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Physical oceanography sets the scene for the Marine Strategy Framework Directive implementation in the Baltic Sea

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ABSTRACT

A challenge of the EU's Marine Strategy Framework Directive (MSFD) is to ensure comparable status assessments for good environmental status (GES) in the European seas. To this end, the role of dynamic oceanographic features affecting GES must be understood. Natural variability is recognized in the MSFD, but only vague advice is available for scientists and managers about how to apply this in the marine strategies. In this paper it is illustrated how physical factors, and their pronounced natural variability, e.g., irregularity of Major Baltic Inflows (MBI), strong and persistent upwelling, and varying ice conditions, affect status indicators and possibly several of the 11 descriptors of GES in the Baltic Sea. It is recommended that these effects are better understood in all regional seas. They may lead to insights that promote adaption of environmental monitoring programmes, as well as re-definitions of GES and other elements of the marine strategy.

1. Introduction

The EU has set an ambitious objective of reaching good environmental status (GES) of its marine waters by year 2020. This objective was laid down in the Marine Strategy Framework Directive (MSFD, [1,2]. For this purpose, GES has to be defined, and the assessments of the environmental status need to be comparable in the four European seas and their defined sub-regions. The MSFD acknowledges that the marine regions and their sub-regions have differences in hydrological, oceanographic, and biogeographic features. The differences or the natural variability of these features have not, however, been summarized in the MSFD context so far and their effects on GES assessments have not been discussed.

In this opinion paper, we have two objectives: (1) to summarize a few oceanographic features of the European marine regions and show that the regions are influenced by different factors and (2) to showcase a few predominant oceanographic factors in the Baltic Sea and their influence on GES assessments. We argue that this oceanographic influence has been neglected in many of the GES indicators, and that it may be difficult to interpret the role of oceanographic variability in the assessment results. This is illustrated using a few examples. The purpose of this paper is not to make a thorough analysis of this challenge but for the first time raise discussion and concerns over how our marine monitoring data can be misleading if interpreted without considering the natural variability.

2. The Baltic Sea, a specific European Sea

The four European seas – Baltic Sea, Black Sea, Mediterranean Sea and Northeast Atlantic (divided here into North Sea and northeast Atlantic shelf due to their differing characteristics) – all have unique characteristics, featured in the range of physical parameters, differences in biogeographical zones, variety of human activities and associated pressures as well as different food web characteristics (Fig. 1, Table 1). The grand objective of the MSFD, to achieve GES in all the European seas, cannot be reached without careful consideration of the specific conditions of each of the regions – separately and jointly. For instance, GES cannot be discussed in the Baltic Sea context without understanding that even if strong management actions are taken, the region will be under heavily eutrophic conditions for the next five decades [5] and that this is a result of both physical and anthropogenic factors. Meanwhile, eutrophication is not the driving force of the state of marine environment in the three other regions of the European seas. In this study we demonstrate that similarly, major differences between the marine regions exist also among physical parameters.

The basic features of the European seas reveal key differences, including areal extent, depth profile, salinity level, fresh water budget, climate, and tidal motions (Table 1). The Baltic Sea is the only EU region with a regular ice cover. The Baltic Sea and the North Sea are shallow, with mean depths of 54 m and less than 100 m, respectively. The Black Sea and the Mediterranean Sea are considerably deeper with mean depths of 1200 m and 1500 m, respectively, whereas the NE

