European Commission

ENVIRONMENT

NEA-PANACEA Activity 2 - Eutrophication and physical conditions informing MSFD D1, D4 and D6 assessments

Task 2.1b, Annex P: Climate change impacts on biodiversity

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NEA PANACEA

North East Atlantic project
on biodiversity and eutrophication
assessment integration
and creation of effective measures

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1. Summary

General aim of Task 2.1 was to use the existing modelling system LiACAT (Literature-based Analysis and Cumulative Assessment Tool) for linking environmental conditions to biodiversity indicators in order to estimate the effect of changing eutrophication and climate conditions on biodiversity.

The basic proceeding should involve the analysis of selected habitat or organism groups regarding multiple impact stressors from the environment. By including modelled and measured data for different eutrophication and climate scenarios, predictions of the expected changes in the analysed groups should be made and related to biomass changes. These biomass changes are part of the indicator assessments within Descriptors 1 and 4, notably the OSPAR pelagic habitat and food web indicators PH2 and FW2.

Main subject of the subtask 2.1b described in this report were climate change aspects that have direct impacts on the living environment with a special focus on benthic organisms in the marine system. For that reason, literature studies were used to define different climate scenarios yielding respective setup data for the LiACAT model system. Especially for the North Sea, a series of model runs have been published with surprisingly different projections, e.g. on the stratification and the resulting projected oxygen depletion. For that reason, it was necessary to provide a scope of possible projections which could be further investigated in their impact by applying the LiACAT and ENA (Task 2.2) model.

Thus, the Task will contribute to the QSR assessments and is therefore encapsulated in OSPAR work to deliver the QSR assessments in 2022/2023. Coherence of the OSPAR eutrophication and biodiversity assessments is the aim of Theme B, where this Task contributes to.

2. Introduction

2.1. The NEA PANACEA project

NEA PANACEA is an EU-funded project in which 8 partners from 5 OSPAR Contracting Parties (Germany, France, the United Kingdom, Spain and the Netherlands) collaborate to deliver biodiversity assessments for OSPAR's Quality Status Report (QSR) 2023.

The project focus lies specifically on pelagic habitats, benthic habitats, food webs and marine birds' assessments in the framework of the OSPAR Quality Status Report (QSR) 2023. These assessments can be used by EU member states in the North East Atlantic region to inform their reporting to the EU for the Marine Strategy Framework Directive (MSFD). In addition, Activity 2 uses the newly developed and coherent approaches applied in OSPAR's eutrophication assessment (COMP4, based on the EU funded project JMP EUNOSAT). It provides tools to link pressure and state indicators to achieve more informative assessments of pelagic and benthic habitats and food webs, that will increase our understanding of ecosystem functioning in a changing climate and enable more effective management. Within this frame, Activity 2 - Task 2.1b compiles recent information on the actual status of climate change research results with special regard to the factors that have an impact on pelagic and benthic habitats, and food webs.

Since the NEA PANACEA Task 2.1a within Activity 2 is looking into relationships between benthic organisms and changes in physico-chemical parameters such as temperature, pH values, salinity, and oxygen contents as well as certain aspects of eutrophication by applying an ecological network model (ACIM/LiACAT), an important aspect of the resulting impacts are the changes that currently are and in future will be caused by climate change effects.

