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 Opinion Paper

Offshore wind park monitoring programmes, lessons learned and recommendations for the future

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Abstract Over a decade of monitoring offshore wind park environmental impact triggered a reflection on the overall objectives and how to best continue with the monitoring programmes. Essentially, basic monitoring has to be rationalised at the level of the likelihood of impact detection, the meaningfulness of impact size and representativeness of the findings. Targeted monitoring is crucial and should continue to be applied to disentangle processes behind observed impacts, for instance the overarching artificial reef effect caused by wind parks. The major challenge, however, remains to achieve a reliable assessment of the cumulative impacts. A continuous international consultation and collaboration with marine scientists, managers, government officials and industry will be needed to ensure an optimisation of the future monitoring programmes.

Keywords Offshore wind parks · Environmental impact monitoring · Monitoring advice · Basic and targeted monitoring · Cumulative and in-combination effect monitoring

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Introduction

Offshore wind energy is becoming more and more important in European energy politics and by 2020, the aim is to generate 12% of European energy

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demand from renewable sources. If this mainly has to come from offshore wind parks (OWPs) a minimum of 10,000 turbines are needed (Westra, 2014).

The first wind turbines at sea were installed in Danish waters in 1991. The first real offshore North Sea wind park came into operation in Denmark in 2002, followed by The Netherlands in 2007, UK and Belgium in 2008 and Germany in 2010. For all OWPs, monitoring programmes to investigate the impacts on the surrounding marine ecosystems were started and many results have now been published (Elliott, 2002; Wilson et al., 2010; Lindeboom et al., 2011; Degraer et al., 2013; Beiersdorf & Radecke, 2014; Bergström et al., 2014). In this article, we summarise the present state of art, lessons learned and recommendations for future monitoring programmes.

Offshore wind park environmental monitoring—where are we now?

The global scientific knowledge base associated with the environmental effects of OWPs has been led by northern European countries. Environmental data collection on OWPs started around 2000, first in Denmark (Petersen & Malm, 2006; Leonhard et al., 2011). Many of the early efforts only served to develop survey methods, primarily driven by societal, legislative or conservation demands (e.g. Degraer & Brabant, 2009). Early results indicated possible effects on (the introduction of) hard substratum fauna, seabirds and marine mammals (Petersen & Malm, 2006). Since 2006–2008, research effort at a European/global level has increased significantly. During the last ($\sim$) 6 years, the Danish, Dutch, British, German and Belgian monitoring programmes accomplished an unprecedented knowledge base on OWP effects on the marine system, covering a wide range of potential impacts and all ecosystem components (Lindeboom et al., 2011; Bergström et al., 2014). All these investigations have contributed to an almost exponential increase in the knowledge of the understanding of potential OWP effects over the last years (Fig. 1). The scientific understanding has been enhanced in some topic areas, particularly at the species level for some benthic animals, fish, birds and marine mammals, whereas other ecological topics such as ecosystem functioning have been left behind or neglected (Inger et al., 2009; Miller et al., 2013). Nowadays, we have a good knowledge on many of

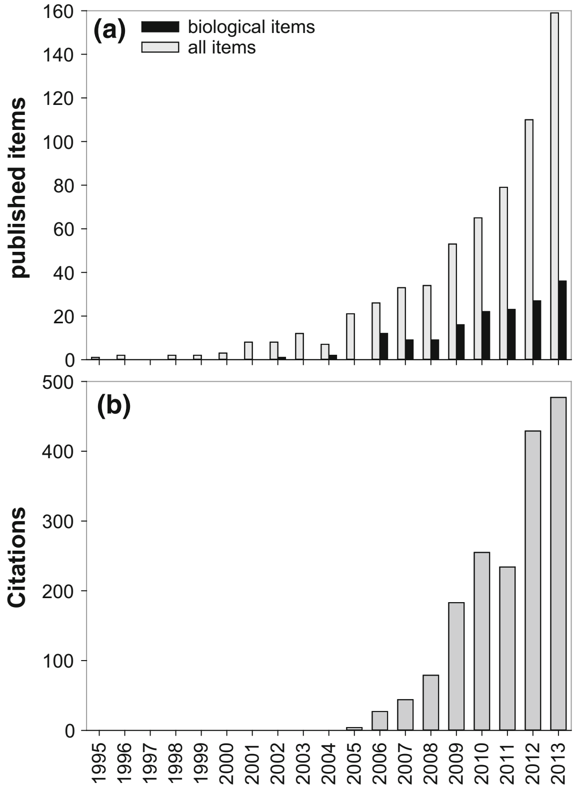

Fig. 1 Offshore wind-related environmental publications; **a** publications and **b** citations per year. (source ISI Web of Knowledge)

