* or submerged rooted plants (exposed/sheltered), and only one pressure layer.

The broad habitat types of each water body were mapped by SGU (Törnqvist, *pers comm*). Infra- and circa littoral were separated using the limit between euphotic and aphotic zone, >=1% light penetration. As the high-resolution substrate data was classified due to reasons of Swedish national security it was not possible to perform GIS-analyses directly overlaying substrate and impact maps. Instead, aggregated areas per water body were used. The total area of each habitat class was summed per water body, thus enabling an assessment of BHTs per coastal water body.

The results from the analysis of cumulative impact on *Zostera* beds or submerged rooted plants was used to classify all sand and mud in each water body as adversely affected or not. The total area of infralittoral sand and mud in waterbodies classified as adversely affected was summed, and the respective proportion of area of the two BHTs being adversely affected was calculated for the entire Swedish west coast as well as for the county of Blekinge.

As the assessment at this point is based on a singular biotope and its potential exposure to estimated physical disturbance, the associated uncertainties are quite large. We do not know the spatial overlap between the biotope and the BHTs, or the physical disturbance and the BHTs, therefore the same assessment per water body is used for both sand and mud. Also, to assess overall status according to D6C5, the actual state of *Zostera* beds or other relevant biotopes needs to be determined.

6. LINKS TO MEASURES

Considering the initial assessments made for Swedish marine waters, we know that anthropogenic pressure on benthic habitats is considerable and we will likely need appropriate measures in order to reach both good environmental statuses according to MSFD as well as national and regional environmental aims (e.g. Baltic Sea Action Plan). In order to evaluate potential measures and their potential effectiveness, we need to be able to spatially identify individual pressures and assess their effects. As a proof of concept, we tested the application of spatial distribution models of underwater vegetation in the Blekinge archipelago in scenario modelling of the potential effects in reductions of physical disturbance on vegetation cover (Figure 11).

We used raster layers of environmental variables in 10x10 m resolution, described further in Törnqvist et al. (2018) and Wijkmark et al. (2015) (morphological impact; depth, curvature, rugosity, slope, wave exposure, average water temperature and average salinity), as well as in 250x250 m described by Hammar et al. (2018) (proportion of soft substrate, proportion of transport substrate as well as background load of nitrogen, phosphorous, toxic metals and synthetic toxins). Only environmental variables that can be assumed to influence the distribution of underwater vegetation were included in the modelling.

Data from SMHI, GRUNDA 2002-2008[5] and vegetation data from sampling of juvenile fish[6] were used for modelling. All biological data was taxonomically harmonized, and quality checked, and data from the past 15 years were selected for further analysis. The remaining 8681 observations were aggregated (mean) to 10x10 m cell size to match the scale of the environmental layers, resulting in 4524 cells with data used for modelling. Some of these were excluded due to missing environmental layers. Of the final 3938 observations charophytes were present in 406, *Zostera marina* in 554 and submerged rooted plants in 3004. At a later stage, absences at 1.3x the maximum depth of each response were excluded, as these would inflate the model by giving too much weight to areas outside the potential distribution of the response.

The models were used together with the environmental layers to predict the potential cover of the response variables for the entire area. As the morphological impact layer explained some of the variation in the response variables, we created a scenario where the morphological impact was set to zero throughout the area, all other predictors kept the same. By calculating the difference between the zero scenario and current distribution, cells where the response variable potentially would increase with decreasing physical pressures were identified (pink areas of lower panel in Figure 11).

This approach could be used to identify areas where measures leading to decreased physical disturbance would be most effective.

[5] Supplied by Hafok AB
[6] Mainly collected by CAB Blekinge, supplied by SLU Aqua