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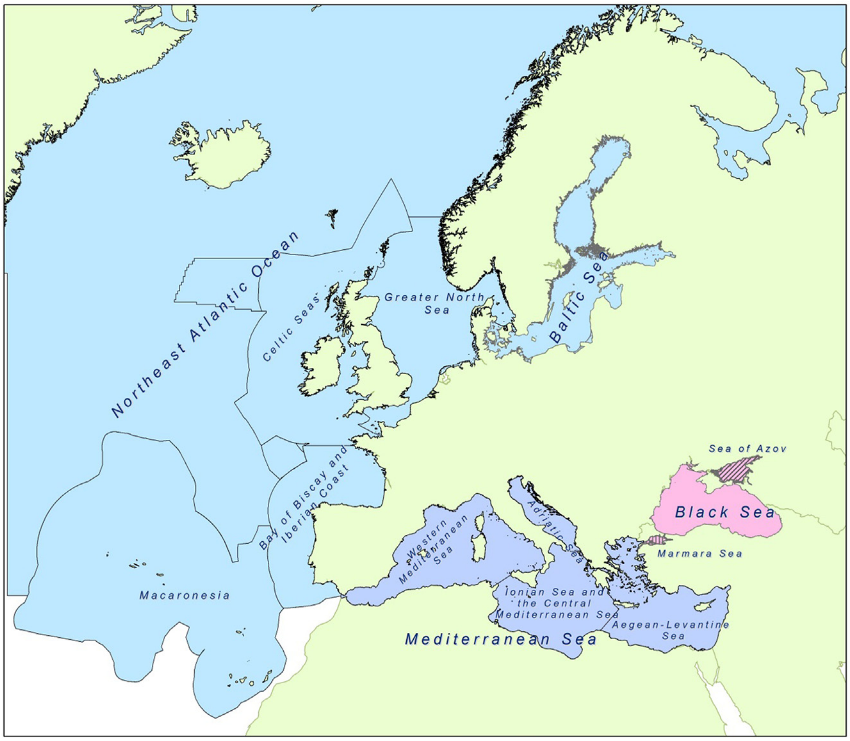

Fig. 1. European marine regions and sub-regions as identified for the Marine Strategy Framework Directive. Source: European Environment Agency (https://www.eea.europa.eu/data-and-maps/data/msfd-regions-and-subregions).

Table 1
The main characteristics of the physical features of the European Seas [3,4]; www.ospar.org/, British Oceanographic Data Centre). Greater North Sea – being the neighbouring sea area to the Baltic Sea - is shown as a sub-region of the NE-Atlantic, but other European sub-regions are not listed.

Basin	Area 10^3 km^2	Mean depth m	Mean salinity ‰	Fresh water budget	Ice cover on average	Tides	Water residence time (years)
Baltic Sea	393	54	7½ (0–30)	Pos.	37% [a]	Weak	40
Black Sea	422	1 200	18	Pos.	Northeast only	Weak	3 000
Greater North Sea	750	80	34–35	Pos.	No	Strong	Not applicable
Mediterranean Sea	2 970	1 500	38	Neg.	No	Weak/Moderate	80–100
NE Atlantic shelf	13 500[b]	1 500	34–35	Not applicable	No	Strong	Not applicable

[a] Mean maximal ice cover between 2000 and 2017, see Fig. 4.

[b] Defined as the OSPAR convention area, incl. the Greater North Sea.

Atlantic reaches the oceanic depths of ca. 4 km but its continental shelf areas are of much shallower depths of circa 400 m. These depth differences influence, among other things, the mixing of the water column, variability in temperature, and distribution of benthic biological features.

3. Baltic Sea oceanography and its implications to the GES assessments of the MSFD

Among the European Seas, the Baltic Sea physics has several specific features, including its low salinity, strong salinity stratification, spatially and temporally frequent upwelling, regular ice cover and anoxic conditions dictated by Major Baltic Inflows (e.g. Refs. [3,6,7]. These are the main drivers of the Baltic ecosystem, setting margins for the species' living conditions (e.g. Ref. [8]. In sections 3.1-3.3 we present examples how three primary physical factors affect a few biological status indicators which are used for assessing GES in the region and in section 3.4 we summarize how these findings influence a GES assessment.

