

Effect monitoring in Danish offshore Wind

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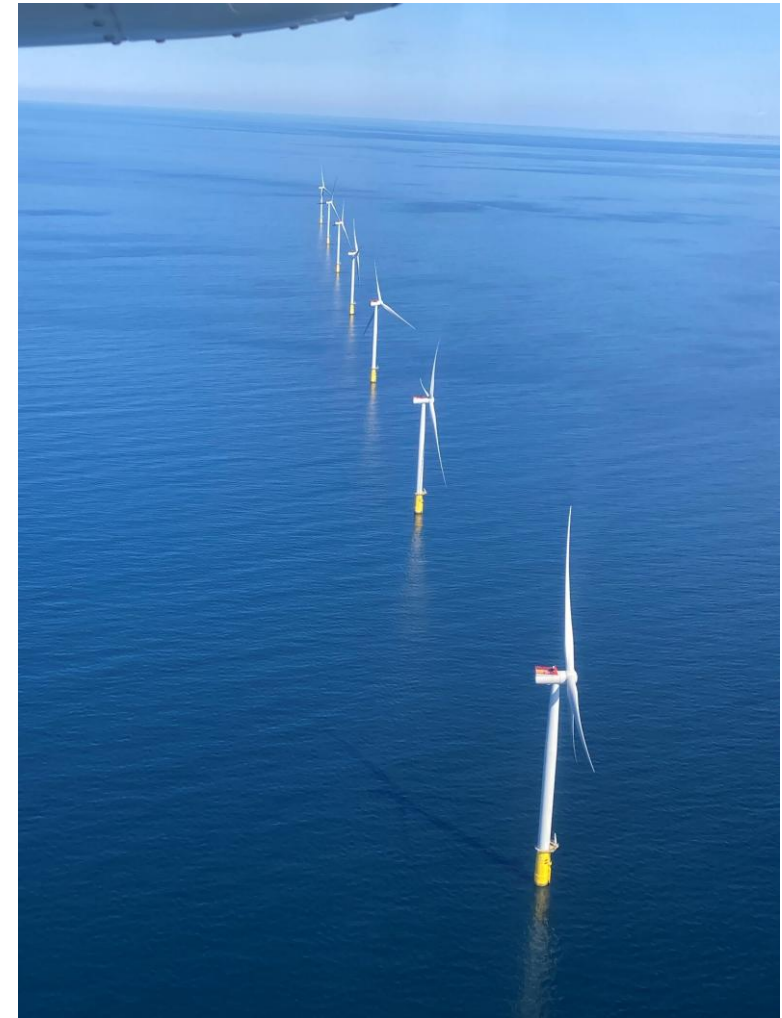
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Background

Process

- There have been offshore windfarms in Danish Waters since 1991.
- However, very few studies worldwide have studied actual effects on the environment, especially over lifetime.
- Denmark has at present 2.3 GW offshore wind.
- There are plans for up to 3 GW in the Baltic (2030), 1.3 GW in Kattegat (2032) and **35-80 GW** in the North Sea by 2050.
- The Danish Energy Agency (DEA) has a wish for understanding effects of offshore wind on the Marine Environment to be obtained during the building of these windfarms.
- NIRAS was given the task to construct such an effect monitoring program.
- Third party review was conducted by Aarhus University.



