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Climate change and intensifying human use call for a monitoring upgrade of the Dutch North Sea

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ABSTRACT

Regulatory monitoring of the Dutch part of the southern North Sea does not provide sufficient information to understand the observed changes in the physical, chemical and ecological environment. As a result, the Dutch North Sea policy and management is not appropriately supported by data. The monitoring lacks explicit objectives for integrated management and knowledge enhancement about system functioning. Ecological processes are not included in the programs. There is neither integration of monitoring of physical, chemical and biological parameters, nor is there integration of regulatory monitoring, project monitoring and applied in-depth research. In the meantime, the effects of climate change, the upscaling of renewable energy, and plans for intensifying offshore aquaculture make appropriate monitoring even more urgent. The Dutch North Sea management is therefore faced with the challenge of adapting the current monitoring without compromising continuity. This can be done by making monitoring hypothesis-driven, setting up an integrated monitoring strategy based on regulatory and project-based monitoring, combining structure and process measurements, applying new smart automated techniques, increased use of modelling and remote sensing, and conducting in-depth measurement campaigns. As the North Sea is bordered by several countries, such a renewed effort should be done in coordination with these countries.

1. Monitoring is due for an “upgrade”

The management of the North Sea is faced with the task of organizing all human uses in such a way that it leads to a good environmental status (GEnS) and a healthy ecosystem (*sensu* the Marine Strategy Framework Directive, MSFD, Borja et al., 2013). The GEnS needs to be achieved under increasing human pressures from activities such as the energy transition (offshore renewable energy, decommissioning of oil and gas platforms), dredging and sand extraction, and aquaculture farms (Andersen et al., 2013; EEA, 2015). In combination with the impacts from current and future climate change, this places great demands on our understanding of the functioning of that ecosystem and thus on monitoring and research of the North Sea (Birchenough et al., 2015; Coolen et al., 2020; Edwards et al., 2020; Foley et al., 2010; Murray et al., 2018).

This opinion paper argues that the current Dutch regulatory monitoring program is insufficient to understand the recently observed changes in ecosystem functioning (section 2). Concurrently, we face a future with imminent climate changes and changes in and intensification of human use of the North Sea (section 3). This demands an “upgrade” of our current regulatory monitoring practices (section 4).

2. The Dutch North Sea monitoring program

Only in the last fifty years laws were developed to protect the natural environment and regulate the use thereof, such as the Birds Directive (BD), Habitats Directive (HD), Common Fisheries Policy (CFP), Water Framework Directive (WFD) and Marine Strategy Framework Directive (MSFD). The first steps towards obtaining data over a longer term through structural and regulatory monitoring are related to these laws. Hence, also the Dutch monitoring history is relatively recent. The Dutch regulatory monitoring network started in the 1970s with a relatively high spatial density and temporal frequency and covered various physical, chemical and biological parameters. While commercial fish stock measurements have been carried out since the 1950s, monitoring for suspended matter, nutrients, oxygen, contaminants, phytoplankton,

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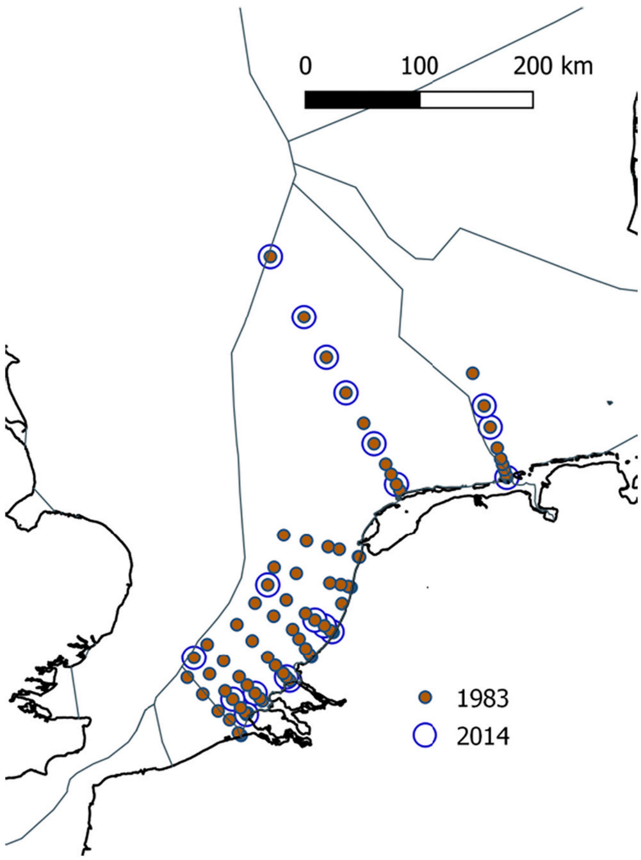

