NIOZ REPORT

NIOZ Report 2021-02

Potential ecosystem effects of large upscaling of offshore wind in the North Sea: Recommendations for further work

Johan van der Molen & Karline Soetaert

Deltares

Rijkswaterstaat
Ministerie van Infrastructuur en W

WAGENINGEN UR
For quality of life

NIOZ

NIOZ Royal Netherlands Institute for Sea Research

NIOZ REPORT

Potential ecosystem effects of large upscaling of offshore wind in the North Sea: Recommendations for further work

Johan van der Molen & Karline Soetaert

This report was commissioned by Deltares as part of the WOZEP research programme funded by Rijkswaterstaat.
In collaboration with Deltares and Wageningen Marine Research.

Please cite as:
Van der Molen, J., and Soetaert, K., 2021. Potential ecosystem effects of large upscaling of offshore wind in the North Sea: Recommendations for further work. Report 2021-02, Royal Netherlands Institute for Sea Research (NIOZ), 't Horntje, Texel, The Netherlands, 13 pp.

Contents

1. Aim of the project 4
2. Short summary of project achievements 5
3. Weaknesses of the current approach and results 6
4. Inventory of potential avenues for further work 6
5. Prioritization and recommendations 12
6. References 13

1. Aim of the project

The main aim of this part of the WOZEP programme was to elucidate and address gaps in the knowledge on the effects of implementation of offshore wind energy generation on environmental targets for indicator species with a high conservation status. When the project started, such indicators included (sea)birds, sea mammals, sharks and rays. A synthesis of the project results is provided by Van Duren et al. (2021). The main research questions are given in Table 1, and a summary of the cascade of the main effects in Table 2. The project was separated into a 'bottom-up' and a 'top-down' approach, where the former addressed the physical and biogeochemical elements of the system up to phytoplankton, and the latter proposed an approach for top predators to assesses their potential vulnerability for changes in bottom-up food web relationships that could be provoked by offshore wind farms. The table also highlights which parts of the cascade of the effects were addressed by these **bottom-up** and **top-down** approaches of the project. Here, we provide a brief summary of the project's achievements and formulate, recommendations for further research.

Table 1. The most important research questions of the project.

Local scale	**Basin scale**	**Ecosystem functioning**
What is the site sensitivity, what is the (minimum) environmental impact, what are the best sites, and what is the best farm layout?	What are the large-scale, long-term consequences for the North Sea ecosystem?	How do these effects cascade/interact/propagate through the system and affect the indicator species?

*Table 2. Overview of the cascade of main ecosystem regulation mechanisms. The elements of the cascade of regulation mechanisms (partially) addressed by the **bottom-up approach** are highlighted in yellow and by the **top-down approach** in blue. Light shades indicate elements currently addressed in the project, dark shades indicates elements recommended for further work.*

Effect of wind farms	**Bottom-up ecosystem regulation mechanisms**	**Top-down ecosystem regulation mechanisms**
Changes in wind forcing, introduction of structure friction	Effects on residual currents, turbulence and mixing	
Changes in wind forcing, wave refraction on structures	Effects on waves, turbulence and mixing	
	Effects on stratification	
	Changes in resuspension	
Filter feeders on structures	Effects on turbidity, light, organic deposition	Effects of filterfeeders on turbidity, potential effects of changes of abundance of all species on organic deposition
	Effects on sediment and benthos	Modified predation on benthos by fish
	Changes in benthic nutrient regeneration	
	Effects on primary production	Modified grazing pressure on phytoplankton
	Effects on zooplankton abundance	Modified predation pressure on zooplankton
Shelter, noise	Effects on fish abundance	Modified predation pressure on fish
	Effects on birds and marine mammals abundance	

2. Short summary of project achievements

The project contained separate top-down and bottom-up approaches in terms of ecosystem dynamics. The work on the **top-down approach** has aimed primarily at the formulation of a recommended approach for further work (Van der Meer and Aarts, 2021). The **recommendations** are to:

1. develop individual-based models (IBMs) for selected top-predators: a sea mammal and a sea bird, these should be chosen based on data availability and indicator value; along with
2. distribution models of their prey fish, the food these fish and prey profitability, and to
3. use these to address the project's questions. This requires
4. matching measurement campaigns of density distributions of the selected species and of their behaviour and physiology (tracking).