3.1. *Stratification and Major Baltic Inflows*

The Baltic Sea is sometimes considered as a very large estuary where freshwater outflow from numerous rivers form a horizontal and vertical salinity gradient. The vertical salinity gradient is abrupt and forms two separate and permanent water masses above and below a halocline, i.e. stratification. The strong halocline hinders mixing of the water mass, which consequently weakens oxygen conditions and increases nutrient availability in the photic layer. For instance, in the autumn 2016, ca. 70 000 km^2 of the seabed experienced hypoxic events.

Even if salinity stratification of the Baltic Sea is pronounced and stable, in typical conditions, the dynamics ruling it are complex and derived by many factors (meteorological forcing, thermohaline circulation, fresh water balance, water exchange with North Sea, etc.). The typical stratification phase is interrupted only when irregular Major Baltic Inflows (MBI) bring oxygen-rich waters from the North Sea to Baltic deep bottoms (e.g. Ref. [9]. MBIs play a crucial role in the overall condition of the sea and will dramatically change stratification and oxygen conditions (see Table 2; Fig. 2). Such inflows take place irregularly, on average once in a decade, and are unpredictable.

The MBIs will cause manifold changes in the Baltic ecosystem. As its main basin receives oxygen-rich waters from the North Sea, the deep areas are finally “ventilated”, at least partly, and the oxygen conditions will improve, for a while [3]. The inflow also increases salinity in deeper water layers and therefore strengthens stratification. However,

Table 2
Magnitude of the major saline water inflows to the Baltic Sea and reported effects to the Baltic marine environment [9].

Year	Water volume (km^3)/ Salt (Gt)	References to effects in marine environment
Nov–Dec 1951	225/5.17	[9–14]
Dec 1921–Jan 1922	258/5.12	
Dec 2014	198/3.98	
Nov–Dec 1913	174/3.80	
January 1993	159/3.40	

the implications of the MBIs are variable in the other basins. The "old", oxygen-poor bottom waters of the main basin flow to the Gulf of Finland, potentially deteriorating its oxygen conditions. The Gulf of Riga and Gulf of Bothnia are located behind sills towards the main basin, and therefore the bottom waters of the main basin will not enter those basins. During long stagnation periods with no MBIs, the stratification weakens and e.g. in the relatively weakly stratified Gulf of Finland oxygen situation might improve through intensified vertical mixing, while in the main basin the oxygen conditions gradually worsen because the pronounced stratification still remains.

The stratification and MBIs are clearly visible in biological indicators in the region. An example of this is seen in one of the oldest biological monitoring programmes in the Baltic, the zoobenthos monitoring by soft bottom grabs, which has been used for a Baltic wide indicator to inform, for example, the EU MSFD [15]. The indicator correlates positively with species richness, which correlates positively with salinity [16]. Changes in salinity and oxygen conditions – another consequence of stratification – cause strong fluctuations in zoobenthic fauna and the indicator [16], peaking in periods of MBIs [11]. Laine et al. [11] noticed that the MBI effects are also spatially different and Zettler et al. [16] recommend careful analyses of any benthic assessment results against salinity and oxygen. This variability was found to influence the results used in indicator assessments [17], and Schiele et al. [18] proposed setting salinity-adjusted species scores for the indicator [15]. To our knowledge this is the only case in the HELCOM's Baltic state assessment where oceanographic variability has been taken into account in a status indicator.

As a natural phenomenon, MBIs may improve the state of the sea, particularly sea-floor related aspects of biodiversity, food webs, and fisheries, depending on the area. However, MBIs are also beyond human control and, hence, their effects - whether positive or negative - should be separated from anthropogenic effects when assessing the MSFD objectives. This can be done only afterwards and we discuss this possibility in Chapter 4.

3.2. Upwelling

Upwelling is a typical and characteristic process in the Baltic Sea (see e.g. Ref. [19]; Fig. 3). As the Baltic Sea is small and semi-enclosed, winds from almost any direction blow parallel to some section of the coast to cause upwelling. E.g. at the Swedish south-western coast, upwelling occurs 25–40% of time. Sometimes even one third of the entire Baltic may be under the influence of upwelling simultaneously. During the thermally stratified period, upwelling can lead to a sea-surface temperature drop of more than 10 °C in a few days, changing drastically the thermal balance and stability conditions at the sea-surface. Hence the upwelling events can locally break the overall stratification conditions and cover a substantial part of the Baltic Sea area.