Introduction

Requirements

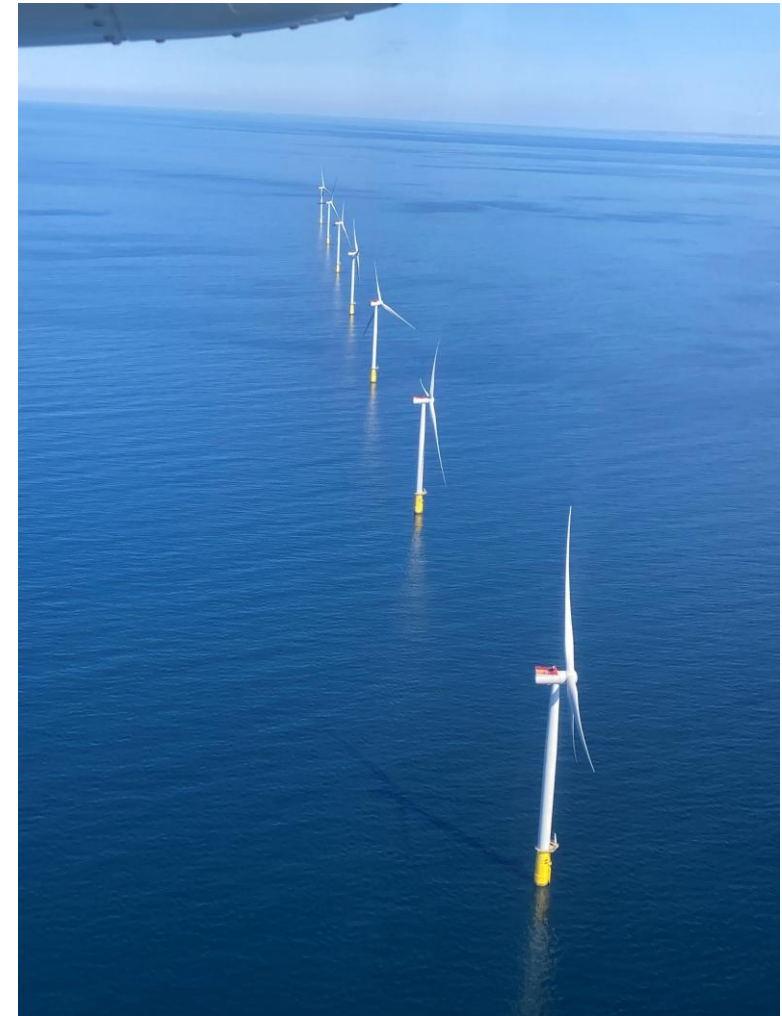
- The effect monitoring program should make the collected data comparable between years, phases and windfarms.
- The effect monitoring program should include a specified number of abiotic and biotic parameters.
- The effect monitoring should take account of possibilities for synergies.
- The program should be comparable to the National monitoring program NOVANA and align with the technical descriptions here fore.



Outcome

The result

- A quite ambitious program.
- Very long duration of the program – baseline, construction, 15 yrs of operation.
- Statistically based.
- The program makes it realistic to obtain knowledge on effects on the environment.
- The effect monitoring program will be mandatory for future windfarms in Denmark.



Overview

The effect monitoring program consists of

Abiotic parameters

- Hydrologi and Sediment
- Water quality
- Marine debris
- Underwater noise

Biotic parameters

- Bottom flora and fauna
- Invasive species
- Fish
- Marine mammals
- Birds
- Bats



Overview

Every parameter has a background report and a data sheet with a description of the work to be carried out.

The background report contains:

- Background/biology of the parameter
- Argumentation for choice of method
- Method description
- Assumptions
- Equipment
- Statistics
- Documentation
- Calibration
- Laboratory requirements
- Scientific references



Overview

Every parameter has a background report and a data sheet with a description of the work to be carried out.

The data sheet contains:

- Thorough method description (ex. Passive acoustic monitoring).
- Description of how to conduct the monitoring (ex. service interval, settings, filtering, analysis etc.).
- Sampling regime (ex. where to place the PAM station).
- Replicates (ex. number of stations).
- Data analysis
- Statistical approach
- Laboratory requirements



Approach

The effect monitoring program must be able to document changes over time.

Assumptions

- Data must be conducted so that statistics can be applied (no apples and pears)
- The individual data points must be comparable
- A sufficient number of replicates
- Data to be collected at the right time (season, depth, phases etc.)
- Data must be comparable over time
- Detailed requirements for metadata
- Data from windfarms, national monitoring or projects must be included, if they live up to the methodological approach and are < 5 yrs old

Time line in the effect monitoring programme

- Pre-investigations
- Baseline
- Construction
- Operation

		Geophysics	Baseline			Geophysics	Construction		Operation														
Parameter	År:	<1	1	2	3	X	1	2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Hydrography & Sediment		X	X			X		X						X									
Water quality (3 matrices)				X					X		X							X					
Water phase							X				X												
Sediment								X															
Marine debris				X							X					X					X		X
Underwater noise		X	X			X	X		X														
Invasive species			X	X					X				X					X					
Marine mammals			X	X			X	X	X				X					X					X
Fish			X	X					X		X		X										
Bats			X	X			X	X	X				X					X					X
Birds			X	X			X	X	X		X		X					X					
Bottom flora and fauna		X	X	X			(X)	(X)	X				X					X					

Geophysical and geotechnical surveys, UXO clearance etc. are noisy and can not be conducted during baseline data collection for marine mammals.

