Insights from conference on the coexistence of **offshore wind,** and the **marine environment**

May 21st 2026

VELUX FONDEN

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Introduction

Denmark and its neighboring countries are planning a large-scale development of offshore wind. In connection with the establishment of the National Committee for the Ocean Decade in Denmark, Greenland, and the Faroe Islands, a working group was set up in 2023 with the aim of supporting knowledge sharing regarding the implementation of environmental considerations in the development of offshore energy infrastructure.

As part of this work, a conference was held on May 21st 2026 at Læderstræde 20 in Copenhagen in collaboration with the research and development projects ULTFARMS, OLAMUR and WIN@sea dedicated to the related topic of “multi-use”. The conference was structured around a morning session focusing on the results from recently completed pilot studies on low-trophic aquaculture within offshore wind farms, and an afternoon session focused on the topic of the working group of understanding and mitigating impacts on the marine environment from offshore wind and strengthening environmental considerations in future development of offshore wind.

As a key component of the afternoon session, three parallel sector-focused workshops were conducted with the aim of supporting 68 participating stakeholder representatives in sharing their experiences and assessments regarding the opportunities and challenges. In preparation, a project portfolio of current relevant Danish research projects that are expected to contribute to developments within the field (see Annex 1) was collected. This project portfolio was distributed to all participants in advance of the conference as a common knowledge base and inspiration.

Thematic summary of workshop reflections

The workshops highlighted that the main challenges with respect to reconciling offshore energy expansion with nature protection are less about technology and more about governance, knowledge, and implementation. Progress will require advances in relation to

- Clear environmental goals and success criteria with focus on cumulative impact
- Better data, monitoring, and impact assessment
- Stronger coordination across authorities, sectors, and countries
- Ecosystem-based marine spatial planning in light of cumulative impacts
- Closer collaboration between science, policymakers, and industry
- Incentives and funding that support environmental performance and standardised data sharing
- A pragmatic approach to managing uncertainty while continuing offshore wind deployment

Overall, stakeholders agreed that offshore wind expansion and environmental protection should be pursued as complementary objectives. Delivering both will depend on aligning policy, knowledge, planning, and investment around a shared long-term vision and targets for sustainable marine development.

Environmental considerations workshop A – challenges and opportunities for **authorities and related organizations**

Policy Implementation

1. Governance and coordination
There is a need for stronger coordination, knowledge sharing, and transparency across authorities.

2. Marine Spatial Planning (MSP)
The Danish Maritime Spatial Plan could play a more active role in facilitating co-existence between marine uses through stronger incentives, clearer prioritization, and more frequent updates.

3. Nature Inclusive Design (NID)
A more differentiated and region-specific approach to NID is needed, recognizing that ecological conditions and appropriate measures vary between areas.

4. Policy goals and incentives
There is need for clearer ambitions and targets, particularly regarding the role of co-existence measures in mitigation and restoration.

Knowledge and data gaps

1. Data availability and accessibility
While substantial data exists, important gaps remain, particularly regarding historical datasets and spatially comprehensive information.

2. Data standardization and ecosystem-based planning
Although large amounts of environmental data are collected, a lack of common standards and reporting formats limits their usability. There is need for common standards and systems that can support environmental impact assessments etc.

3. Environmental impacts of offshore wind
There is limited knowledge of the long-term environmental effects of offshore wind development. There is need for improved access to monitoring data and lessons learned from other countries to help address these gaps.

4. Impacts of Nature Inclusive Design
There is need for further research on the long-term ecological effects of nature-inclusive design measures, including possible negative impacts such as introduction and spread of non-indigenous species into nearby marine protected areas, and ecological connectivity of species e.g. not belonging on soft bottom communities.

Environmental considerations workshop B – challenges and opportunities for **private companies**

Policy implementation

1) Governance, coordination and strategic alignment

The absence of a shared vision and consistent definitions of environmental goals, including nature restoration and nature-inclusive development combined with fragmented governance, differing stakeholder priorities, and varying national approaches hinders progress. There is a need for stronger collaboration across authorities, alignment of political and regulatory objectives, EU-level standardisation, and clear integration of environmental ambitions into planning processes.

2) Marine spatial planning and environmental management
Competing demands for limited marine space, and environmental uncertainties challenge offshore wind development. More integrated marine spatial planning and ecosystem-based management are required, including a stronger focus on ecosystem-scale protection and restoration rather than project-specific mitigation measures.