the general short-term effects on the marine system, while we are far away from fully understanding the ecological significance of the effects and only just beginning to consider the knowledge requirements for long-term changes. While most aspects associated with the interactions between OWPs and the environment have been included to a greater or lesser extent, there has not been a consistent development of the topic areas building on the evidence from previous studies in different countries (Boehlert & Gill, 2010).

Lessons learned

The overriding lesson from the monitoring that is currently taking place across Europe is that OWPs do change the local environment. Importantly, these changes are across all ecosystem components and some can be regarded as (potentially) negative, e.g. avoidance and collisions of birds and some (potentially) positive, e.g. increased biodiversity and local fish populations (e.g. Wilhelmsson et al., 2010; Lindeboom et al., 2011; Bergström et al., 2014). The major impacts of OWPs are focused on the most obvious changes within the local environment such as the very high sound levels produced during the construction phase (Huddleston, 2010; Norro et al., 2013), the introduction of (new) hard substratum (Petersen & Malm, 2006; Langhamer, 2012; De Mesel et al., 2015), the rotating blades (Drewitt & Langston, 2006; Mendel et al., 2014) and the exclusion of fisheries, such as trawling (Lindeboom et al., 2011; Dannheim et al., 2014). We have gained knowledge on the short-term effects on benthos, fish, birds and marine mammals, including attraction to and avoidance of the OWP (for references: see Lindeboom et al., 2011), while the longer term effects of successional stages and consequent changes in e.g. the food web still are in the early stages of understanding. We have learned more about the variability of the ecosystem indicating that long-term monitoring is needed to be able to detect various effects through time, e.g. the effect of trawling cessation on the benthos (Lindeboom et al., 2011) or the displacement effects on seabirds (Vanermen et al., 2015a). We learned that basic monitoring by itself (e.g. following the BACI design of OWP versus reference area) is not sufficient to disentangle specific cause–effect relationships, especially in systems with a high natural variability (Gray & Elliot, 2009; Lindeboom et al., 2011). Particularly, targeted monitoring such as the near turbine effects studies on benthos (Coates et al., 2014), feeding behaviour of demersal fish in the wind park (Reubens et al., 2011, 2014a, b) or escape behaviour of harbour porpoises during piling (Haelters et al., 2015), have provided significant new and important knowledge on cause–effect relationships (see also Degraer et al., 2013: Chapters 13–16).

Although some of the outcomes are only preliminary, the interpretation of what is occurring and whether it is partly negative, partly positive or unknown or unclear is in accordance with the general ecological implications scientists expected (Gill, 2005; Boehlert & Gill, 2010; Miller et al., 2013). Probably, the most striking changes in the marine system are, however, yet to come: effects of the continuous operational sound (Slabbekoorn et al., 2010), the long-term habitat change by epifouling communities on the turbines and scouring protection, i.e. the artificial reef effect (Wilhelmsson & Malm, 2008; Kerckhof et al., 2011; Krone, 2012) including subsequent changes in the surrounding soft sediments (Coates et al., 2014), and the recovery of benthos and fish after fisheries cessation (e.g. Collie et al., 2000; Duineveld et al., 2007; De Juan et al., 2011).