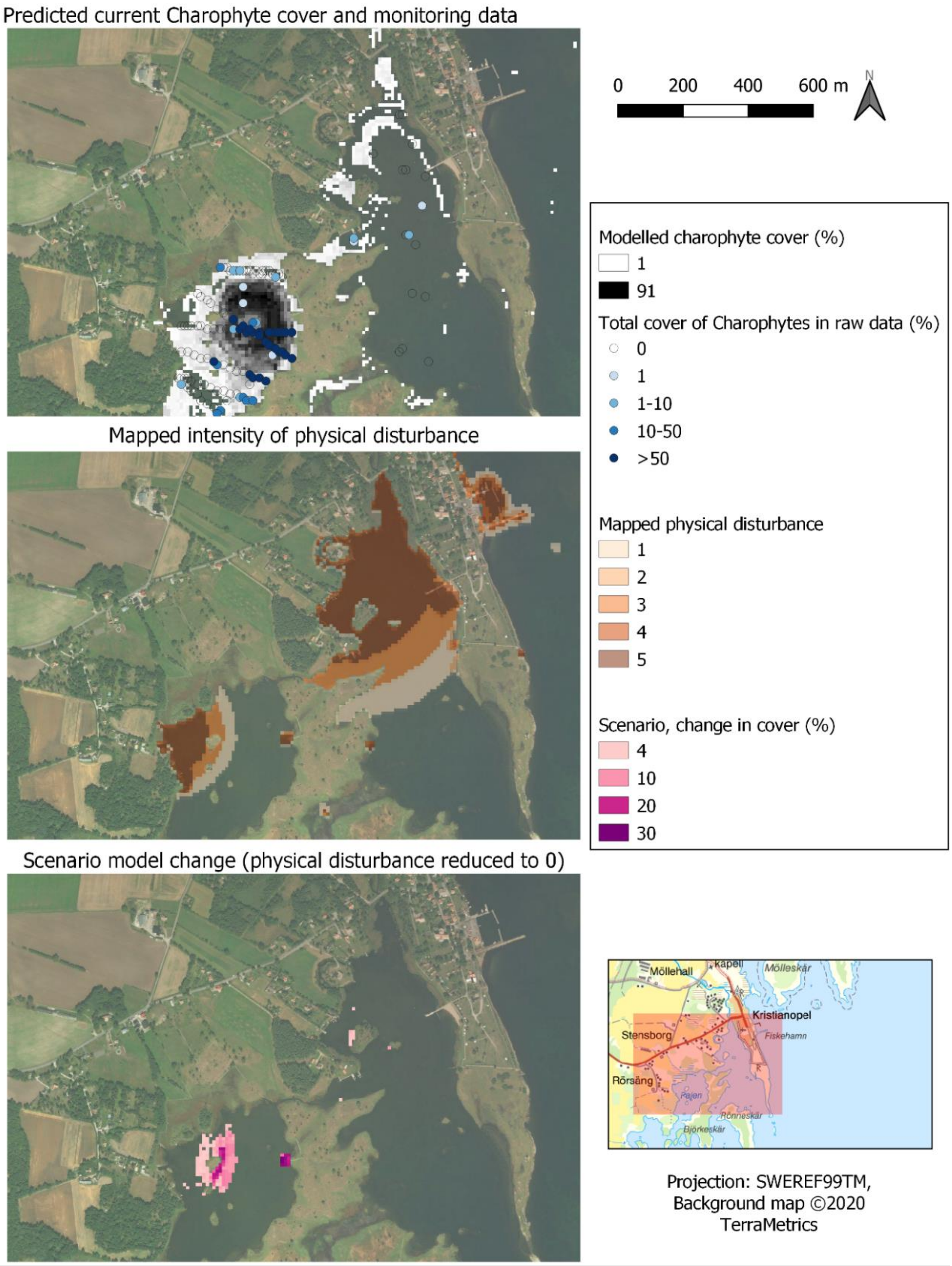

Figure 11. Predicted cover of charophytes (top), mapped intensity of physical disturbance (middle) and potential change in cover of charophytes at zero physical disturbance.

7. DATA AND MAPPING NEEDS

During the past years, extensive mapping of both biota and physical pressures have been completed. Distribution of selected species, biotopes and habitats have been mapped by AquaBiota for approximately half of the Swedish coastal area at 10 or 25m cell resolution, (Näslund et al., 2019), and all of the Swedish Baltic Sea at 250 m resolution. Physical impact in coastal areas was comprehensively mapped by Metria on behalf of SwAM at 10 m resolution (Törnqvist et al., 2018) and land use/vegetation cover as well as marine water delineation by the Swedish Environmental Protection Agency at 10 m resolution in 2019 (Nationella marktäckedata). Within the Symphony project, seafloor substrate, selected oceanographic variables, human activities and ecosystem components have been mapped at 250 m scale and is publicly available. The public database for marine data, SHARK (https://sharkweb.smhi.se/), contains at date almost 16 000 sampling points for phytobenthic species, and almost 12 000 grab samples for zoobenthos.

However, although a vast amount, the data has not been sampled to answer questions specific to the assessment of D6. Thus, the data needs to be evaluated in terms of quality and applicability, and knowledge gaps identified.

8. SUGGESTED SURVEYS AND FURTHER PROCESS

Suggestions for continued work regarding the assessment of all Swedish sea areas up until next assessment.

- Preparing and testing of a framework for the use of sub-habitats for monitoring and assessment of the broad habitat types.
- Data analyses to establish scale-relevant pressure-response relationships between selected pressures, ecosystem components and functions, including suggested field surveys above.
- Development of science-based estimates of physical loss and disturbance
- Development of confidence estimates of assessment of area lost or impacted in relation to the broad habitat types
- Testing and development of guidelines for how to assess the extent of adverse effects from anthropogenic pressures on the condition of the biotic and abiotic structure and functions of benthic habitats.
- Testing of principles for aggregation of habitats and scales to achieve a more comprehensive assessment of D6

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