3) Implementation, incentives and scalability
Limited funding, weak incentives, and uncertainty about costs and benefits restrict uptake of environmental measures. Demonstration projects, financial support, and scalable business models are needed.

Knowledge and data gaps

1) Monitoring, effectiveness and environmental outcomes
Insufficient monitoring and a lack of common standards for metrics make it difficult to assess the effectiveness of environmental measures. Enhanced long-term monitoring and common effectiveness metrics are needed to support evidence-based decisions.

2) Environmental data and ecosystem understanding
Knowledge gaps on habitats, cumulative impacts, and ecosystem effects limit informed decision-making. Better data collection, mapping, and assessment frameworks are required.

3) Knowledge sharing and research-industry integration
Poor use of available knowledge and knowledge transfer between researchers, industry, and authorities slow down implementation. Improved data sharing, collaborative research, joint environmental mapping, & strong stakeholder collaboration are needed.

4) Environmental uncertainty and risk management
Uncertainty about ecological impacts discourage action or lead to overly cautious decision-making. More research and long-term monitoring are needed to reduce risks and identify measures that maximise environmental benefits while minimising risks.

Environmental considerations workshop C – challenges and opportunities for **research institutions and NGOs**

Policy implementation

1. Need for prioritized management targets
To deliver e.g. scientific advice in relation to ‘coexistence’, the present lack of explicit and prioritized management targets is a major challenge.

2. Interpretation of ‘co-existence’ and ‘nature-inclusive design’
The conceptual interpretation of the term “co-existence” needs clarification from the policy-side to clearly articulate what is meant in various contexts.

3. Sector-based silos in the government reduce synergies
Silos appear to be a barrier for bringing in relevant knowledge at the right time in maritime spatial planning in general. A more transparent and open process is needed.

4. Assess the role of wind farm siting and design
The desired role of e.g. wind farm projects in relation to general maritime spatial planning should be further clarified to support progress towards defined targets.

5. Address decommissioning
Similarly to the planning phase, ecosystem targets for ‘good’ decommissioning should be resolved, also to guide scientific advice on this topic.

Knowledge and data gaps

1. Understand and predict ecosystem dynamics
It remains scientifically challenging to understand and predict ecosystem scale responses to offshore wind and multi-use developments.

2. Planning for decommissioning
How decommissioning activities can be carried out with the lowest possible impact on the marine environment remains a key scientific question to explore.

3. Understand the potential value of nature-inclusive designs (NID)
The extent to which nature-inclusive add-ons are environmentally *worthwhile* considering their own impact from production, deployment and potential decommissioning, will likely be very context dependent. To be of value developers should likely be guided by the mitigation hierarchy and clear restoration targets.

4. The role of science in reconciling energy and nature under time pressure
Developing evidence-based approaches that support coexistence and clever synergies between nature protection and energy development should remain a strategic priority.

Cross-cutting themes and relevant actions across the stakeholder groups

1. Establish Clear Environmental Objectives

A common challenge is the lack of clear and shared objectives for co-existence, nature restoration, and nature-inclusive design (NID). Stakeholders highlighted the need for explicit targets, agreed definitions, and measurable indicators to guide planning, implementation, and evaluation.

2. Strengthen Data, Monitoring, and Evidence Generation

All groups identified a need for better environmental data, long-term monitoring, and standardised assessment methods. Improved understanding of cumulative impacts, ecosystem responses, and the effectiveness of environmental measures is essential for informed decision-making.

3. Improve Governance and Coordination

Fragmented governance, sectoral silos, and inconsistent regulatory approaches continue to hinder progress. Stronger coordination between authorities, policymakers, researchers, and industry is needed to align objectives and streamline implementation.

4. Adopt Ecosystem-Based Marine Planning

Stakeholders emphasized moving beyond project-level assessments towards ecosystem-based planning that considers cumulative impacts, ecological connectivity, competing sea uses, and long-term restoration goals. Marine spatial planning is seen as a key enabler of this transition.

5. Connect Science, Policy, and Practice

While significant knowledge already exists, it is not always effectively applied nor shared. Stronger mechanisms for knowledge sharing, data accessibility, and collaboration between research, industry, and authorities are needed to turn evidence into action. As learned through this conference, gathering actors around continuous dialogue is (still) important.

6. Act Under Uncertainty

Environmental uncertainty should not prevent progress. Stakeholders highlighted the need for adaptive, evidence-based decision-making that supports offshore wind deployment while continuously improving environmental understanding.