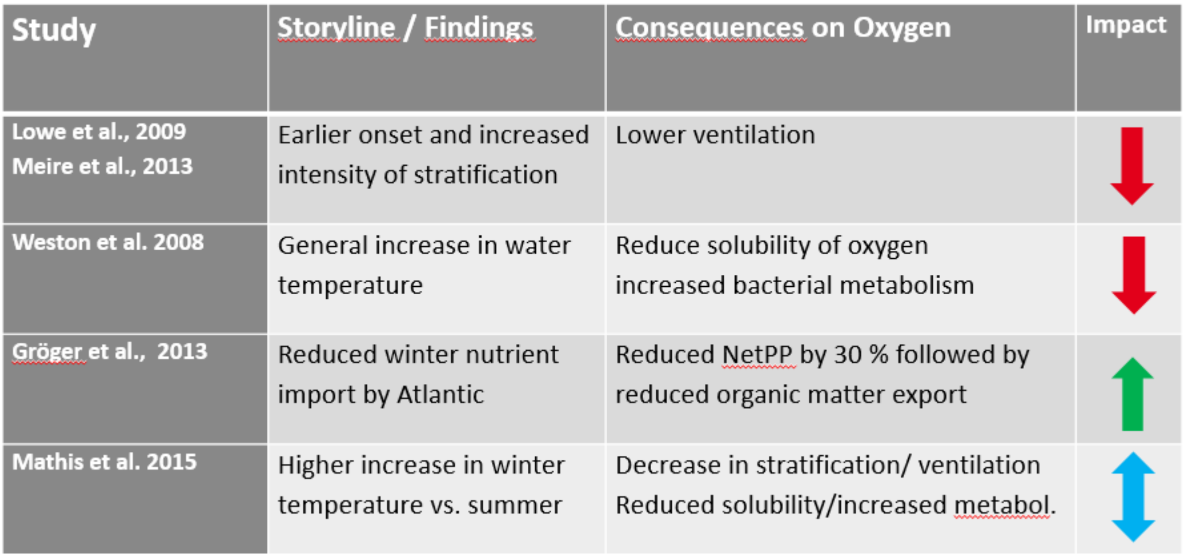
Within this context, an article on the "spreading dead zones" by Diaz and Rosenberg (2008) resulted in an increased public awareness for the problem of oxygen deficiency in the context on the effects on climate change. The paper could prove the evidence for an exponential expansion of global O_2 deficiency (and furthermore, hypoxia) since the 1960s and concluded that future changes in O_2 conditions will strongly depend on the effects of climate change on stratification and riverine nutrient supply. Since these are basically the same „ingredients" that are discussed under the aspect of eutrophication, which also leads to low O_2 conditions, we will further discuss climate change with focus on its impact on oxygen deficiency.

2.2. Activity 2 Task 2.1b – Regional aspects of climate change impacts

There are a number of studies that deal with impact of climate change on a regional level like the North Sea. However, the outcome of these studies differs considerably in their projections which is related to their regional downscaling as well as on the overall setup, for example if the model setup includes climate change adaptation of the boundary condition for the Atlantic inflow.

A comprehensive climate change assessment for the Greater North Sea region and adjacent land areas was presented by the study ‘North Sea Region Climate Change Assessment’ (NOSCCA) in 2016 (http://link.springer.com/book/10.1007/978-3-319-39745-0). Even though this work was initiated to provide a consistent overview on the impact of climate change for the North Sea, the model studies cited in two different chapters provide a contradicting picture on the development on bottom oxygen. In chapter 6 with the title “Projected change – North Sea” future scenarios by Skogen et al. (2004) and Eilola et al. (2013) are cited, which project the general eutrophication status of the North Sea as unchanged. While the later model study hints towards a slight increase in summer chlorophyll-a in the German Bight and Kattegat, there is no expected change on the North Sea oxygen minimum. In contrast, in chapter 12 “Socio-economic impacts – Fisheries” two studies by van der Molen (2013) and Meire et al. (2013) are cited which express severe changes in bottom oxygen conditions in relation to climate change up to the year 2100. Van der Molen (2013) suggested marked declines as a result of a number of factors, like changes in the balance between phytoplankton production and consumption, vertical mixing (stratification), and oxygen solubility with temperature. Meire et al. (2013) state a decrease in bottom water oxygen concentration of about 11 % based on his model simulation.