The results give cautious optimism that some of the anticipated changes that will occur are perhaps not as bad as perceived at first. The separation into positive and negative changes—in part a requirement of the EIA process (cf. EC Environmental Impact Assessment Directive)—enables the OWP sector to champion the good and mitigate the bad (Cramer Buch, 2013). By doing so, the sometimes presumed conflict between the OWP industry and the environmental sector can be addressed by using an evidence-based, rather than emotive-based assessment of what large-scale deployment of OWP means for the environment and human society. The longer term and harder-to-quantify potential ecological benefits of OWP, such as the no-fishing zone factor improving the fish community, are important to determine if there is to be general acceptance of the OWP being beneficial, especially when the parks become much larger. To decide whether or not an observed impact is to be considered positive or negative one has to be aware of the fact that such evaluation is scale and hence context dependent. Prior to such evaluation, scale and context have to be clearly defined. Our vision of OWPs as good or bad features in the seas will hence always be debated, but the evidence presented in this special issue of Hydrobiologia sets a valuable basis for the debate to continue on a more informed basis.

Furthermore, the changes that occur to one component of our marine ecosystem can have implications on other ecosystem components. Hence, the indirect aspect of changes to the ecosystem components (whether that is species abundance change or sediment movement for example) and the processes that cause these changes (such as food web cascade or hydrodynamic processes) are issues that should be highlighted and will be a major driver for the future direction of the research and monitoring programmes. For example, demersal fish might benefit from additional prey items on the OWP foundations and therefore might be attracted (Wilson and Elliot, 2009; Reubens et al., 2014a). At the same time, these species might also feed on species of the soft-bottom in the vicinity of the turbines which might increase predation pressure (Dannheim, 2007). By this predation pressure, these "multi-choice" consumers can switch between different prey items and thus reduce prey population oscillations and prevent one single species from becoming dominant (Berlow, 1999; Post et al., 2000; McCann & Umbanhowar, 2005), potentially changing the composition of the benthic system at a local scale. Naturally, marine ecosystems are chaotic by the unpredictable and manifold species interactions (e.g. mutualistic, competitive and trophic interactions) and the large natural variability (Weijerman et al., 2005). Hence, the question that emerges is if the outcomes of the research on the long-term effects can really be explained by the increasing presence of many different wind parks.

A more specific lesson is that for any monitoring programme for OWPs to be effective, it needs to have an objective, multi-disciplinary approach (see also Elliott, 2011). For example, the understanding of sediment distribution requires certain skills while the socio-economic research uses another set of skills; both of these topics are as equally valid as each other.

Advice for future monitoring

Future monitoring is a requirement of environmental legislation across many countries. However, the current knowledge from the OWP monitoring programmes makes a very strong case for not just monitoring (sensu post hoc observations) aspects that are the minimum (usually based on existing environmental legislation). There are significant advances in understanding and also identifying limitations and gaps that need to be addressed. The future challenge for monitoring OWP effects will be to achieve a balance between legally prescribed monitoring procedures, nationally and internationally, and at the same time to allow a flexible and adaptable approach that allows for the analysis of clearly defined priority issues. For a robust ecology-based monitoring programme there must be consideration of all components, from which a subset of priority components can be selected. The prioritisation should be considered over different time and spatial scales and for a combination of the different components of the ecosystem, otherwise only single components will be monitored as is currently the case. The wider and potentially more significant indirect effects need to be addressed and should be in the monitoring focus for the upcoming years. In the next paragraphs different monitoring needs applicable to wind parks are discussed.

Basic monitoring

Basic monitoring focusing on the resultant effect of human activities, such as the construction and operation of offshore wind parks, is the most common type of monitoring in environmental impact studies. It allows keeping track of major and even unforeseen impacts and is therefore a suitable research strategy for a better understanding of the environmental impact of development. It may trigger adjusting or even halting activities in case unacceptable impacts would occur. The continuation of the basic monitoring covering all ecosystem components should hence be considered mandatory from a marine ecosystem management perspective. Some reflections on what has been done so far and how to best continue are, however, indispensable for an optimisation of the future basic monitoring programme.