Upwelling can play a key role in replenishing the euphotic zone with the nutrients necessary for biological productivity during the growth season. The altered nutrient availability and temperature change planktonic primary production and species composition along the upwelling areas [22]. As concentrations of phosphate, nitrate and chlorophyll-a are also status indicators in the Baltic Sea [23], the temporal (a few weeks) and spatial effects (tens to hundreds of kilometres) for the indicator performances can be considerable. The HELCOM guidelines for status assessments of eutrophication smooth the consequent data variability by assessing large areas over 6-year periods [24], but the influence of upwelling has received only very little attention (however see Ref. [25]. Increased phytoplankton biomasses support also the total biomass of zooplankton [26], which has direct coupling with the abundance and weight of planktivorous herring (*Clupea harengus membras*) and sprat (*Sprattus sprattus*) and even condition of seals in the Baltic Sea (Kauhala et al., submitted manuscript). All these three features are currently indicators of the Baltic Sea health [23], but Kauhala et al. suggest that the thresholds for good state of seal breeding and nutritional condition are set without considering the natural variability in the food resources.

We argue that upwelling causes "random noise" to time series and is especially a challenge for monitoring programmes with temporally limited sampling. This variability noise easily obscures any signal there may be in the time series and may mask anthropogenic effects in state assessments of MSFD.

3.3. Ice conditions

The Baltic Sea is at least partly ice-covered every winter [3]; Fig. 4).

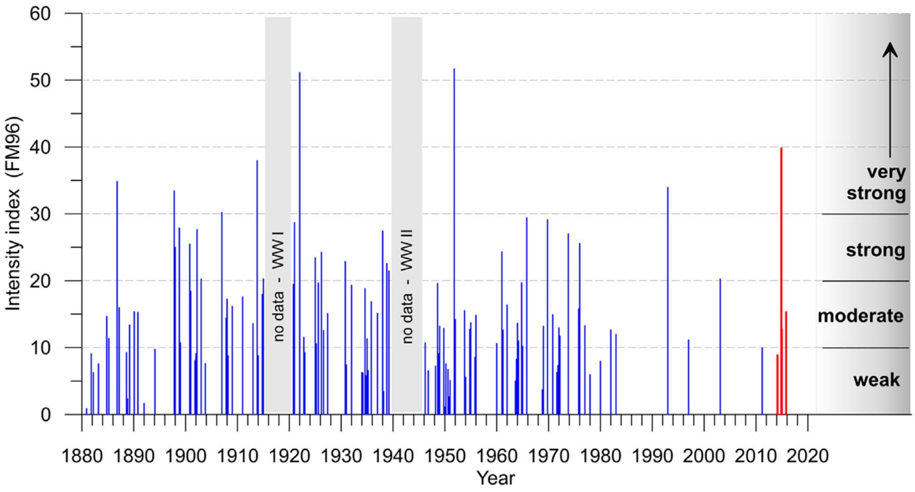

Fig. 2. Intensity of MBIs (Fisher and Matthäus, 1996), depicted from Mohrholz et al., [9]. Inflow measurements were started already in the late 1800s, but there are data gaps due to World War I and II.