Fig. 1. Overview of the Dutch monitoring network in the North Sea for (*inter alia*) nutrients. The brown dots indicate the locations of the measuring stations in 1983 and the blue circles indicate the location of the stations in 2014. No stations are within 2 km of the shore, indicating that all processes occurring in shallow waters are missed (like sand transport). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

zooplankton, benthos, marine mammals and birds was added later.

Much has changed in the monitoring practice over time, some for the good, but unfortunately also for the bad. For example, the number of sampling stations and the frequency for the monitoring of chemical substances and phytoplankton have been considerably reduced (. Fig. *1*, see also Baretta-Bekker et al., 2009). Also, the number of measurement parameters for phytoplankton has been reduced whilst zooplankton is not measured at all (Alvarez-Fernandez and Riegman, 2014).

The decline in the regulatory monitoring network is to some extent offset by an increase in project-based monitoring effort related to (new) activities in the North Sea, such as those for protected areas, offshore wind farms, sand extraction and coastal nourishments. For macrobenthos, project-based monitoring over the last decades has supplied valuable additional data on local benthic species diversity, adding insights into changes on benthic quality changes (Wijnhoven, 2018. Also, offshore wind farm monitoring programs have provided valuable data on marine bird and mammal abundance and distribution in recent time (Lindeboom et al., 2011).

2.1. *Monitoring is not aimed at gathering causal knowledge and insight*

The following core objectives for monitoring are specified in the Dutch MSFD Monitoring Plan 2014–2020 (Ministries of Environment and Infrastructure and Economic Affairs, 2014):

- trends and status description of water systems, both chemical and biological
- testing against the water quality objectives (norms) of national policy
- complying with national and international agreements, treaties and other obligations regarding the measurement of water quality (…).

The current Dutch regulatory monitoring program thus explicitly is not aimed at gaining insight into cause-effect relationships that are relevant for management. It serves the OSPAR and MSFD reporting cycles (status reports) that focus on changes in status parameters.

The MSFD explicitly mentions the ecosystem approach as the basis for how management should be carried out. This is not possible without proper knowledge of the processes that drive ecological functioning and the human uses that interact with them. The current regulatory monitoring is data-rich, but information-poor (DRIP, Wilding et al., 2017), or, as other researchers frame it, "collect data now, ask questions later" (Haughland et al., 2010). One example is the monitoring of phytoplankton. For all the data from regulatory monitoring, there still remain large questions on how phytoplankton actually is limited by nutrients and light (Loebl et al., 2009, see also section 2.3). These issues have been highlighted regularly over the last decade, yet without any change to the phytoplankton monitoring program or dedicated monitoring programs.