The **bottom-up approach** (Zijl et al., 2021) has provided first model results of the large-scale effects of two wind-farm scenarios (present-day and a hypothetical upscaling scenario) on hydrography (sea-surface temperature, stratification, sea-surface salinity, tidal elevations and residual currents), suspended sediment concentrations (surface and near-bed), and biogeochemistry (surface primary production, surface chlorophyll concentrations, surface nutrient concentrations). Finally, initial simulations of mussel growth on turbines using a dynamic energy budget (DEB) model were carried out, but these did not yet result in stable simulated mussel populations. The suspended sediment simulations included calculations of wave conditions, but wake effects still need to be included.
The approximate magnitude of the simulated effects of in particular the hypothetical upscaling scenario suggest substantial changes in the strength and timing of seasonal stratification and residual currents over large areas (Table 3). So these processes, and the ecosystem processes they influence, should take priority in further work. Indeed, the first simulation results on suspended sediment concentrations, timing of the spring bloom and primary production also show substantial relative changes. Typically, changes for the present-day scenario tended to be confined to the wind farms, while the upscaling scenario also displayed substantial changes in the far field.

Table 3. Magnitude of main identified effects of wind farm scenarios. Difference with reference. Yellow: substantial change.

Quantity	**2020 scenario**		**Upscaling scenario**		**Comment**
	Inside/ near field	***far field***	***Inside/ near field***	***far field***	
Sea-surface temperature	-0.1 dgr	0 dgr	+0.1 - -0.3 dgr	0 dgr	Minor, e.g. compared with climate change
Vertical temperature difference	-0.3 dgr	0 dgr	-0.5 dgr	-0.2 dgr	Substantial in stratified areas
Sea-surface salinity	-0.1	0	-0.5 Rhine ROFI	0	Locally confined
Tidal elevations	not local	-0.002 m	not local	-0.01 m	minor
Residual currents	+-0.02 m/s	+-0.005 m/s	-0.02 m/s	0.01 m/s	Substantial
Wave height during storm	<10 cm	<2 cm	<25 cm	<5cm	Reductions <10% (Upscaling scenario)
SPM near surface	0 - >20% increase	0	0- >20% increase	-10% - 10%	Up to factor 10 underpredicted
SPM near-bed	-10% - 5%	0	-20% - 5%	-15% - 20%	No validation
Primary production, annual 2007	changes not correlated with farms	fluctuating pattern up to 0.15 gC m^{-2} day^{-1} change	up to 0.25 gC m^{-2} day^{-1} increase in stratified areas	fluctuating pattern up to 0.1 gC m^{-2} day^{-1} change	Excluding SPM changes
Primary production spring 2007	not available	not available	> 0.25 gC m^{-2} day^{-1} increase in stratified areas	fluctuating pattern up to 0.2 gC m^{-2} day^{-1} change	Excluding SPM changes
Primary production, annual 2007	up to 0.25 gC m^{-2} day^{-1} reduction	fluctuating pattern up to 0.05 gC m^{-2} day^{-1} change, increases larger than decreases	up to 0.2 gC m^{-2} day^{-1} increase in stratified areas,up to 0.2 gC m^{-2} day^{-1} decrease in stratified areas	fluctuating pattern up to 0.1 gC m^{-2} day^{-1} change	Estimated SPM changes

3. Weaknesses of the current approach and results

The current results of the **bottom-up approach** show that substantial effects of large-scale roll-out of wind power generation in the North Sea on the marine environment can be expected. However, for a number of reasons, these changes should be interpreted as a first indication. Most importantly:

1. Some likely important interactions/processes have not yet been (successfully) included, most notably: a) the effect of fully dynamic changes in suspended sediment concentration on the under-water light regime and primary production, b) atmospheric wakes of wind farms, and c) mussel growth on turbines and their effect on biogeochemical cycling
2. Changes due to several effects of wind farms (wind deficit, friction, biofouling) on the hydrographical and biogeochemical environment have only been simulated together, making it difficult to understand their individual contributions to the over-all effects
3. The upscaling scenario is a hypothetical scenario designed to illustrate effects in various different hydrographical regions, ignoring several spatial planning factors/considerations, so cannot be considered as a realistic future scenario

The **top-down approach** lags significantly behind, if this persists it will be problematic to 'bring both approaches together'. IBMs have so far not been applied to management scenarios, and reliable methods to do so need to be developed; as a result this step carries a risk.
Both approaches cannot be brought together unless zooplankton is included in one of the approaches.

The current approach is a valid first step, but the project may not, in the next stage(s), capture the full potential effects of wind farms on top-predator indicator species as only a subset of ecosystem processes will be addressed (Table 2). This cannot be expected, as integrated, spatially resolved (model)approaches that include all feedbacks do not yet exist. Moreover, predation of fish is currently dominated by fishing, so it is unclear to which extent top-down ecosystem regulation mechanisms play a role. This may change if fishing effort is reduced.

4. Inventory of potential avenues for further work

During the last stages of the project, we made an inventory of potential avenues for further work on the **bottom-up and top-down approaches** based on discussions in project meetings, suggestions by project participants, and consideration of draft versions of project reports. The subjects were grouped into the topics 'Measurements' (Table 4), 'Monitoring' (Table 5) and 'Modelling' (Table 6), in analogy with Herman et al. (2019). Note that these three topics are linked and should generally not be treated in isolation. Within the resulting tables, we then classified:

1. In **grey**: elements that:
   a. are relatively easy to achieve,
   b. are likely feasible and low risk, and
   c. constitute a consolidation or immediate extension of the current project.
   d. As such, these represent first next steps, for which progress is desirable.
2. In **yellow**: elements that:
   a. require a significant effort,
   b. are less easy to achieve and carry higher risk,
   c. are likely to require more substantial funding, or
   d. would require elements classified as grey to be carried out first, and
   e. would typically benefit from the involvement of academic partners.
3. In **green**: elements that:
   a. are currently under investigation in existing or upcoming projects, or
   b. may be addressed within the MONS programme that is currently under construction.
4. In **blue**: Monitoring elements, because:
   a. these should not be part of research projects.

The last columns of the table include our assessment of the relevance to the current WOZEP aims as high (1), medium (2) or low (3). The main criteria were that:

1. the current results need to be consolidated
2. the most important effects of wind farms for the **bottom-up approach** can be quantified, in particular where they are likely to affect top predators
3. **the top-down approach** can be applied
4. **the bottom-up and top-down approaches** can be connected.

We note that the boundaries between all the above categories are not always sharp, and that there is an inevitable level of subjectivity in this subdivision.

Table 4. Measurements. Overview of collected recommendations for further work. Read columns per item from left to right, the content is consistent per item but not between items. White rows: less relevant or unclear. Grey rows: high, short-term priority, constitute a consolidation or immediate extension of the current project. Green rows: subject of other studies/initiatives. Yellow rows: high, longer term priority, or more complicated, or higher risk, or of less direct relevance to immediate aims of the current project, best addressed separately (e.g. project(s) in collaboration with academic partners). Blue rows: subjects that could be part of a monitoring programme. Priority within the current remits of WOZEP (high: 1 to low: 3) in the last column.