In many monitoring programmes, there is an attempt to differentiate between ‘positive’ and ‘negative’ responses to OWPs. Ecologically ‘negative’ impacts may include the altered sediment characteristics, increased erosion of the natural sandy sediments around wind turbine foundations (Vanden Eynde et al., 2013), an increase in the non-indigenous species on the hard substrata (Kerckhof et al., 2011), an obvious disturbance of seabirds because of avoidance and collision (Busch et al., 2013; Vanermen et al., 2015a) and the increased sound pressure on the marine environment and its impact on marine mammals (Haelters et al., 2015; Dähne et al., 2013) and fish (Gill et al., 2012; Krägefsky, 2014). The ‘positive’ impacts include, for example, the enrichment and colonisation of the soft and hard substratum invertebrates and fish (e.g. De Mesel et al., 2015; Coates et al., 2014). So far, all ecosystem components investigated have already shown some degree of response to OWPs. However, as the altered ecosystem is still developing at most if not all OWPs, the patterns observed so far should be considered short term and hence most probably only reflect the initial stages of the ecological change and succession (Lindeboom et al., 2011). Some impacts may not have been detected yet, simply because they are still not developed to the extent needed to become detectable. The enrichment of the soft-sediment macrobenthos observed close to the wind turbines for instance, has been demonstrated to spatially extend through time (Coates et al., 2014) but is likely not to have reached the spatial extent to be picked up by the basic monitoring of macrobenthos, collecting samples at more than 200 m from the turbines (Coates et al., 2013; Gutow et al., 2014). A long-term continuation of the basic monitoring of all ecosystem components is therefore recommended.

For the future of basic monitoring, one should acknowledge the likelihood of impact detection being dependent on research effort, impact size and data noise. Research effort is mainly determined by the focus of the study, the amount of observations or samples collected. Impact size is the degree of deviation from a defined reference condition and data noise is natural or sampling-induced variability in the data (e.g. Collie et al., 2000; Gray et al., 2006). The low likelihood of impact detection possibly blurring impacts of Belgian offshore wind parks on seabirds, has for example been statistically underpinned by the basic monitoring for several seabird species (Vanermen et al., 2015b). The current difficulties in demonstrating consistent impacts on the soft-sediment epibenthos and fish throughout the first 6 years of monitoring in Belgian waters is probably related to a combination of natural and sampling-induced variability and the time scale over which sampling occurs in relation to physico-chemical and biological response. This issue certainly needs further consideration when (re)designing future basic monitoring programmes. Attention should be given to the statistical power needed to quantify the likelihood that an impact of a given extent can be detected, while methods on how to lower the noise in the data should be further explored.

Natural variability may be lowered for instance by focusing data collection on one season and as such excluding seasonality (see also Rogers et al., 2008). Sampling-induced variability will be lowered by increasing the sample size. A higher number of passive acoustic monitoring devices inside and outside wind parks for example, could facilitate investigating possible harbour porpoise *Phocoena phocoena* repulsion or attraction to offshore wind parks (Thompson et al., 2010; Scheidat, 2011; Brandt et al., 2011, 2012; Teilmann & Carstensen, 2012). Moored equipment will allow recording long time series of underwater sound, during a broad range of weather conditions and various wind park development stages, and will hence increase the representativeness of underwater sound results (Dazey et al., 2012). Within a Before-After Control-Impact (BACI) design, an appropriate balance in number of samples per group needs to be targeted.

Finally, the relevance of the impact size needs discussion, as one has to accept a certain degree of human-induced impacts on the marine environment as long as these impacts do not exceed thresholds of sustainability. Current exercises in the context of the European Habitats- and Bird Directives (Nature 2000), and the Marine Strategy Framework Directive (MSFD) to determine what is acceptable from a nature conservation point of view (Nature 2000: Favourable Conservation Status and Conservation Objectives) or from an ecosystem-based management perspective (MSFD: Good Environmental Status and Environmental Targets), will help setting the scene for selecting a meaningful impact limit (Busch et al., 2013).

Also representativeness of the basic monitoring findings is a major issue to be considered in the future monitoring programme. The research so far mainly focused on single wind parks which may not be representative for other wind parks by default. Other wind parks are present, are being built or will be constructed, each of these taking a specific position along an onshore-offshore, a bathymetric and/or a sedimentological gradient. These gradients all represent and/or influence the hydrodynamics and water characteristics, which in turn affect underwater life. When planning future basic monitoring programmes, the spatial distribution of the sampling effort along natural environmental gradients will therefore have to be well considered.