With a focus on a regional North Sea application, one can start with the straight forward argument that climate change scenarios show an earlier onset and increased intensity of stratification in the North Sea due to increasing surface temperatures (Lowe et al., 2009; Meire et al., 2013). This would more strongly inhibit the ventilation of bottom water and also extend this period in summer. Mathis and Pohlmann (2014) also found an increase in the water temperatures of the North Sea, however, accompanied by a weakening of stratification which would in contrast support enhanced ventilation of the bottom water. However, the increase in the water temperature alone will already lead to a decrease the O_2 solubility in the bottom layer (Weston et al., 2008). Changes in the weather conditions, such as an intensified precipitation or other extreme events (Rabalais et al., 2010), could furthermore lead to increased nutrient loads which triggers higher primary production which could result in an increase the risk of low O_2 conditions (Justic et al., 2003). On the other hand, Gröger et al. (2013) predicted a North Sea wide reduction in primary production by about 30% due to reduced winter nutrient import from the Atlantic. Another potential impact was argued by van der Molen et al. (2013), who concluded that the temperature-driven increase in metabolic rates and nutrient cycling will be followed by an increase in primary production. In combination with an increase in the benthic metabolic rates and other constrains, this will eventually lead to a decrease in the bottom O_2 concentrations. All this shows that primary production and related processes are controlled not only by nutrients but by a complex interaction of different processes including temperature changes, light limitation, grazing, and metabolism processes. The following Figure 1 extracted from OSPAR (2017) gives an overview of the consequences of these processes on oxygen:



Study	Storyline / Findings	Consequences on Oxygen	Impact
Lowe et al., 2009 **Meire et al., 2013**	Earlier onset and increased intensity of stratification	Lower ventilation	↓
Weston et al. 2008	General increase in water temperature	Reduce solubility of oxygen increased bacterial metabolism	↓
Gröger et al., 2013	Reduced winter nutrient import by Atlantic	Reduced NetPP by 30 % followed by reduced organic matter export	↑
Mathis et al. 2015	Higher increase in winter temperature vs. summer	Decrease in stratification/ ventilation Reduced solubility/increased metabol.	↕

Figure 1: Overview of various processes resulting from climate change developments and impacting North Sea oxygen concentrations (OSPAR 2017)

This contradicting picture of possible future developments of the North Sea under climate change conditions should be evaluated in the context that despite the relevance of the bottom O_2 concentrations for the assessment of the ecological status of an ecosystem, O_2 measurements are rather sparse and either temporally or spatially limited. It is therefore important to understand the complex interplay of hydrodynamical and biogeochemical processes controlling the bottom oxygen dynamics in the North Sea, either based on measurements (Greenwood, et al., 2010; Topcu and Brockmann 2015) or ecosystem model studies (Große et al., 2016).

An important aspect of the assessment of bottom near oxygen, which plays an important role for the status and the biodiversity of organisms living at the sea bottom, is the spatial distribution of the concentrations. While averaging aggregations over large areas such as the whole North Sea, English Channel, Bay of Biscay, and other areas show overall bottom near concentrations being > 6 mg L^{-1} (Figure 2) and thus, implicate reaching a good status, the picture becomes very much different when looking at particular regions.

A differentiated consideration of the small-scale distributions of oxygen deficiencies gives Figure 3: Across most of the assessment areas of the OSPAR COMP regions, there is no widespread oxygen deficiency. However, Figure 3 also reveals localised areas of oxygen deficiency within the ICES rectangles, particularly in the Eastern North Sea, Kattegat and Gulf of Biscay.