7. Create Stronger Incentives for Environmental Outcomes

Achieving environmental ambitions will require clearer business cases, dedicated funding, and policy incentives that reward environmental performance, co-existence solutions, and nature restoration efforts.

8. Advance and redefine Nature-Inclusive Design

NID is widely viewed as a promising tool, but clearer objectives and definitions, area- and type-specific approaches, and stronger evidence of effectiveness are needed before it should be implemented consistently and at scale.

Next steps

With this report the organizers wish to establish a common understanding of the state of the field in Denmark, as seen through the lens of the field's various stakeholders. In the coming years ongoing work, e.g. through many of the participating actors and the projects presented in the annex, will continue to develop and advance the understanding of both challenges and options to address them. Thus, to capitalize on the received input, the working group under the Ocean Decade Committee will aim to map out the generated portfolio of DK-based projects to clarify how, and the extent to which, the identified priorities are presently being addressed in a Danish context, enabling a new stock taking by the end of the decade, to understand where progress have been achieved or where action is still needed. This should support all stakeholders from authorities to funders, academia and industry in the planning of future efforts.

The organisers would like to thank all participants for a productive conference and workshop, the Velux Foundation for generous financial support, and Ocean Institute (OI) *Tænketanken Hav*) for providing a venue, logistic support and moderation of workshops.

While this conference was mainly focused on experiences with offshore energy infrastructure in a Danish context, the working group under the Ocean Decade Committee plan to initiate a dialogue with Greenlandic and Faroese representatives to explore how future output could also become of value in their context.

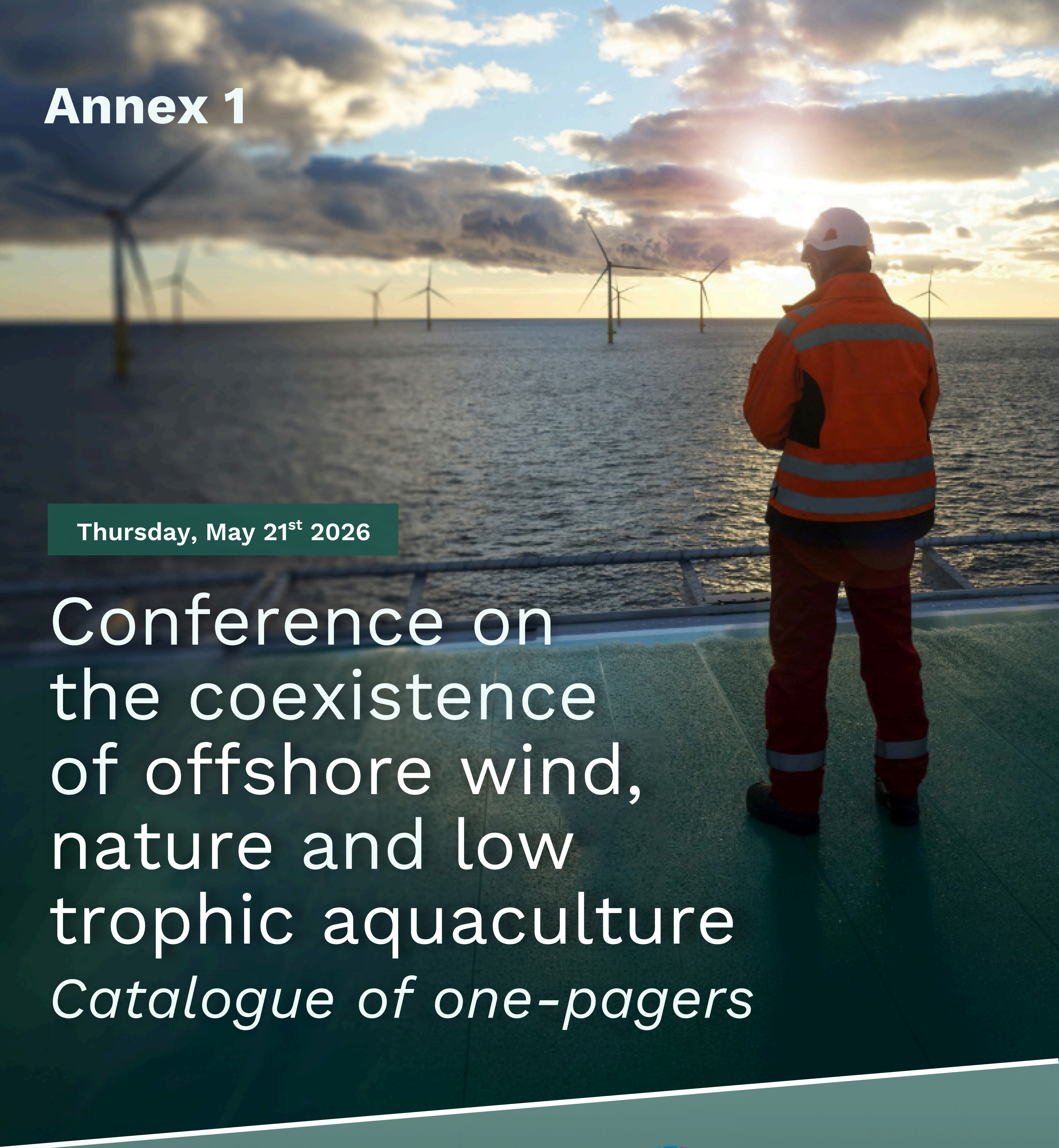
Contributors to the organization of the Conference