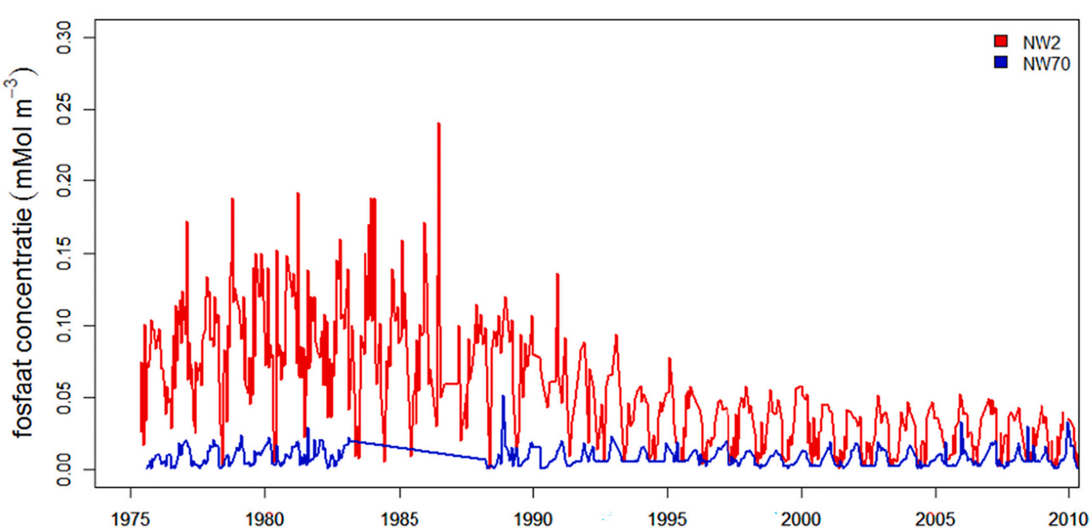

Fig. 2. Phosphate concentrations on two stations of the Noordwijk transect. NW2 is 2 km from the coast, NW70 is 70 km from the coast.

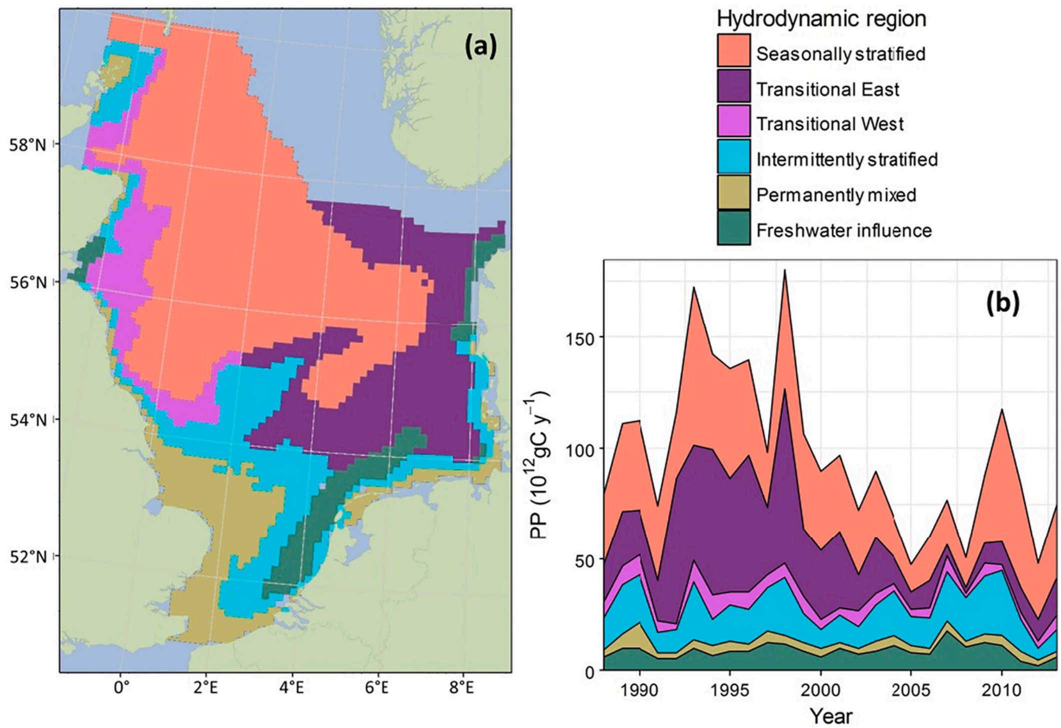

Fig. 3. Gross primary production (PP) in the southern North Sea subareas from 1988 to 2013 (Capuzzo et al., 2018). (a) spatially denotes the hydrodynamic regions; (b) gives the changes in PP from 1987 to 2015 in these regions.