Variable/process	**Methods**	**What to measure?**	**Where?**	**Who?**	**Comment**	**Priority for WOZEP**
Harbour Seal or Grey Seal	Tagging	Predation behaviour & wind farms, temperature measurements			top-down report	1
Air-sea exchange	Offshore meteo masts	Wind, currents, waves, temperature, irradiation, fluxes/turbulence, precipitation, thermistor chain, sea spray	Inside/outside wind farms	TUD/KNMI		2
Waves	HF radar & remote sensing	response inside and in the wake of wind farms				2
SPM & turbidity	Cruise(s)	Seasonal dynamics floc size, composition, settling velocity	Regional differences, new data			3
	Desk study		gathering existing data			3
	Cruise(s), moorings	Effects wind farm(s): 3D variations			Do as add-on to other studies partly NWA2 Footprint	1
Erosion & scour	Sea-bed landers, Flume experiments	Variation inside/outside wakes of piles			Operators, flume studies, CFD calculations, Deltares	3
	Desk study	Inventory/interpretation existing experimental and field data			Do this before considering new work HR Wallingford reports Get access to wind industry data	3
Zooplankton	Cruises	a.o. image analysers			NIOZ Dick van Oevelen	1
Birds	Cruises	In and around wind farms: behavioural studies, tracking studies, diet studies in colonies, sampling prey abundance at sea Lesser black-backed gull and Sandwich tern, small pelagic fish			top-down report	1

Table 5. Monitoring. Overview of collected recommendations for further work. Read columns per item from left to right, the content is consistent per item but not between items. White rows: less relevant or unclear. Grey rows: high, short-term priority, constitute a consolidation or immediate extension of the current project. Green rows: subject of other studies/initiatives. Yellow rows: high, longer term priority, or more complicated, or higher risk, or of less direct relevance to immediate aims of the current project, best addressed separately (e.g. project(s) in collaboration with academic partners). Blue rows: subjects that could be part of a monitoring programme. Priority within the current remits of WOZEP (high: 1 to low: 3) in the last column.

Variable/process/programme	**Methods**	**What to measure?**	**Where?**	**Comment**	**Priority for WOZEP**
Inventory and disclosure existing data sets	Desk study	Upload data Reformat Analyse Make suitable for validation			1
Succession biofouling epibenthos on pilons & response ecosystem	Repeated cruises	Inventory biofouling communities, benthic community/sediment samples	Address regional differences	Build on Belgian studies	2
	Landers & moorings	Analysis settling sediment and POC			2
Surface temperature, salinity, phytoplankton, turbidity, wind, waves	Remote sensing	Analysis effects wind farms; detectability, temporal variations, footprint		NWA2 Windfarm project: turbidity	2
Primary production	Repeated cruises	Incubation experiments, Fast Repetition Rate fluorometry (FRRf)	Inside and outside wind farms	NIOZ Dick van Oevelen	1
	Moorings & landers	Fluorescence, regular water samples			2
MWTL		Resolve effects of wind farms	Reconsider spatial distribution, vertical resolution		1
Fish	Desk study	correlations with trends in environmental data		MONS?	1
	Cruises	Relevant non-commercial fish Multiple times per year		WOT Topdown report	1
	Gather/analyse existing data	Presence/absence/densities, spatially and temporally resolved	North Sea	Food fields for top-down approach	1

Table 6. Modelling. Overview of collected recommendations for further work. Read columns per item from left to right, the content is consistent per item but not between items. White rows: less relevant or unclear. Grey rows: high, short-term priority, constitute a consolidation or immediate extension of the current project. Green rows: subject of other studies/initiatives. Yellow rows: high, longer term priority, or more complicated, or higher risk, or of less direct relevance to immediate aims of the current project, best addressed separately (e.g. project(s) in collaboration with academic partners). Blue rows: subjects that could be part of a monitoring programme. Priority within the current remits of WOZEP (high: 1 to low: 3) in the last column.