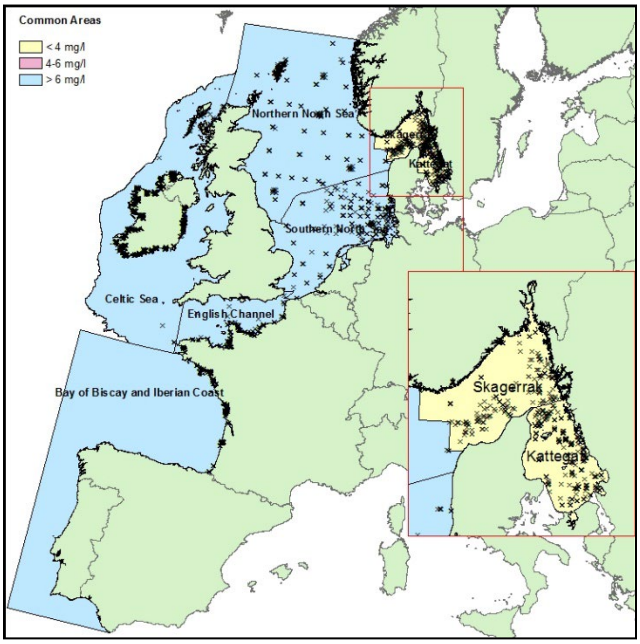


Figure 2: Mean concentrations of dissolved oxygen in the lowest quartile of the data plotted for common OSPAR areas for the period 1990–2014 (OSPAR 2017)

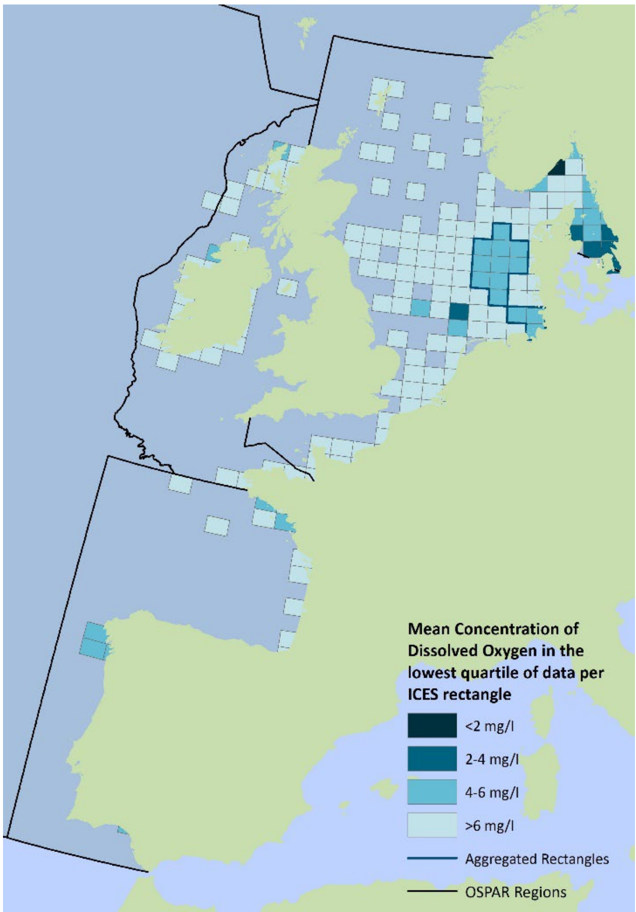


Figure 3: Mean concentrations of dissolved oxygen in the lowest quartile of the data plotted by ICES rectangles for the period 1990–2014 (OSPAR 2017)

These findings have been confirmed by model assessments carried out by Ciavatta et al. (2016). The authors did a decadal reanalysis simulation of the biogeochemistry of the North West European shelf and identified similar regions in the Eastern North Sea and the Bay of Biscay as potential oxygen deficiency areas (Figure 4):

Figure 4: Model assessment of areas susceptible to oxygen deficiency with at least one day per year beneath 6mg/l. (Ciavatta et al. 2016)

The model results are supported by the measured assessment values (5th percentile) for dissolved oxygen (DO) over the four assessment periods (1990-2000, 2001-2006, 2006–2014, 2015-2020) for the Eastern North Sea (Figure 5):