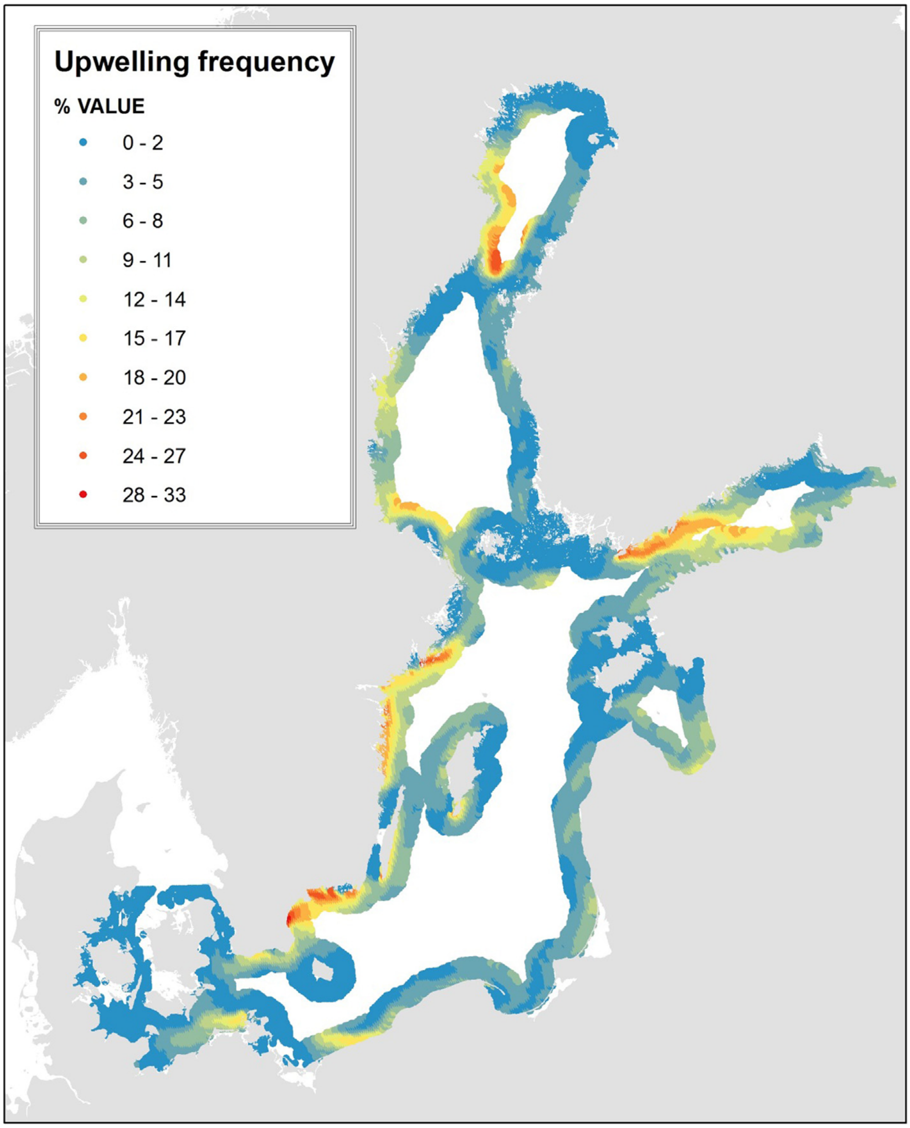

Fig. 3. Mean upwelling frequency (%) in the Baltic Sea. Redrawn from Ref. [20] based on 3360 SST maps for the period 1990–2009 (May–September): an upwelling event was recorded if the SST measurement showed an abnormal drop of at least 2 °C compared with earlier or surrounding measurements (see Ref. [21].