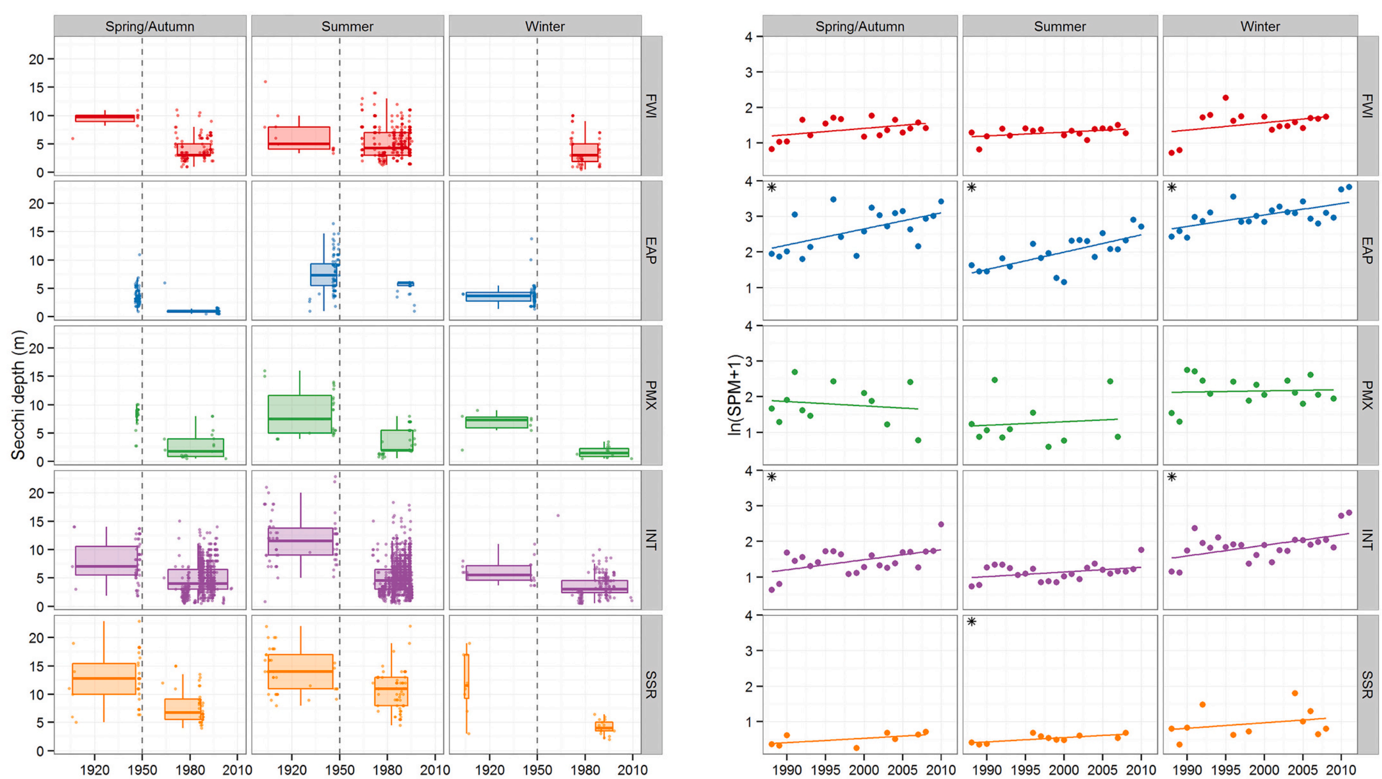

Fig. 4. Seasonal observations of Secchi depth (left) and SPM concentrations (right) in different parts of the North Sea (Capuzzo et al., 2015). The abbreviations to the right of each figure denote different North Sea areas: EAP, East Anglia Plume; FWI, freshwater influence; INT, intermediate; PMX, permanently mixed; SSR, seasonally stratified.