Ocean Decade working group members: Liselotte Hohwy (OI), Christian Riisager-Simonsen (DTU), Lars O. Mortensen (DHI), Jakob Nabe-Nielsen (AU), Katrina Povidisa-Delefosse (TTE).

Project leads from contributing multi-use projects: Annette Bruhn (AU), Jens Kjerulf Petersen (DTU)

Additional support: Mathilde Mammen (OI), Mathilde Højrup (OI), Pernille Schou Jakobsen (OI), Ditte Mandø Andreasen (OI)

Editors: Mathilde Mammen (OI), Mathilde Højrup (OI), Liselotte Hohwy (OI), Christian Riisager-Simonsen (DTU).



Annex 1

Thursday, May 21st 2026

Conference on the coexistence of offshore wind, nature and low trophic aquaculture

Catalogue of one-pagers

VELUX FONDEN

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

ULT FARMS

OLAMUR

WIN@sea

NiD4OCEAN

Nature-inclusive designs for reconciling offshore renewables with ocean protection

Horizon Europe – EU Mission Restore our Ocean & Waters

Grant Agreement: 101156861 **Call:** HORIZON-MISS-2023-OCEAN-01-06

Duration: October 2024 – September 2027

12 Consortium partners:

Norwegian Institute for Water Research (NO), Akvaplan-NIVA (NO), Spanish National Research Council CSIC (ES), Wageningen Marine Research (NL), Stichting Deltares (NL), Technical University of Denmark (DK), Klaipeda University (LI), Science Crunchers (PT), Renewables Grid Initiative (DE), DNV (NO), Equinor (NO), ScottishPower Renewables (UK)

The overall goal of the project is to advance the emerging field of Nature-inclusive Designs (NiDs) for offshore renewables and provide effective, context-dependent solutions to industry, managers, and policy makers.

Specific objectives:

- Knowledge foundation - **mapping existing solutions and fostering co-creation of novel NiDs for offshore renewables across European Seas**.
- Assess **biological, socio-economic, and social benefits and risks of NiDs for offshore wind farms** (at different spatial scales and across the life-cycle) to evaluate performance and goals.
- Provide **science-based guidelines for the selection, implementation, and monitoring requirements for NiDs** for offshore wind by co-creating and validating fit-for-purpose decision-support tools, frameworks, and **recommendations towards standards and for easing regulatory scrutiny** together with end users (industry, managers, policy makers), and tailored to regions, ecosystems, and technologies, emphasizing that there is not a one-size-fits-all solution.
- **Find pathways to prioritise solutions that simultaneously address biodiversity and decarbonisation** through stakeholder engagement and tailored strategies.

Case studies

- **CS1:** Southern North Sea. Technology: bottom-fixed wind turbines and floating solar infrastructure. Status: Operational farms with NiDs
- **CS2:** Northen North Sea. Technology: floating wind turbines. Status: Operational farms.
- **CS3:** Eastern Baltic Sea. Technology: bottom-fixed wind turbines. Status: Planned.
- **CS4:** Northwestern Mediterranean Sea. Technology: floating wind turbines. Status: Planned.