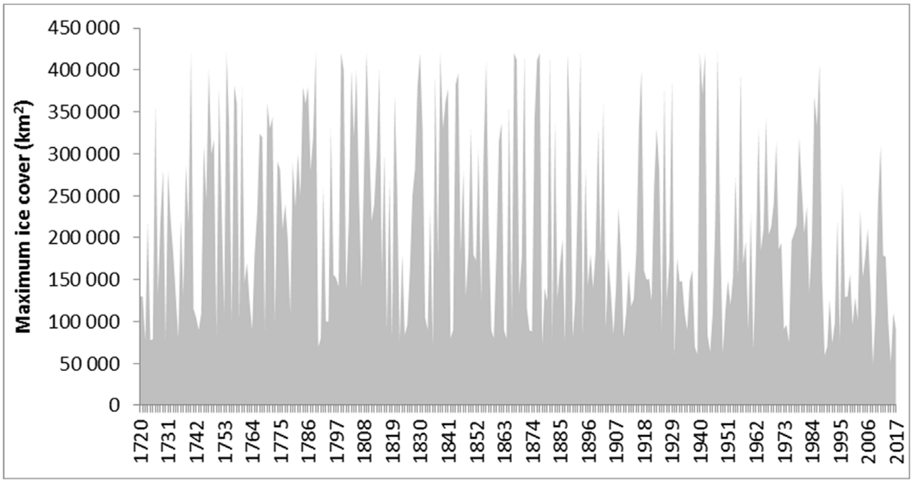

Fig. 4. Annual maximum area of ice cover in the Baltic Sea between 1720 and 2017. Source: Finnish Meteorological Institute.

This is a rare feature in the other European Seas; only the Sea of Azov in the Black Sea experiences regular ice-cover. The presence of ice has a pronounced influence on the transfer of wind energy and light into the water and on the air– sea exchange of moisture and heat. Ice and snow bring high albedo and cold surface, which lowers the turbulent exchange of sensible and latent heat. Atmospheric fallout is accumulated in the ice sheet to be released during the short melting phase. The impact of ice melting is significant for the surface water salinity as it starts up the stable spring stratification where the less saline (light) water locates on the top of more saline (denser) water. The stable stratification has further consequences to the spring bloom. The ice has also a remarkable role in the human living conditions in the sea area, in particular in regards with traffic and fisheries.

The climate change has already caused decline of ice extent, ice thickness and the length of the ice season in the Baltic [27], and further decrease is predicted [28]. The diminishing ice will change the air-sea interaction: in winter high seas become more frequent due to the absence of ice cover and mixing of the water column may become prevalent. The decline of sea ice exerts multiple effects on biota, e.g. for primary production [29], wintering seabirds [30], and seals. The ringed seal (*Pusa hispida*) reproduction is tightly linked with ice cover and breeding on land has been observed only two times in the Baltic [31,32]. Also the grey seal (*Halichoerus grypus*) pup production is significantly poorer on land than on ice in the Baltic [33]. The ringed seal and grey seal pup breeding success are GES indicators in the Baltic Sea [34], and the changing ice climate will lead into a new baseline situation where the influence of anthropogenic activities (such as ice breaking for shipping) is difficult to separate from ice decrease. Although both are of anthropogenic origin, the former is the focus of EU MSFD and target for mitigation action under that policy regime.

The ringed seal abundance is another GES indicator in the Baltic and its assessment is based on annual counts of breeding females on ice [35]. The final population estimate is calculated by multipliers which take into account monitoring bias under typical ice conditions. Under reduced ice conditions, such as during 2013–2015, the seals aggregate and are, hence, easier to monitor which leads to more precise population count and disturbs the assumptions of the population estimation formula. This is reflected in 2–4 times higher seal number estimates for those years, as the ice conditions are not taken into account in the assessment model.

3.4. *Oceanographic factors' effects on the GES assessment*

In the MSFD, GES is assessed through eleven qualitative descriptors (MSFD Annex I) which cover different aspects of the marine ecosystem – both states and pressures – which are affected by human activities and may require management actions. In this paper, we have given examples of biological GES indicators and how they are affected by abovementioned three predominant oceanographic features. In this section we further discuss why these effects are serious for our assessments of environmental status.

Firstly, GES assessments need to take into account any systematic change in oceanographic conditions, such as the climate-change related melting of sea ice or increased stratification. The Decision 2017/484/EU, which further defines the directive, states that GES reflects prevailing physiographic, geographic, climatic and biological conditions, *'rather than return to a specific state of the past'* [2]. This means that GES assessments need to be coupled to oceanographic knowledge in order to set the baseline for 'prevailing conditions'. Similarly, we think that any regime shifts taken place in the system adhere to this definition. The Baltic Sea experienced a clear regime shift in late-1980's [36] and therefore any GES definition based on earlier conditions may reflect a condition into which there is no return to.