Additionally, the type of foundation differs between and even within wind parks. Steel monopile, tripods and jacket foundations, the latter generally without erosion protection layer, are most common in European waters (EWEA, 2014), while substantial reef effect monitoring, especially concerning fish and megafauna attraction, has been performed respectively near concrete gravity-based foundations with an extended erosion protection layer (e.g. Belgian OWP monitoring programme, Reubens et al., 2014a, b) or jacket foundations (e.g. German OWP monitoring programme, Krone et al., 2013a). Preliminary comparisons already demonstrated a difference in ecology between the different foundation types (Krone, 2014). To allow for a solid nearshore-offshore comparison and to exclude foundation-related variability, future monitoring programmes should include similar types of foundation both nearshore and offshore. On the other hand, foundation type-effects should be investigated in soft-sediment environments with similar physical conditions and grain sizes. Because available resources for monitoring are limited, a well-considered focus and associated sampling effort and allocation is recommended.

Targeted monitoring

Monitoring results that can be used to steer the design of future industrial projects offer a significant added value to monitoring programmes. For this purpose, a proper understanding of the cause–effects relationships is needed, which will allow extrapolating the study results beyond the study area. Targeted monitoring aims to understand the ecological processes behind the observed impacts and hence allows extrapolating its results for a better design of future wind parks. Targeted monitoring should become an important aspect of all OWP monitoring programmes.

The hypothesised cause–effect relationships behind OWP impacts are plentiful. The Working Group on Marine Benthos and Renewable Energy Developments (WGMBRED) of the International Council for the Exploration of the Sea (ICES) reviewed the cause–effect relationships between offshore renewable energy installations, mainly OWPs, and marine benthos (ICES, 2013). They discovered a wide variety of (possible) causal relationships, all framed in a context of the marine environment ecosystem services affected by renewable energy installations as benthos being a biogeochemical reactor, a large source of biodiversity and an important food resource for higher trophic levels. The biogeochemical reactor context alone, for example, already revealed no less than 17 cause–effect relationships (ICES, 2013). From their analysis, it became obvious that a well-considered selection of priority relationships will be needed to ensure focused but feasible monitoring programmes (see also Cormier et al., 2013). Elliott, (2011) suggested separation in 'needed' and 'nice to know' monitoring. However, if questions concerning EU MSFD descriptors, like marine food webs or sea floor integrity need to be addressed, the difference between need and nice to know becomes rather vague. We suggest that monitoring priorities are defined taking the leading questions into account.

Several cause–effect relationships have already been tackled during the first decades of monitoring. The local enrichment of organic matter in the soft sediment close to wind turbines was found to cause an increase in macrobenthic species richness and density (Coates et al., 2014). Some fish and seabird species were found to be attracted to the wind turbines as a consequence of habitat alterations, such as improved feeding conditions (Reubens et al., 2014b). Individual cod *Gadus morhua* specimens stayed near wind turbine foundations for at least 9 months for shelter and to feed, while common sole *Solea solea* did not stay near individual turbines but just passed through the parks (Lindeboom et al., 2011). Stomach analysis of cod and pouting *Trisopterus luscus* proved that these species primarily predate on the hard substratum epifauna (Reubens et al., 2011, 2014a).

The artificial reef effect will undoubtedly play a key role in future targeted monitoring. It has already received a lot of attention so far, but various cause–effect relationships remain yet to be tackled. The attraction-production hypothesis in artificial reefs has been investigated in detail for several fish, e.g. cod and pouting (Reubens et al., 2014b), but several invertebrate (e.g. edible crab *Cancer pagurus* and European lobster *Homarus gammarus*) and fish species common to OWPs, were so far less investigated (Krone, 2012; Krone et al., 2013a). Investigations of their habitat use for example would shed light on the key habitat features that are essential to maintain a sustained local population of these species.