Statistical - BACI design (Before, After, Control, Impact)



Control refers to reference area



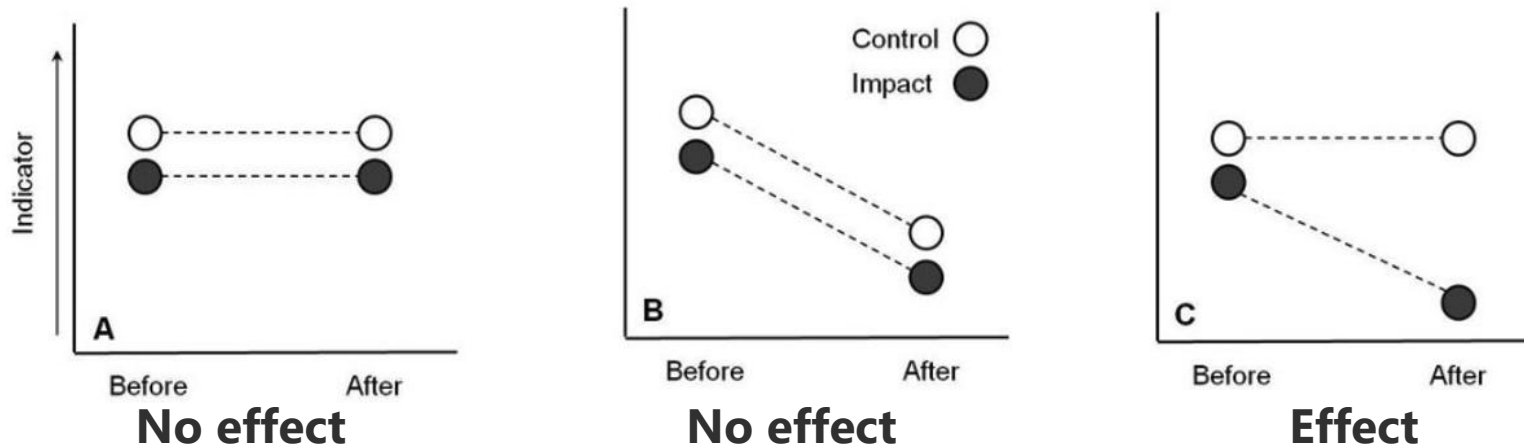
Impact refers to project area (windfarm area)

	Before	After
Control	Mapping of natural variation in reference area before impact. Baseline	Mapping of the development in the natural variation since impact (construction) begins, and during operation
Impact	Mapping of natural variation in project area before impact. Baseline (uden geophysics)	Mapping of the new variation in the project area since construction and during operation



BACI design

The purpose of BACI is to examine if the new state of the environment following construction (impact) is different from the natural variation (control).



Without reference stations, it is not possible to verify if a change in the state of the environment is caused by changes in the natural variation or the construction of the windfarm.

Assumptions

- There must be a reference area.
- Reference stations must describe the natural variation in the project area and represent the state of the environment in the project area before the impact begins.
- BACI design requires that the reference stations/area remain unaffected by the construction.
- Reference stations must be conserved throughout the monitoring program and requires knowledge of future activities that could affect the area.

Main points of the effect monitoring program relevant for marine mammals



Underwater noise



Underwater noise



Methods

- Sound recordings in all phases.
- Monitoring is divided in phases with varying measuring program.
- All equipment must be standard calibrated before use
- Sample rate (min 92 kHz) and duty cycle: 25%, where the 25 % is continuous.
- (several additional requirements for the equipment)
- Nothing on the mooring must create noise

Pre-investigation/geotechnical surveys/geophysical surveys:

- If any of the instruments are audible to marine mammals, recordings of the noise type must be obtained.
- The recordings must follow the DEAs requirement for noise recordings.