Task	**Model type**	**Variable/process/task I**	**Variable/process/ task II**	**Variable/process/ task III**	**Comment**	**Relevance to WOZEP**
Additional analyses of the current results	Hydrodynamics	-Changes in tidal current (harmonics) -Changes in wave conditions -Quantifying/understanding relative contributions of the various effects of wind farms (wind deficit, friction, etc) to the total effect	Effects on tidal currents may be more substantial than on elevations, in particular when their effects on suspended sediment concentrations are taken into account			1
	Suspended sediments	-Understanding why some farms show reduction in near-bed spm and others an increase -Translation into changes in light extinction and under-water light climate -Quantifying/understanding relative contributions of the various effects of wind farms (wind deficit, friction, etc) to the total effect				1
	Biogeochemistry	-Quantification shifts in timing of spring bloom in space -Causes/meaning of fluctuating pattern far-field changes -Vertical structure and depth-integrated values of ecosystem variables -Understanding regional differences in response -Quantifying/understanding relative contributions of the various effects of wind farms (wind deficit, friction, etc) to the total effect				1
Validation	Hydrodynamics model	Temperature and salinity	Informatiehuis Marien, visnet, emodnet, ICES, zeehonden, waterbase, remote sensing	Aim for local response to wind farm(s)	For validation: also include years pre-dating the installation of the first wind farms	2
	Wave model(s)	wave heights and directions inside farms and in wakes				1

Task	Model type	Variable/process/task I	Variable/process/ task II	Variable/process/ task III	Comment	Relevance to WOZEP
	Hydrodynamics & biogeochemistry	Detailed data outside and within wind farm(s)	Reproduce observations Floeter et al. (2017) German wind farm	Validate parameterisations pilons/farms		1
	SPM model	Validation near-bed spm concentrations	MWTL data, SmartBuoy lander data, CTD cats			1
	Biogeochemical model	Zooplankton	CPR data			1
	Spatial distribution models (e.g., GAM)	Fish	use landing data		Top-down report FutureMARES: IBM population models	1
	Biogeochemistry & SPM	Test interactions & recalibrate biogeochemistry				1
	Biogeochemistry: benthic-pelagic exchange				Partly: NWA2 Footprint	2
	Biogeochemistry	Primary production				1
	Biogeochemistry & DEB biofouling	Use data Belgian wind farms for validation where possible			NWA2 Windfarm project	1
Model experiments/ scenarios	Hydrodynamics & biogeochemistry	Sensitivity to farm layout	Spacing turbines, farm size, farm orientation, inter-farm spacing		NWA2 Windfarm project	2
		Shared use: seaweed farming	Interactions, location within wind farm, carrying capacity		MONS?	3
		Cumulative effects and interactions	Sea weed, Solar farms, Fishing, Climate change		MONS/NZA	3
		More realistic spatial distributions of farms	Account for the demands of Shipping lanes, Military zones, Sand mining areas, Important fishing grounds that in future may be kept free from wind farm development, Important fly-ways for migrating birds, Important areas for seals		For all scenario runs: beware of whether existing wind farms are included correctly for the year(s) under consideration	1
		Interactions with climate change			FutureMares	2
	Particle tracking	Larval connectivity studies to assess effects of changes in residual circulation on life cycles of key species; e.g. flat oyster, plaice	Combination with climate change		collaboration with NIOZ	3
Model development	Hydrodynamical model	Improvement parameterisations air-sea exchange	Impact of wind farms on wind speed (forcing fields), e.g.		First step, should precede more	1

Task	Model type	Variable/process/task I	Variable/process/ task II	Variable/process/ task III	Comment	Relevance to WOZEP
			improved representation of wind speed reductions and wakes		direct coupling with atmospheric model	
	Wave models	Use spectral wave model to develop/improve computationally efficient parametric wave model				2
	Biogeochemical model	Additional processes	Include picophytoplankton	improved seasonal cycle & low production conditions	Partly in ERSEM	2
	SPM	Improve bed stress and mixing in combined currents and waves				1
		Influence of biology on flocculation				2
		Influence of biology on benthic-pelagic fluxes			Partly in ERSEM, BFIAT project	2
	DEB models of biofouling communities and zooplankton	biomass density limitation, predation mortality, competition			Some overlap with NWA2 Windfarm project	1
		Include zooplankton	top-down, bottom-up interactions			1
	Biogeochemistry: benthic-pelagic exchange				Partly: NWA2 Footprint	2
	HTL model	IBM model Lesser Black-backed Gull and Sandwich Tern in combination with small pelagic fish	Develop from scratch, link with observational programme			1
Model coupling	Biogeochemical model to HTL model	Structural solutions for current 'patched' couplings			Develop smart parameterisa-tions and/or proxy methods instead of full coupling for computational efficiency?	2
	Atmospheric models to hydrodynamic model	Air-sea heat exchange	Effects of wind farms (forcing fields)	net solar radiation (affected by changes in cloud cover), relative humidity, downwelling long wave radiation (also affected by cloud cover, and relative humidity) and air temperature		2
		Vertical representation of turbines in atmosphere & wind-farm wakes	Collaboration with KNMI/Whiffle			2
	SPM model to Biogeochemical model					1