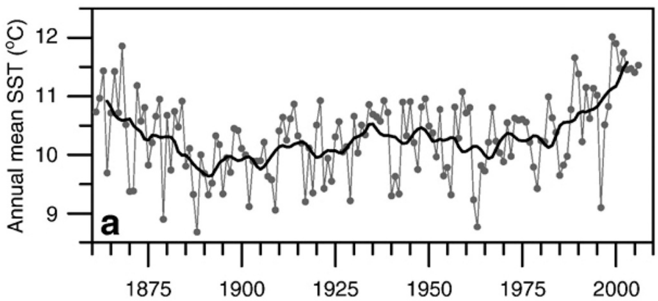

Fig. 5. Sea Surface Temperature (SST) since 1910, North Sea (van Aken, 2008).

Also, the lack of zooplankton monitoring is quite enigmatic from an MSFD point of view. For that reason, all monitoring should be hypotheses-driven and process-oriented, explicitly addressing the how and why of changes.

2.2. There is too little coherence between the various monitoring plans

Consistency and coherence in the monitoring plans must be based on knowledge about the functioning of the ecosystem related to its management and, in turn, contribute to deepening that knowledge (Barnard and Elliott, 2015; Lindenmayer et al., 2011). Integration of long-term monitoring programs and dedicated monitoring surveys is necessary to move from a 'collect data now, ask questions later' approach to a more interactive, questions driven and adaptable monitoring (Haughland et al., 2010; Lindenmayer et al., 2011). The aforementioned MSFD monitoring plan mentions the European Commission's recommendation to "ensure greater coherence between the criteria used in good environmental status, the impact assessment and the proposed objectives". However, in Dutch policy there is no reference to be found that provides text and explanation about this elaboration. The above-mentioned project monitoring is not integrated with regulatory monitoring, and it is thus not clear how this information and the regulatory monitoring ensue this greater coherence. Recently, a serious attempt has been made to bring together data sets on macrobenthos monitoring to assess a 'T0' quality status for Dutch macrobenthic assemblages (Wijnhoven, 2018). Such approaches can form the basis for deriving the necessary, 'forward-planning' and hypothesis-driven monitoring strategies. In the Belgian monitoring program for offshore wind farms, this strategy is brought forward by making the distinction between *a posteriori* baseline monitoring, and *a priori* targeted monitoring (Degraer et al., 2018). How such hypothesis-driven targeted benthic monitoring could look like for offshore renewables has been worked out in (Dannheim et al., 2019).

2.3. The monitoring lacks integration

As a reaction to widespread eutrophication effects, most countries around the North Sea started an extensive monitoring program for nutrients and chlorophyll *a* (Baretta-Bekker et al., 2009; Desmit et al., 2019). Measurements from the MSFD program for nutrients and phytoplankton show long-term changes in nutrient concentrations and in nutrient stoichiometry (Fig. 2). However, algal biomass or production do not follow suit.

Fig. 2 shows that the phosphate concentration along the Dutch coast has fallen sharply. Because nitrate has decreased less, the nitrogen-phosphate (N / P) ratio along the coast has increased, while further off the coast the changes are small. Comparison of this data with primary production (PP, Fig. 3) shows that the phosphate decrease does not keep trend with the decrease in PP (Capuzzo et al., 2018; McQuatters-Gollop et al., 2007). Apparently, there is more going on. Simultaneously with the changes in nutrients, researchers observed that large parts of the North Sea are becoming more turbid (Capuzzo et al., 2015), Fig. 4). The potential carrying capacity of the North Sea ecosystem may therefore be