Secondly, this definition of GES also means that GES should be assessed in the context of the natural oceanographic variability in the area. In other words, the anthropogenic impact should be disentangled from the natural variability. As shown by the selected biological indicators, oceanographic variability has strong effects on regionally agreed GES indicators. An important question is: do the indicators currently reflect anthropogenic pressure or oceanographic variability? In our examples, saline water inflows, upwelling events and ice conditions alter indicator results (macrozoobenthos, phytoplankton, zooplankton, planktivourous fish, seals) but are still a natural phenomenon, even if unpredictable and sometimes extreme.

Third, GES is to be assessed in 6-year intervals and for ecologically relevant assessment areas (see Refs. [23,24] for Baltic assessment areas), which means that proper scales are to be selected to capture a reliable snapshot of data for the assessment. For instance, a practical solution for a scale could be that a coastal strip with high upwelling frequency would be selected as an assessment unit and a nearby area with rarer upwelling events would be a different unit.

Finally, the oceanographic variability is not only a question of indicators, but also of monitoring. All our indicator examples suggest that assessment certainty can also be improved by developing monitoring design. Scarce monitoring of rapidly changing parameters in upwelling coasts will not provide reliable data but could be an adequate frequency in another area. Furthermore, including relevant oceanographic parameters into the monitoring programme will support the indicator development and assessment as shown by the previous macrozoobenthos example.

3.5. *Scientific challenges and suggestions for developing GES assessments*

The multiple linkages between GES and the oceanographic variables mean that the determination and assessment of GES cannot be made without considering oceanographic variables and particularly their seasonal and spatial influence on the monitoring programmes as well as definitions and assessments of GES. In the Baltic Sea, the natural variability of specific oceanographic parameters is pronounced and the dynamics behind the changes are complex and difficult to forecast. This aspect has, however, been largely overlooked in the current MSFD implementation practises as shown by examples in this study.

While the MSFD GES concept has motivated scientists to publish tens of studies and discussion papers, no papers are found discussing oceanography in relation to GES in European seas. Nonetheless, the present analysis shows, firstly, that there are clear differences in physical characteristics among the MSFD regions and, secondly, that the marine physics influence the assessment of biological status indicators. We gave examples of this by a handful of regionally agreed core indicators, but one can assume that this can be generalized to a broader context as well. In Fig. 5 we have presented the three major oceanographic factors of this paper, linked them with relevant general ecological phenomena and propose how they influence the MSFD descriptors. We did not go into details of assessment methodologies (e.g. criteria and integration rules), but only raise the concern for the confidence of the assessment outcomes. As it is not the aim of this paper to make a complete review, we have emphasized those descriptors where we have given specific evidence in Chapter 3. For other linkages we have provided only anecdotal evidence in the figure legend.

The complex stratification of the Baltic Sea, in particular, has caused challenges for the marine scientists. The global ocean models do not work well in the Baltic without careful adjustments because of the very high horizontal and vertical resolution needed to describe specific stratification and mixing conditions. This means that the Baltic Sea modelling requires extra work and expertise. From the MSFD point of view, understanding the stratification has direct consequences, for instance, for the predictions of the state of eutrophication, algal blooms, conditions at seabed, and functioning of the food web. An additional element complicating these predictions is the upwelling phenomenon. Although upwelling events can be hindcast in the oceanographic models and even predicted a few days ahead, they can cause variability to SST and nutrient concentrations and, consequently, to blooms of