5. Prioritization and recommendations

For **the bottom-up approach**, in general terms, **priority should be given** to further investigation of **processes that have been shown to be sensitive to large-scale development of wind farms**. These include stratification, residual currents, suspended particulate matter and primary production (Table 3), **and likely effects of changes in these processes on the wider ecosystem** that may influence top predators (see cascade of processes, Table 2). Such work should include investigation and improved representation of atmospheric processes feeding into these: wind-wake effects, wind-stress parameterisations including vertical wind profile estimation under different atmospheric conditions. It should also include oceanographic and ecosystem processes that are influenced by these: changes in wave-current coupling and resulting effects on stratification, SPM concentrations, under-water light regime, primary productivity and zooplankton, as well as biofouling communities on turbines. Consideration should be given to interactions with climate change, e.g. do large-scale wind farms mitigate or exacerbate effects of climate change on the marine ecosystem and in particular top predators?

For the **top-down approach**, priority should be given to implementing the IBM models, gathering data on their food landscapes (fish and zooplankton), gathering validation data for top predators (counts, tracking) and producing model scenario runs. As the construction of IBMs requires a significant effort and data input, a small number of species should be selected. When successful, the method can be applied to other species or species groups. The selection should be based on considerations of the availability of relevant data of these species and their prey, and also their sensitivity to the presence of wind farms (attraction or avoidance) early on. The development of the top-down approach should be accelerated to catch up with the bottom-up approach in order to combine the results of both approaches. Inclusion of top-down ecosystem processes (i.e. effects of predation on prey abundance) should be facilitated.

The **connection of the bottom-up and top-down approaches** requires attention. Earlier efforts to couple lower trophic level models to higher trophic level models suffered from mismatches in temporal and spatial scales, and overlap in or missing ecosystem components at the interface of such models. As the IBM models still need to be implemented, there is an opportunity to minimise or potentially eliminate such mismatches.

For consolidation or immediate extension of the current project within the current WOZEP aims, the following should have priority (selected from Table 4, Table 5, Table 6):

1. Achieving further progress on investigations and analyses that were started but have not yet been completed (validation, effects on tidal currents, waves, SPM concentrations under combined currents and waves, biogeochemistry and primary production, biofouling communities, **implementing the top-down approach**). Attention should be given to obtaining understanding of, on one hand, the contributions of single processes, and on the other hand, on the interactions between the various processes.
2. Obtain additional observations for system understanding and (ultimately) model validation in and around wind farms: for the **bottom-up approach,** where possible meteorological observations, together with satellite and HF radar wave observations, and also 3D oceanographical observations; for the **top-down approach**, collect data on zooplankton, fish, sea birds, and sea mammals. These should be part of an integrated study of preferably a minimum of two wind farms: one in stratified and one in well-mixed waters. Where possible existing monitoring programmes should be used/modified/extended to facilitate this, otherwise additional measurement programmes should be designed.
3. Develop the models to improve the most relevant processes associated with wind farms that may affect top predators. This includes improved parameterisations of air-sea exchange, improved implementation of bed-shear stress and mixing for SPM simulations, inclusion of zooplankton, inclusion of biofouling communities, coupled SPM-biogeochemistry simulations, an IBM suite of models for top predators that can connect to/integrated with the lower trophic level models. In doing so, top-down ecosystem processes and the role of fishing should be considered.
4. Design more realistic model scenario's (wind farm distributions in the North Sea), leading to climate change scenario's.