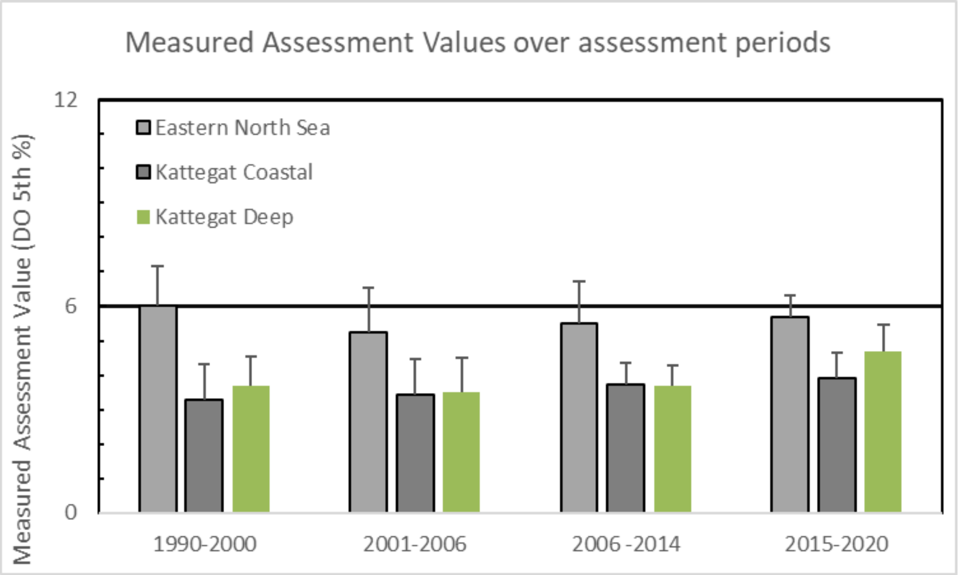


Figure 5: Measured assessment values for dissolved oxygen (DO, 5th percentile) over the four COMP periods for Eastern North Sea, Kattegat Coastal and Kattegat Deep (Devlin et al. 2022)

Covering a 30-year period, oxygen concentrations fall below the 6 mg L^{-1} threshold for all years. The Kattegat Deep and Kattegat Coastal areas show even lower DO values (Devlin et al. 2022). No significant statistical trends have yet been identified, but while the Kattegat trends might be positively affected by local measures such as strong reductions of nutrient inputs, the Eastern North Sea conditions are most likely to be susceptible to the climate change consequences, especially the expected temperature rise in the water column over the next decades.

3. Identification of Scenarios

Within the NEA PANACEA project, an application of the LiACAT/ACIM model system on benthic organism groups is planned (AquaEcology 2023). In order to get an impression of the possible cumulative impacts caused by changing environmental conditions, climate change scenarios shall be defined within the context of the NEA PANACEA project. As mentioned before, the various publications on regional model applications for climate change scenarios only provide inconsistent, partly even contradicting, conclusions. Consequently, there is not simply the „one and only scenario“, but we will have to define a range of scenario definitions based onmliterature research and thus, provide a bandwidth of possible related impacts for selected ecosystem components. For this reason, we will refer to a number of studies that can provide relevant information for the scenario settings as a basis for a possible ecological management of North Sea ecosystem under future condition.

Physical conditions have been described by Wakelin et al. (2020): „The water column is well mixed in the winter, stratified during spring in response to increased solar radiation heating surface waters, and remains stratified until autumn when decreasing solar radiation and increasing mixing due to storms break down the stratification. During the stratification period oxygen concentration below the pycnocline can fall to below the oxygen depletion threshold“, defined by OSPAR (2003) as 6 mg L^{-1}. Große et al. (2015) could identify regions being most vulnerable for oxygen depletion in the North Sea, such as the shallow region around and east of the Doggerbank. Even though the thermal stratification is far weaker than in the northern North Sea, the reduced water depth simply provides a much smaller sub-thermocline volume and therefore only a small initial oxygen reservoir on which the biological consumption processes can feed on during stratification, when no circulation is possible. Based on this knowledge, it can be stated that the expected oxygen deficiencies occurring more frequently and to a wider temporal and spatial extent in the future will have a very strong effect on the biological communities and thus, being comparable to the global warming effects with regard to the impact

Climate change has the potential to influence the oxygen cycle in a number of ways through changes in the hydrodynamic climate and the impact on the biogeochemical cyles. These changes will have a strong impact on the biological components of the marine ecosystem with regard to the ecological status and the biodiversity of the organisms. To a great extent, the bottom-living fauna will be affected by these processes. In the context of the LiACAT study, we need to identify parameters or processes that can be linked to relevant settings in the LiACAT tool in order to provide aggregated information on the changes in the ecosystem. In the following chapter, some examples of the impacts on the marine ecosystem caused by global climate change processes will be given and at the same time, some proposals will be made on how to regard these impacts in respective model setups.