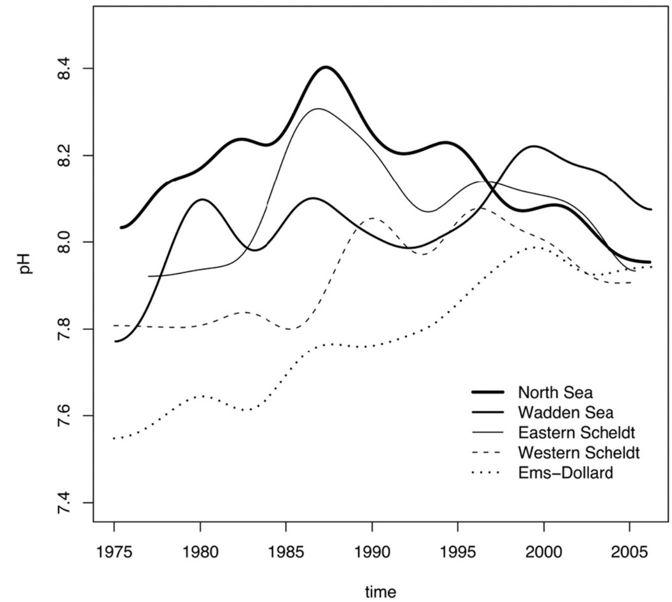

Fig. 6. Long-term changes in pH of Dutch North Sea and inland waters (Provoost et al., 2010).

affected by the increased turbidity, which according to (Wilson and Heath, 2019) can be attributed to changes in the North Sea wave climate, most probably resulting from climate change.

Apparently, North Sea-wide changes in resource availability are occurring at the base of the food chain, without our understanding of responsible processes and current human activities. Current regulatory monitoring will not provide this insight. To understand how these incongruencies come about, there is the need for integrated monitoring of nutrients, chlorophyll *a*, primary production and suspended matter concentrations with more spatial and temporal detail than in the current monitoring program.

3. Monitoring is not future-proof

The North Sea ecosystem will have to deal with many changes at the lower trophic levels in the near future, both as a result of changes in human activity and due to ongoing climate change. It is worth remembering that we are now only in the initial phase of warming up (Fig. 5) and acidification (Fig. 6). Nevertheless, it is already clear that the North Sea is warming up faster than the surrounding marine areas (Tinker et al., 2020).

The plans for large-scale wind power installation in the near future may lead to additional system-wide changes in nutrients, turbidity and primary production (Boon et al., 2019; Carpenter et al., 2016; Floeter et al., 2017) and changes in connectivity (Coolen et al., 2020). Wind farms therefore generate local changes at the basis of the food web. Such local changes can lead to larger-scale, even systemic changes when large-scale offshore wind farms are constructed (Boon et al., 2019), which can be exacerbated by climate change (Rees et al., 2006). In this area we lack the most basic measurements and understanding. Knowledge of offshore windfarm effects on ecological functioning is severely limited (Boon et al., 2019; Dannheim et al., 2019). Also, plans for large-scale offshore aquaculture for seaweed and mussels are underway, which may lead to extensive extraction of nutrients and carbon (Campbell et al., 2019; Kim et al., 2015). Although such farming may reduce nutrient loading in highly eutrophied coastal seas such as the East China Sea (Zheng et al., 2019), when applied in less nutrient-rich shelf seas such as the North Sea, reducing nutrients stocks may affect the amount of organic matter fuelling the marine food web.