We add a few thoughts here on monitoring (blue elements in Table 5), as monitoring programmes are distinct from research programmes in their aims and management. The currently active North Sea monitoring programmes of relevance to marine energy generation are MWTL (Monitoring Waterstaatkundige Toestand des Lands) and KB WOT (KennisBasis Wettelijke OnderzoeksTaken). MWTL was set up for water quality monitoring, predominantly related to anthropogenic pollutants. As such, it cannot be expected to optimally detect changes in the marine ecosystem due to the development of large-scale wind farms. Extension of the MWTL should be considered to allow it to detect such changes, e.g. by introducing additional transects near wind farms, by recording vertical profiles of water column variables in more detail, by better representing the benthic system, and by recording short time series resolving the tidal cycle at key stations in the vicinity of wind farms. The WOT was set up to monitor stocks of commercial fish species. Addition of non-commercial species of particular relevance to the ecosystem and/or considered to be particularly sensitive to effects of wind farms could be considered. Survey frequency should be increased to multiple times per year to provide input and validation data for the IBMs (**topdown approach**). In addition to these large-scale monitoring programmes, there is a need for farm-scale monitoring of ecosystem processes, potentially covering the life cycle of a wind farm.

Computing times have been flagged as an issue. This problem will become worse as more numerical models are coupled, and more dynamical processes are simulated. A number of solutions can be considered:

1. use bigger computers, e.g. SURFsara
2. simplify the models where possible/appropriate by, e.g., using fewer functional groups, or developing parameterisations for computationally intensive components, or uncoupling of submodels that perform the same computations in multiple scenarios
3. use proxy models or data-driven approaches where expensive model runs are approximated as if they were data

The development of such methods can happen alongside the development of fully coupled approaches. For collection of data sets, measurements and monitoring, collaboration could be sought with international partners, e.g. within the BANOS initiative, or through ICES.

6. References

Herman, P.M.J., Asjes, J., Hummel, H., Jak, R., Kromkamp, J.C., Lindeboom, H.J., Soetaert, K., Troost, T.A., van der Meer, J., van der Molen, J., van de Wolfshaar, K., van Duren, L.A., van Kooten, T., 2019. Understanding the North Sea Ecosystem. Deltares Report I1000486-000-OA-0005, 12 pp.

Floeter, J., van Beusekom, J.E.E, Auch, D. et al., 2017. Pelagic effects of offshore wind farm foundations in the stratified North Sea. Progress in Oceanography 156, 154-173.

Van der Meer, J., Aarts, G., 2021. Individual-based modelling of seabird and marine mammal populations. Report C002/21, Wageningen Marine Research, IJmuiden.

Van Duren, L. A., F. Zijl, V. T. M. van Zelst, L. M. Vilmin, J. Van der Meer, G. M. Aarts, J. Van der Molen, K. Soetaert, and A. W. Minns. 2021. Ecosystem effects of large upscaling of offshore wind on the North Sea - Synthesis report. 11203731-004-ZKS-0010, Deltares, Delft.

Zijl, F., Laan, S. C. Emmanouil, A. van Zelst, V. T. M. Van Kessel, T. Vilmin, L. M. Van Duren, L. A., 2021. Potential ecosystem effects of large upscaling of offshore wind in the North Sea. Final report model scenarios. 11203731-004-ZKS-0015, Deltares, Delft.

NWO-NIOZ Royal Netherlands Institute for Sea Research is the national oceanographic institute and principally performs academically excellent multidisciplinary fundamental and frontier applied marine research addressing important scientific and societal questions pertinent to the functioning of oceans and seas.

NIOZ also serves as national marine research facilitator (NMF) for the Netherlands scientific community. NIOZ stimulates and supports multidisciplinary fundamental and frontier applied marine research, education and marine policy development in the national and international context.

NIOZ Royal Netherlands Institute for Sea Research
is part of the institutes organization of NWO.

NWO

www.nioz.nl

NIOZ