4. Possible Scenarios

Based on literature, the following chapters will suggest some scenarios that can be used to apply different environmental conditions due to climate changes as possible impacts within the model system LiACAT/ACIM. As outlined before, climate change processes affect temperature conditions, stratification processes in the water column, net primary production effectiveness, and bacterial respiration processes, which all have an impact on near bed oxygen concentrations and by this, on the status and the biodiversity of the bottom-living fauna.

4.1. Temperature and salinity

As mentioned in the previous chapter, the first scenario will simply apply an increase in water temperature. Wakelin et al., (2020) proposed an average regional warming over the 21st century of between 1.5 and 4.0 °C in near bed temperatures (NBT) and between 2.7 and 4.0 °C in Sea Surface Temperatures (SST), which is in good accordance with other modelling studies of the European shelf. Tinker et al. (2016) calculated shelf-wide increases of 2.71 ± 0.75 °C and 2.90 ± 0.82 °C respectively from their model ensemble under the SRES A1B medium emissions scenario, which is less severe than the RCP8.5 scenario used here. Furthermore, under the A1B scenario, Holt et al. (2010) calculated SST increases of 1.4 – 4.0 °C for the European Shelf and Gröger et al. (2013) calculated SST warming of 1.6 – 3.2 °C on the European Shelf and 2 °C in the North Sea. The change of −0.7 to −1.9 in near bed salinities (NBS) compares to published estimates for the European shelf of −0.33 ± 0.38 (Tinker et al. 2016). The Sea Surface Salinity (SSS) changes of −0.9 to −2.8 are also larger than published values of −0.41 ± 0.47 (Tinker et al. 2016), −0.2 (Holt et al. 2010) and −0.75 (Gröger et al. 2013).

Recommendation:

Following the outline of Mathis and Pohlmann (2014), scenarios of a temperature increase of 1.5, 2.7, and 4.0 °C in near bed layers should be taken into account for possible model approaches.

4.2. Stratification

Simulation from Wakelin et al. (2020) show that the duration of seasonal stratification in the water column progressively increases over the northwest European continental shelf (NWES) and adjacent Atlantic in the near future (NF, 2025–2054) and far future (FF, 2070–2099) scenario. By the FF, most of the North Sea is stratified for an additional month per year. The stratification also becomes significantly stronger in the future with the open ocean, the shelf edges, the Celtic Sea and the Eastern and Northern North Sea being most affected. In these areas, Wakelin et al. (2020) found a strong correlation between the strength and duration of stratification and minimum oxygen values in the bottom layers. To a lesser extent, this holds also for the net primary production and the bacterial respiration.

Recommendation:

Since Wakelin et al. (2020) showed that the increase in stratification strength and duration have an impact on the oxygen situation at near bed layers, this aspect should be regarded by setting up different bottom oxygen scenarios.

4.3. Net Primary Production

According to the simulation of Wakelin et al. (2020), net primary production (netPP) will have increased in all areas except for the western and central North Sea by the end of the 21st century. A regional POLCOMSERSEM simulation under the SRES A1B medium emissions scenario (Holt et al. 2012) shows that nutrient availability exerts major control over the primary production, finally leading to reduced netPP in the open ocean and the northern North Sea and higher netPP elsewhere on the northwest European continental shelf (NWES). In a global MPIOM-HAMOCC simulation under the A1B scenario, Gröger et al. (2013) found a strong decline (~30 %) in the productivity of the whole NWES by 2100 due to reduced nutrient supply from the deep Atlantic. According to Holt et al. (2018), a reduced circulation of the North Sea can lead to significant increases of

winterly dissolved inorganic nutrient concentrations in the near-coastal regions. This will be matched by a corresponding change in annual net primary production (increase of up to 30 %), suggesting an enhanced risk of coastal eutrophication.