As a result of these man-made activities and climate change, fisheries

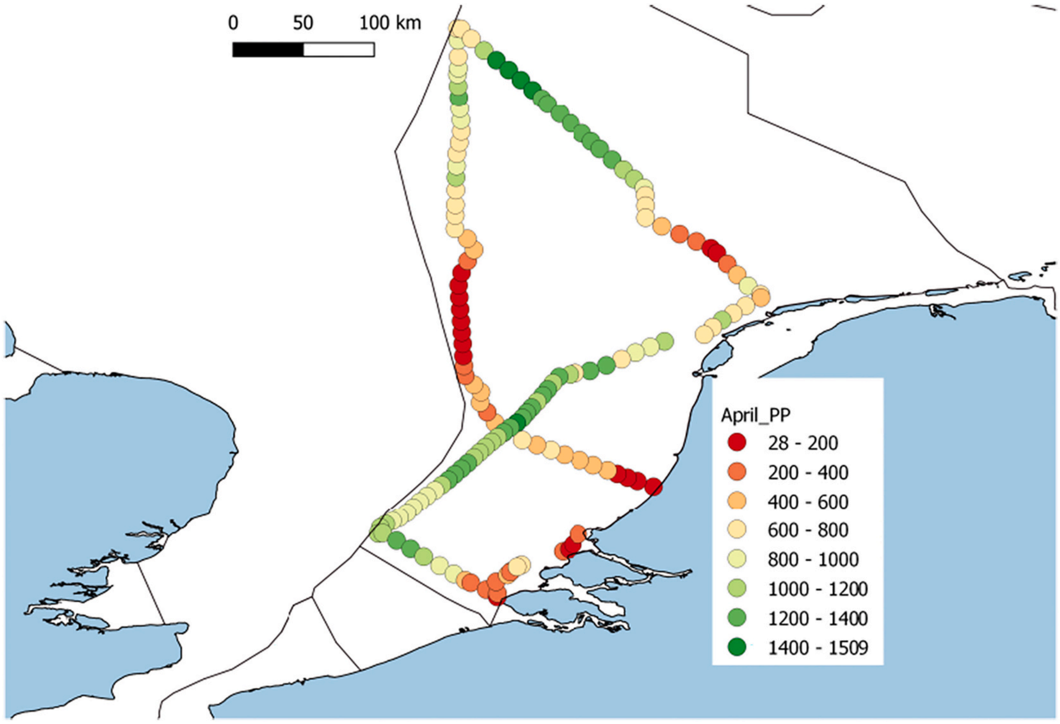

Fig. 7. Estimates of primary production (mg C.m^{-2}.day^{-1}) obtained from automated photosynthesis measurements obtained using Fast Repetition Rate Fluorometry in April 2017 (see (Aardema et al., 2019)).

pressure will shift spatially. Furthermore, shipping is projected to increase (Matthias et al., 2016) and sea level rise will lead to more sand extraction and coastal nourishments (Stronkhorst et al., 2018). These changes are likely to have a major impact on the physical, chemical and low-trophic (algae, zooplankton, benthos) biology of the North Sea (*e.g.* Boon et al., 2019; Dannheim et al., 2019). The number of trophic levels from phytoplankton to apex predators may change, and thus the efficiency at which organic matter produced by phytoplankton can end up in higher trophic levels may change thereby as well, and this will impact the carrying capacity for individuals populations (Coll and Libralato, 2012). To get a better handle on this requires process knowledge and integrated approaches. Our system knowledge is limited and insufficient to understand the effects of human actions on the functioning of the system, its carrying capacity and to translate these into management adjustments (Rees et al., 2020).

4. Moving forward

Various studies have pointed to the importance of adaptive, iterative, hypothesis-based monitoring as part of the so-called ecosystem approach for managing the marine environment (Atkins et al., 2011; Heenan et al., 2016; Jacobson et al., 2014; Kupschus et al., 2016; Wilding et al., 2017). Moreover, the ecosystem approach has become the tenet of the MSFD. A cross-section of the recommendations following from these studies, coupled with the shortcomings outlined, leads to the following suggestions for improvement of monitoring strategies and plans:

4.1. Improve causality in monitoring strategies

Hypothesis-driven monitoring needs to become the basis for setting up regulatory and project-based monitoring (Wilding et al., 2017). It needs to be clear why measurements take place, with which reliability, how monitoring adds to the body of knowledge needed to answer specific research and management questions, and when monitoring needs to be adapted. Such an approach needs to be laid down in the iterative, cyclic programs and assessments for the MSFD. This demands a strong cooperation between scientists, policy makers and managers from the start of setting up monitoring plans (Heenan et al., 2016; Lindenmayer and Likens, 2010).