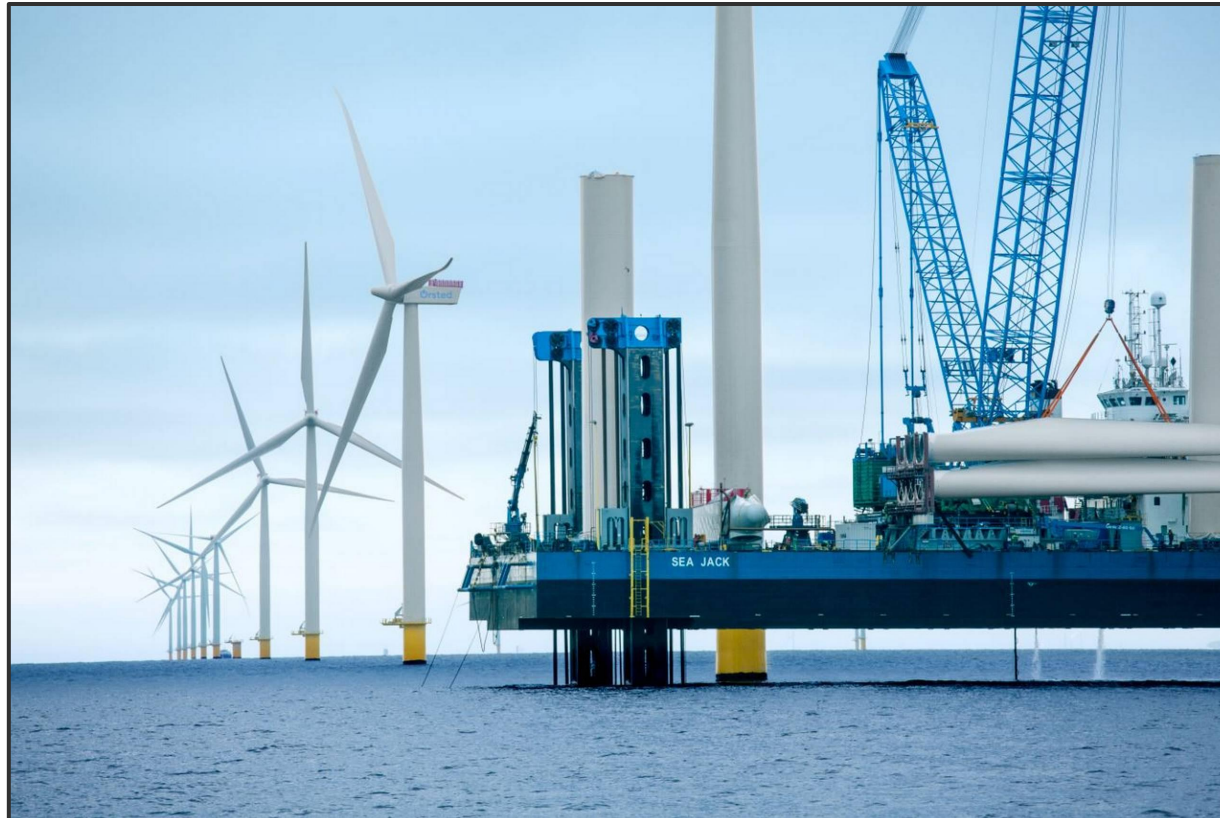
Baseline:

- Number of measuring stations depends on the size of the future windfarm (specified)
- The measuring stations are to be spread out in the project area, with a minimum distance of 1 km to the boarder of the project area.
- If a Natura 2000 area appointed for marine mammals is within 5 km of the future windfarm, then a measuring station must be placed in the Natura 2000 area, at the minimum distance to the future windfarm.

Underwater noise

Construction phase:

- If piling is included, the DEA *"Guideline for underwater noise - Installation of impact or vibratory driven piles"* (Energistyrelsen, 2023) must be followed.