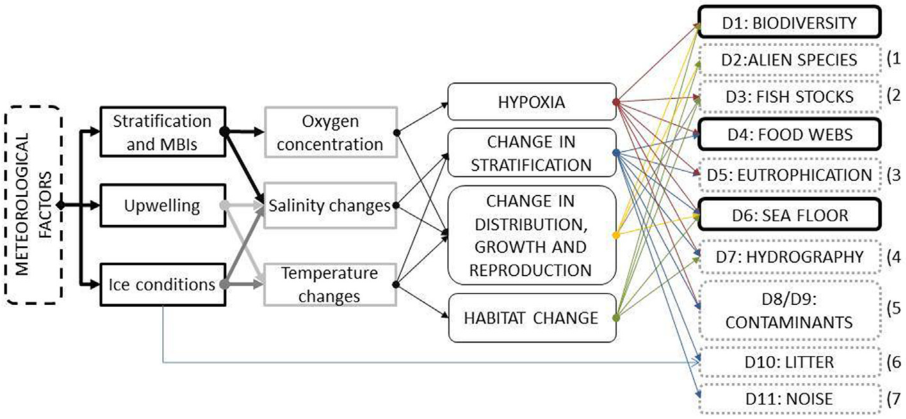

Fig. 5. The paths of effect of three oceanographic phenomena on the MSFD descriptors. The bolded descriptors are shown by evidence in this paper and for the others we only suggest a linkage based on seven lines of evidence (numbers on far right): (1) change in salinity and temperature may free niches for non-indigenous species [37], (2) planktivorous fish are regulated by resources and oceanographic factors [14], (3) upwelling and MBIs bring benthic nutrients into surface waters [10], (4) habitat changes affect the hydrographic descriptor assessment [2], (5) some metals are redox-sensitive which influence their water concentrations [38,39], (6) changes in stratification affect distribution of microlitter and ice movements transport macrolitter [40], (7) water temperature, salinity, ice cover and currents affect the distribution of sound waves [41].

phytoplankton and opportunistic macroalgae [42], producing outliers in time series and complicating GES assessments. A practical solution could be to agree on data rules (e.g. data omission) for status indicators which would benefit of the hindcast oceanographic models of the assessment period. To our knowledge, however, there are no such practices in use or criteria agreed for environmental assessments about when an observation could be omitted due to an extreme upwelling event.

The MBIs function in completely different temporal scale than upwellings and are practically unpredictable. Even though the start of an inflow can be expected after certain meteorological conditions, and monitored at an early stage in the Danish Straits, its magnitude is difficult to predict. Even more challenging it is to predict the spread, effect and duration of an MBI. An illuminating case was the MBI in 2014, which was the third largest in measured history, but still its effect on bottom oxygen conditions remained relatively short compared to many previous MBIs and the spread was limited to the Northern Baltic Proper (Finnish Environment Institute monitoring data). As MBIs create short-term peaks in oceanographic conditions, e.g. seabed oxygen, these events cause high variability in status assessments: If these peaks exceed the GES threshold of any biological indicator, while the ambient status does not, do we concede that GES has been reached for that short period of time? Such questions do not have scientific answers, but good monitoring programmes or assessment guidelines can distinguish such peaks and instruct data managers of the phenomenon. The coordinated marine monitoring and assessment strategy under HELCOM in the Baltic Sea (http://www.helcom.fi/action-areas/monitoring-and-assessment/) is one of the oldest and most developed international marine monitoring programmes and it does not have instructions regarding how to handle MBIs or local upwelling events in the assessment data.

In this study, we pointed out, firstly, that there are evident oceanographic differences among the MSFD regions which mean that GES assessments should be made under specific oceanographic context in each of the regions. In the Baltic Sea, it has been shown that the physical characteristics are not only highly interlinked, but in the case of MBIs also unpredictable, and in cases of currents, upwelling events and stratification, not fully mapped or understood. Nonetheless, with the European wide oceanographic data (e.g. the EMODnet portals) it is possible to start linking the realms of biology, oceanography and assessment practices. Good example is the HELCOM's model for maximum allowable inputs of nutrients (http://www.helcom.fi/baltic-sea-action-plan/nutrient-reduction-scheme/) which has been used to predict that GES can be reached but it will take several decades under the physical and chemical forcing in the region [5].

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