4.2. Integrate regulatory and project-based monitoring

When hypothesis-driven monitoring becomes the central approach, it is possible to integrate the regulatory and project-based monitoring (Zampoukas et al., 2013). The research objectives and management goals need to be compared and adjusted where necessary to provide for complementary monitoring and research. Specific knowledge gaps can be addressed by in-depth measurement campaigns. By applying such a tiered and integrated approach, both structure and process information at different spatial and temporal scales can be gained (Kupschus et al., 2016; Lindenmayer and Likens, 2010).

Another means for integrating monitoring is to strengthen the international cooperation for all levels of monitoring. Such cooperation takes already place to some extent in OSPAR through the Joint Assessment & Monitoring Program (JAMP). Although such processes are expected to progress slowly, effectivity and efficiency can be greatly improved when monitoring programs are coordinated internationally (Heenan et al., 2016). Approaches for project-based monitoring such as those for offshore wind farms in Belgium (Degraer et al., 2017), or the UK MCCIP (Marine Climate Change Impacts Partnership) focusing on the ecosystem impact of and adaptation to climate change in the UK (see *e.g.* Edwards et al., 2020) provide interesting examples for the Dutch situation.

4.3. Future-proof monitoring

The expectation of low-trophic impacts from climate change and the increase in offshore windfarms and aquaculture demand an increase in monitoring effort on phytoplankton and zooplankton (Floeter et al., 2017; Hays et al., 2005). Such changes may drive habitat use by marine mammals and birds (Cox et al., 2018). Hence, for both plankton groups, it is important to get insight into their production, both at a North Sea scale and at smaller scales such as around wind farms and aquaculture farms.

An example of a new and process-oriented monitoring methodology for automated primary production is currently tested in MONEOS (Western Scheldt monitoring) and in the North Sea (H2020 Jerico-Next). Fig. 7 gives an example of automated primary production estimates obtained using advanced and automated fluorometric techniques (Aardema et al., 2019).

Changes at the primary production level are likely influenced by large-scale climate-driven changes in wind and temperature, affecting wave climate and stratification (Sharples et al., 2020; Wilson and Heath, 2019). Large-scale implementation of offshore wind farms may cause systemic changes to regional wind and wave climate in turn influencing regional wave climate and stratification (Boon et al., 2019; Carpenter et al., 2016). Dedicated and integrated measurement programs will be needed to get insight into local oceanographic dynamics around offshore wind farms and how these affect primary and secondary production of plankton and benthos (Dannheim et al., 2019).

Modelling will be essential to simulate and understand these oceanographic changes and anthropogenic activities and how they affect primary and secondary production processes (Burkhard et al., 2011; Capuzzo et al., 2018). Furthermore, modelling will be an important aid in developing and adapting a suitable monitoring strategy (Dowd et al., 2014; Marzloff et al., 2016; Pastres and Solidoro, 2012). Data requirements for modelling can partly be met with the increasing availability and quality of remote-sensing data (Strong and Elliott, 2017; Vanhellemont and Ruddick, 2014).

Lastly, there is discussion on how knowledge and scientists can play a role in the management decision-making process, especially under relatively data-poor circumstances and high uncertainty (Giebels et al., 2016). Making decisions under high uncertainty will likely be more rule than exception in marine management. Understanding this uncertainty, and not shying away from using it to making decisions in monitoring and management is one of the tenets for hypothesis-driven monitoring (Wilding et al., 2017) and assessing the effects of human activities (Willsteed et al., 2017). Monitoring and research should be aimed at decreasing uncertainty for prioritised knowledge gaps (Dannheim et al., 2019). Hence, the above-mentioned changes to the Dutch monitoring strategy need to be solidly embedded in the scientific community. The Dutch scientific community therefore deserves an active and above all independent role in shaping the future monitoring upgrade.

Declaration of Competing Interest

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