Also the hard substratum epifouling community, comprising important prey species for the above mentioned predatory megafauna, needs further targeted attention. Biomass estimates of these prey species may be used to extrapolate food availability to the total footprint of a wind turbine and the whole wind park artificial reef (Joschko et al., 2008; Krone et al., 2013b). Energy and fatty acids profiling of both predators and prey or stable isotope methods can open the door to energy transfer estimates and hence elucidate trophic interactions within offshore wind parks (De Troch et al., 2013). Trawling cessation in the OWP area might lead to changes in energy flow and trophic structure of soft-bottom benthos as shown by Dannheim et al., (2014). Further, the soft-sediment macrobenthos in the vicinity of wind turbines may alter trophic connectance, as the increasing abundance may start playing an important role in the artificial reef food web. The artificial reef effect may further explain the attraction of some bird species (e.g. common tern *Sterna hirundo* or great cormorants *Phalacrocorax carbo*) to the wind parks as it is hypothesised that these species benefit from a yet unexplored increased availability of pelagic fish (Vanermen et al., 2015a). Whether or not pelagic prey fish also attract marine mammals, such as harbour porpoises, remains yet to be resolved (Haelters et al., 2013). Krägefsky, (2014) not only showed that pelagic fish were scared away by construction sound but also proved decreased food gathering of mackerel in the OWP area. Whether this might affect species fitness and consequently pelagic fish occurrences in the long run as potential food resources for higher trophic levels remains to be seen. Attention to the pelagic fish community in the future monitoring programme is hence of utmost importance.

The anticipated positive artificial reef effect may be partially neutralised by the underwater energy (e.g. sound generated during the construction (short term) and operational sound and electromagnetic fields (EMFs) (long term)) of offshore wind parks (Gill et al., 2012; Gill et al., 2014). More hypothesis-driven research on the impact of energy emissions on marine mammals, fish and invertebrates (including ontogenetic effects) is needed not only from an ecological perspective but in line with legislative requirements (i.e. MSFD, Descriptor 11) to get a good understanding of the effects of underwater sound and EMF on the marine ecosystem.

The above mentioned cause–effect relationships should ideally be dealt with in an international setting, as the same or at least similar cause–effect relationships are expected in OWPs within the same biogeographic region and to some extent even beyond. This certainly holds true for the southern North Sea, where numerous wind parks are (planned to be) constructed (EWEA, 2014). Given the fact that cause–effect oriented research by definition allows extrapolation outside the area under investigation, there is no need to tackle the same hypothesises in every single OWP. A well-considered international collaboration as aimed for by initiatives such as WGMBRED will avoid unneeded repetition of research. It would hence significantly contribute to an optimal use of resources available for wind park monitoring and bring more cross-bordering knowledge together to address the significant gaps.

Cumulative and in-combination effects

A major challenge for all offshore renewable energy environmental monitoring programmes will be to assess cumulative impacts and to upscale locally observed impacts to the larger scale at which a number of ecological processes take place. The OWP industry is expanding rapidly and new OWPs are arising fast at several places in the North Sea and beyond (EWEA, 2014). Current monitoring efforts, however, mainly focus on the environmental impact of a single wind park and specific receptors (Lindeboom et al., 2011; Degraer et al., 2013; Beiersdorf & Radecke, 2014). Because the species that are affected are part of populations extending over larger areas, the focus of the impact investigation should be widened to consider the population level of those species. For example, for seabirds attracted to the wind parks, there is an increased risk of collision with the wind turbine blades. Whether or not the number of collisions may actually put the sustainability of certain bird populations at risk can however only be reliably assessed when taking account of the multitude of wind parks throughout the range of their populations spatial distribution (Brabant et al., 2015). Similarly, the effect on the population of harbour porpoises avoiding areas of pile driving (e.g. Dähne et al., 2013) can also only be assessed in a cumulative OWP context throughout their distributional range. Furthermore, effects anticipated to be positive from a local perspective, such as the improved feeding condition for demersal fish attracted to the wind turbines, are yet to be evaluated at the population level before final conclusions on the attraction-production hypothesis can be drawn (Reubens et al., 2014b). Hence, there is an urgent need for scientifically sound threshold ranges for acceptable overall mortality or habitat loss, which should be investigated at the spatial scale relevant to the population of each species under consideration and at the scale of the local food web.

OWPs are only one of the many human activities in the marine environment. This is yet another aspect relevant to cumulative impact assessment. Climate change and (major changes in) fishing activities (e.g. new gear types and the upcoming discard ban) also influence ecosystem structure and functioning (Hooper et al., 2005; Bremner, 2008). Assessing the in-combination effect of all these activities and changes or merely framing the observed impact of wind parks in a broader setting, demands a holistic approach and is of major importance for the future management of the marine ecosystem. While this issue is not new to environmental impact assessment, clear research designs to appropriately tackle the issue are largely lacking. Innovative strategies are needed here.