Recommendation:

In applying model approaches for the impact of climate change processes on the status and the biodiversity of benthic organisms, the net primary production has a strong influence. As proposed by different publications, the netPP should be regarded in respective model scenarios in two ways: with a reduction by 30 % on one hand (off-coast), and with an increase by 30 % (coastal regions) on the other hand. This could get an impression of the magnitude of this impact on the benthic fauna with regard to climate change effects in different marine areas.

4.4. Bacterial Respiration

Bacterial respiration is the main process that consumes oxygen near the seabed. Respiration rates are higher in coastal regions. By the end of the 21st century, respiration will have increased in most regions except for the Norwegian Trench, along the whole shelf edge and in the western North Sea. One reginal event is the fact that west of Denmark respiration increases despite a weak reduction in netPP due a reduction in the strength of the southern North Sea current (Holt et al. 2018), so that a larger proportion of detritus produced in this region reaches the seabed, offsetting the decrease in netPP.

Recommendation:

Since bacterial respiration processes are difficult to be quantified and lack respective measurements over the marine areas of interest and furthermore, have a direct impact on the oxygen conditions, in particular in near bed layers, the impact of possible increases of bacterial respiration on benthic organisms due to climate change should be included via the oxygen pathway.

4.5. Bottom Oxygen

In addition to trends in annual mean oxygen concentrations, the seasonality of the oxygen cycle will change, too. Following the described climate change processes, near bed oxygen will be generally lower throughout the year, but also the amplitude and timing of the seasonal cycles will change. In general, the amplitude change corresponds to the changes in netPP and the related bacterial respiration processes; regions with reduced or small increases in netPP will have reduced amplitudes while regions with larger increases in netPP will have increased amplitudes. The month of minimum oxygen concentration in the western northern North

Sea is about to change from October to November because the peak regional mean SST (sea surface temperature) and NBT (near bed temperature) also occur later in the year. This affects oxygen solubility, which contributes to the delay in the month of minimum oxygen.

In the near future (2025 to 2054), the region in the eastern North Sea with minimum oxygen below 5 mg L−1 will grow and also include a region with minima below 4 mg L−1 while the area with 6 mg L−1 and below will extend to further areas. By the end of the century, minimum oxygen in the eastern North Sea might be widely below 2 mg L−1, and only coastal areas, the outer shelf regions, and the western North Sea – dynamic regions with vertical water exchanges and higher productivity – may still lie above 6 mg L−1.

Recommendation:

Since oxygen conditions – and with a particular focus on the minimum concentrations that can be reached in near bed layers of the water column – have a very high impact on the living conditions for marine organisms, and especially for those who cannot escape minimum conditions such as the benthic fauna, as well as on the biodiversity of the organism groups, the possible future scenarios for minimum oxygen concentrations and the duration of the minimum conditions should be taken into account by the modelling approaches. If possible the effects on selected groups should be simulated for oxygen concentrations of 5, 4 and 2 mg L-1 and for different durations of these conditions in days.

5. Conclusions

As outlined before, climate change processes are an undeniable fact and will have a great impact on the living flora and fauna as well as on the biochemical cycles being related. Strong increases in water temperatures have already been observed and will go on within the coming decades. The temperature changes will the basis for changes of other parameters in the marine system as well, such as stratification processes in the water column, net primary production effectiveness, bacterial respiration, and – as a final consequence – of the oxygen budget. In particular, this will affect minimum oxygen concentrations near the seabed. This and the temperature increases themselves will have a strong direct impact on the conditions and the biodiversity of the bottom-living organism groups, which play an important and often underestimated role in the global biogeochemical cycles.

For a better understanding and a better chance of maybe quantifying these climate change effects, it seems very important to simulate the impacts by appropriate modelling approaches. In this context, the LiACAT/ACIM model system may be a valuable tool with the aim to get an estimate on how strong the climate change processes will affect the benthic organism groups and their biodiversity.

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