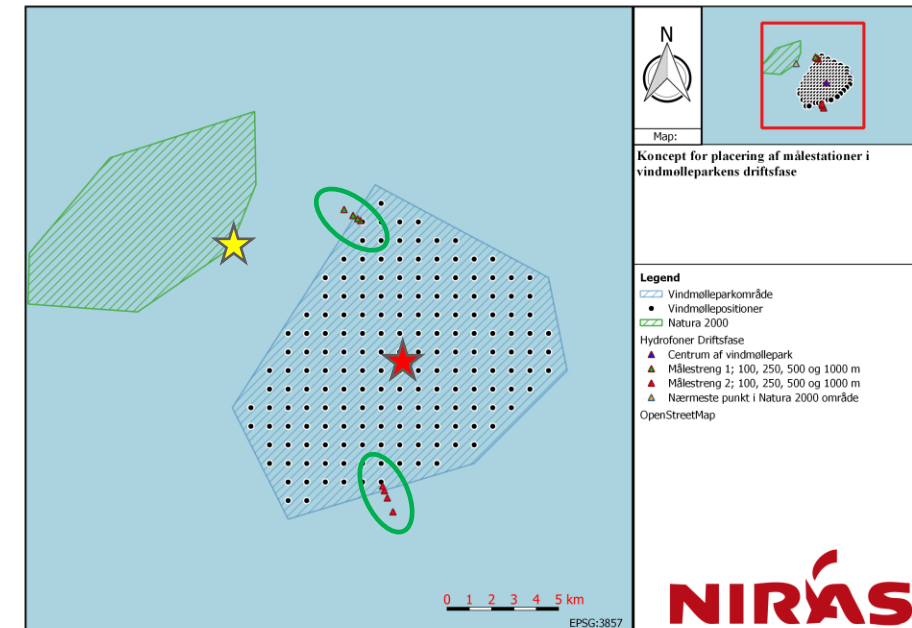


Underwater noise



Operation:

- Minimum two transect measurements of two representative turbines must be obtained.
- For each turbine, four measuring stations are deployed at different ranges to the turbines.
- The turbine must be located in the outer row of turbines.
- One station in the middle of the park is deployed with equal spacing to surrounding turbines.
- If there is a Natura 2000 area within 5 km, then a measuring station is deployed in the Natura 2000 area, where the distance to the windfarm is shortest.
- Recordings must be continuous over minimum six weeks in a period without maintenance / service work.
- All turbines with 5 km must be in normal operation.
- Duty cycle must be 100%.





Marine mammals

Species in Denmark

- Harbour seal
- Grey seal
- Harbour porpoise
- Wite-beaked dolphin
- Minke whale
- Other species



Marine mammals

Cetaceans

Methods	Baseline	Construction	Operation
Aerial surveys	6 surveys/yr in 2 yrs		
PAM	2 yrs	The entire phase	Yr 1, yr 5, yr 10 & yr 15

Aerial surveys in baseline to document:

- species
- calves
- distribution
- absolute density and abundance (line transect distance sampling)

If digital aerial surveys are used for obtaining relative density, the method description for analysis of data must be followed.



Marine mammals

Cetaceans

Methods	Baseline	Construction	Operation
Aerial surveys	6 surveys/yr in 2 yrs		
PAM	2 yrs	The entire phase	Yr 1, yr 5, yr 10 & yr 15