The monitoring of North Sea wide cumulative effects is very ambitious and cannot satisfactorily be dealt with by a single country or research team. It requires a close collaboration between scientists and administrators, preferably across country borders, to assemble and comprehensively analyse all information that is needed. The complexity is illustrated by the analysis of fishing effort, for which realistic distribution maps can only be drafted when Vessel Monitoring System (VMS) data, logbook data and metadata of the vessels from those countries that operate in the area are compiled; an opportunity that is quite often still missing. Future monitoring programmes should therefore strive to upscale their findings in a cumulative and in-combination context, and should search for international collaboration to develop the analytical strategies needed (see e.g. Busch et al., 2013).

Adaptive monitoring

For the transformation to a modern monitoring approach, it is imperative that programmes are adaptive, whereby priorities are reviewed regularly based on the available state of the art evidence within the context of the existing drivers and rationale. It also

Table 1 *In concreto* advice on major topics and issues in future monitoring programmes

Topic	Issue	Advice
General	Uncertainty in conclusions	Incorporate levels of confidence
Sound during construction	Depends on type and technique	Analyse species involved, effects, costs; select sound compromise
Sound during operation	Effects on specific species unknown	Research on different species (e.g. fish, cetaceans, invertebrates)
Electromagnetic fields	Largely unknown, possibly chronic effect	Research on specific groups (e.g. fish, cetaceans, crustaceans)
Species and habitat	Population demographics unknown	Study natural temporal and spatial variability
–	Birds avoidance	Establish avoidance behaviour to develop mitigation strategies
–	Bird collisions unknown or only modelled	Collect factual data, on species of specific concern
–	Effect on bats in wind farms unknown	More research on presence and collision of bats
–	Foundations as stepping stones	Determination of potentially invasive species
Ecosystem and food webs	Ecosystem and seascape scales	Include larger scales than just the OWPs
–	Attraction or production	Establish in situ production and potential fisheries benefits
–	Underlying processes largely unknown	Include more functional (trait-based) assessments
–	Elasmobranchs missing in the system	Investigate how OWPs can potentially contribute to recovery
–	Cascading effects unknown	Develop new methodologies and analytical tools
–	Long-term artificial reef effects unknown	Examine reproduction, growth and survival rates of local species
–	Potential benefits of fish closure unknown	Study closure and displacement effects
Multiple use of OWPs	Can OWPs be used to produce proteins	Study possibilities to culture finfish and shellfish and macroalgae
International cooperation	Exchange of data hampered	Strive for an (open) exchange of knowledge, data and expertise
–	National legislation determines monitoring	More use of science-based ecological criteria and studies of long-term ecosystem developments and regime shifts

means that some components may need to be monitored but on a less regular or less intensive basis. This will enable the targeted monitoring to continue to address the wide set of topics in a strategic manner over the course of the programme of monitoring.

Clarity in the selection of which variables to investigate is another aspect that requires consideration. Monitoring of particular components of the ecosystem has to be fully justified before the actual monitoring takes place. For example, aggregation or displacement are two possible predicted responses to OWPs for certain species. How these are defined and the method used to quantify them is crucial to the analysis and interpretation of the results. An iterative process of clear objective setting and explanation of rationale behind the objectives and consideration of the limitation and any assumptions in the method chosen, is therefore critical.

Future monitoring programmes: *in concreto* advice on major topics

Several issues have been identified as major points needing attention in future OWP monitoring programmes, as derived from literature but equally from discussions at several recent OWP environmental monitoring events such as the OWEZ Symposium (Amsterdam, the Netherlands, 11-12/10/2012: http://www.noordzeewind.nl/owe-2012/), the StUKplus Conference 2013 (Berlin, Germany, 30-31/10/2013: http://stukplusconference.com/conference-material) and the WinMon.BE 2013 Conference (Brussels, Belgium, 26-28/11/2013: hhttp://odnature.naturalsciences.be/winmonbe2013). Table 1 summarises the recommended topics, issues and advices to be considered for a further fine tuning of well-focused monitoring programmes.

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