Passive acoustic monitoring (PAM) is used in all phases to obtain data for

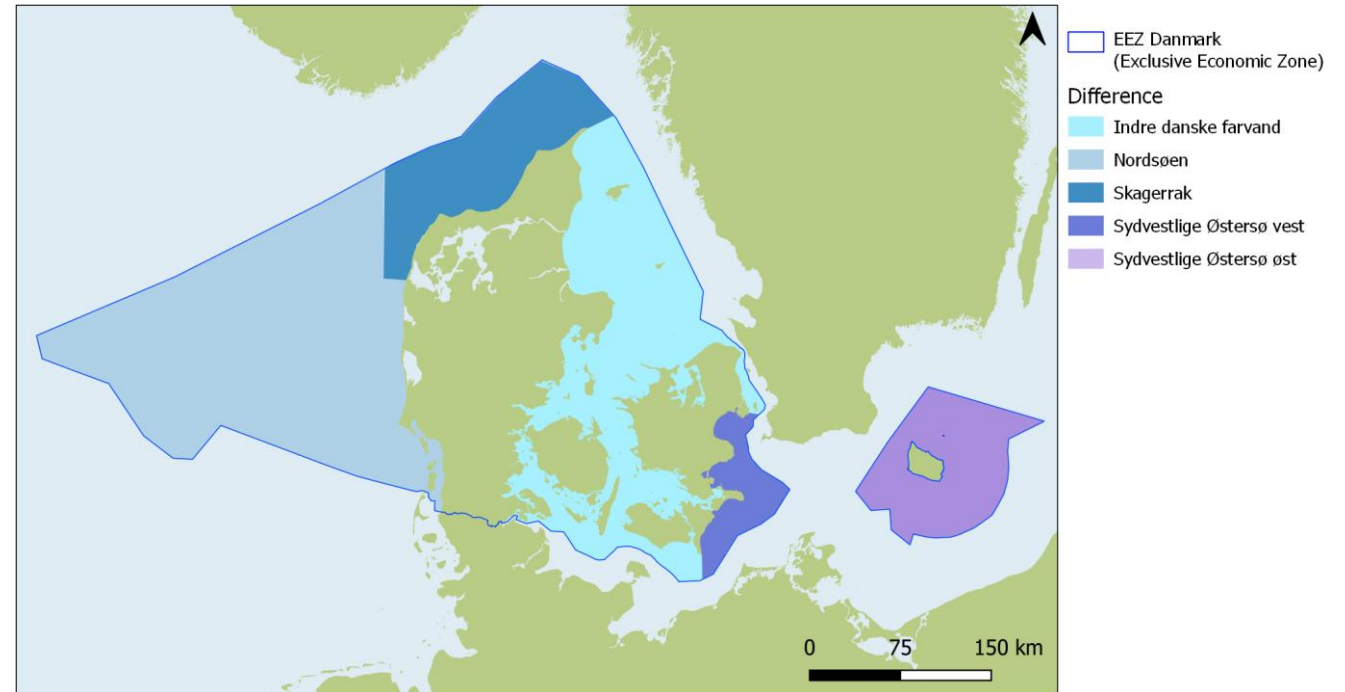
- ❖ BACI on relative abundance
- ❖ Yearly pattern in presence
- Stations to be placed with *random stratified design* to represent the entire environment equally in both reference and project/impact area.
- Stratified random design: Station positions are grid based, but chosen to represent depth, bottom type etc. equally.
- Station positions are kept throughout.
- For dolphins and baleen whales, wideband recorders are used with a minimum sample rate of 356 kHz.
- All instruments must be standard calibrated before use and before each phase.



Marine mammals – harbour porpoise

PAM for harbour porpoises

- FPODs
- Hydrophone 2 m above seafloor to make data comparable to national monitoring, SAMBAH I + II and other datasets.
- Number of dataloggers per area builds on power analysis of national monitoring PAM data (Sveegaard, Owen *et al.* 2026).
- Same number of stations in reference and project/impact area.



Area	Project area	Reference area	Stations pr km2
North Sea	8	8	0,013
Inner Danish Waters	8	8	0,013
Skagerrak	11	11	0,017
Southwestern Baltic West	11	11	0,017
Southwestern Baltic East	20	20	0,032

Marine mammals



Seals

- Seals are included if the nearest haul-out is <50 km of the future windfarm. A representative haul-out is used for reference.
- Seals are counted at these haul-outs, following NOVANA technical advice.
- Seals *can* be counted with *Distance Sampling line transect surveys* in the project and reference area, but the method is not validated for seals, does not give species ID and number of counted seals is often low.
- *Distance Sampling line transect surveys* can hence not stand alone or be used statistically.

Marine mammals

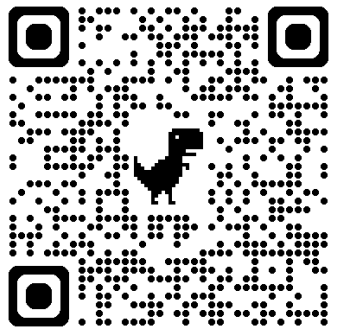


Seals

- If the future windfarm is inside a Natura 2000 area appointed for seals, a representative number of seals must be captured and fitted with satellite transmitters in baseline and operation for mapping use of the project and reference area, before and after construction of the windfarm.
- If the nearest seal haul-out is significant (according to national monitoring data), a representative number of seals must be tagged with satellite transmitters in baseline and operation, and data be used to compare behaviour before and after construction in reference and impact area (statistics uncertain...).



Questions?



Look for 'Dreжебøger for effektovervågning'

So far only in Danish, but will be translated