Midterm results:

- Brought NiD innovations in a unified catalogue and identified gaps for innovation prioritisation
- Provided clarity about biodiversity, social and economic metrics to be considered
- Social, Economic and Ecological assessment frameworks developed
- Modelling approach and data identified for near and mid-filed assessments of NiD net contributions

Contact: Norwegian Institute for Water Research – nid4ocean@niva.no

Presenter: David Lusseau – Technical University of Denmark (davlu@dtu.dk)

Website: nid4ocean.eu **LinkedIN page:** NiD4OCEAN Project

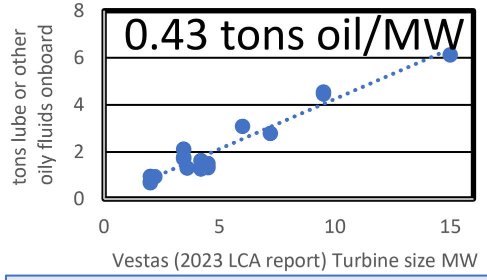
Funded by the European Union

Oily Emissions From Windfarms – Effects on Biodiversity

Project problem and description

- As all classical machinery, a windturbine contains oily substances such as gear oil, hydraulic fluids etc. that may accidentaly leak. The oils serve to decrease wear and other tribological effects. In particular offshore wind turbine oils are formulated for performace and longevity using potent additives reducing maintenance requirements.
- Oils may leak despite efforts using both intricate seals and secondary containment.
- Very little work is reported in literature on leak accidents, rates, risks and impact. Chemical type and release is not regulated in offshore windfarms.
- This project aims at clarifying the ecotoxicity of typical products, the persistency of these in the marine environment, the effect on fish embroy, and the spreading of these oils in nature leading to recommendations to reduce any observed effects.

Data from Vestas LCA report 2023

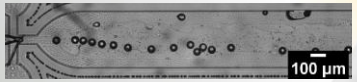


Potential scenario: The NordSø 1 plan of 5-17 GW could hold an inventory of 2000 to 6800 tons oil.
Potential leak rate is currently unknown – and fluid usages and impact is unregulated.
Leak reporting is on a voluntary basis.
1 % leaked would be 20 to 68tons /yr.
Impact is not yet assessed or understood

Current results on five different oil types abundantly used indicate that different trophic levels have different sensitivity towards the oils and that the exposure system has a marked impact on the interaction between the oil droplets compared to dispersed products. The persistence of the oils in marine compartments is higher than what can be predicted from regulatory tests using sludge from wastewater treatment plants, highlighting the need for relevant inoculum and exposure settings for adequate hazard assessment of marine releases. Droplet stability show large variability and dependence on water salinity due to the different interfacial activity. Continued effort to progress insights into this including effects of usage of oil on environmental impact.

Project runs 2024-2027

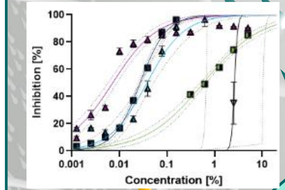
Gear oil droplets in water



Microfluidics analysis of spreading potential

WP1
Oils & droplets

Stable droplets can travel far. The droplets are stabilized by additives that also are assumed to generate ecotoxicity. Stability is found to be affected by water salinity leading to reduced stability in seawater compared to fresh water – which could reduce spreading offshore. Partitioning of species different and also dependent on age and spent of oils



WP4
Impact on Biodiversity

Modelling,Translation,Impact assessment
Collecting all data into Recommendations to industry and authorities
Current gaps:
- *Actual Leak volumes not reported*
- *ID: chemical structures of Toxic additive compounds*
- *Differences in weathering Effects*

-and more…

WP2
Ecotoxicity

Acute effect conc. towards 3 trophic levels ranged ***0.002% to 6%*** *indicating a high variability in both species sensitivity and potency of the compounds. Marked difference observed for different exposure designs (water accomodated fraction or droplets)*

Oil impact on fish embryo development

WP3
Biodegradation

*One gear oil * was investigated in multiple biodegradation tests.*
- Ready biodegradability tests showed 35% mineralization of the base oil (PAG) in wastewater but no mineralization in seawater
- Primary biodegradation of additives were similar in OECD 306 and OECD 309 test but for some constituents higher in OECD 301 test
- Pesistence testing in seawater is crucial for substances emitted to the sea

* Indicated as biodegradable in provider MSDS.

Status of 08-05-2026

Contact: Simon Ivar Andersen: simand@dtu.dk

DTU
INSTITUTE OF MARINE RESEARCH
VELUX FONDEN

OWESOME

Offshore Wind Environmental Survey Optimization for Monitoring impacts on Ecosystems

Funded by TotalEnergies

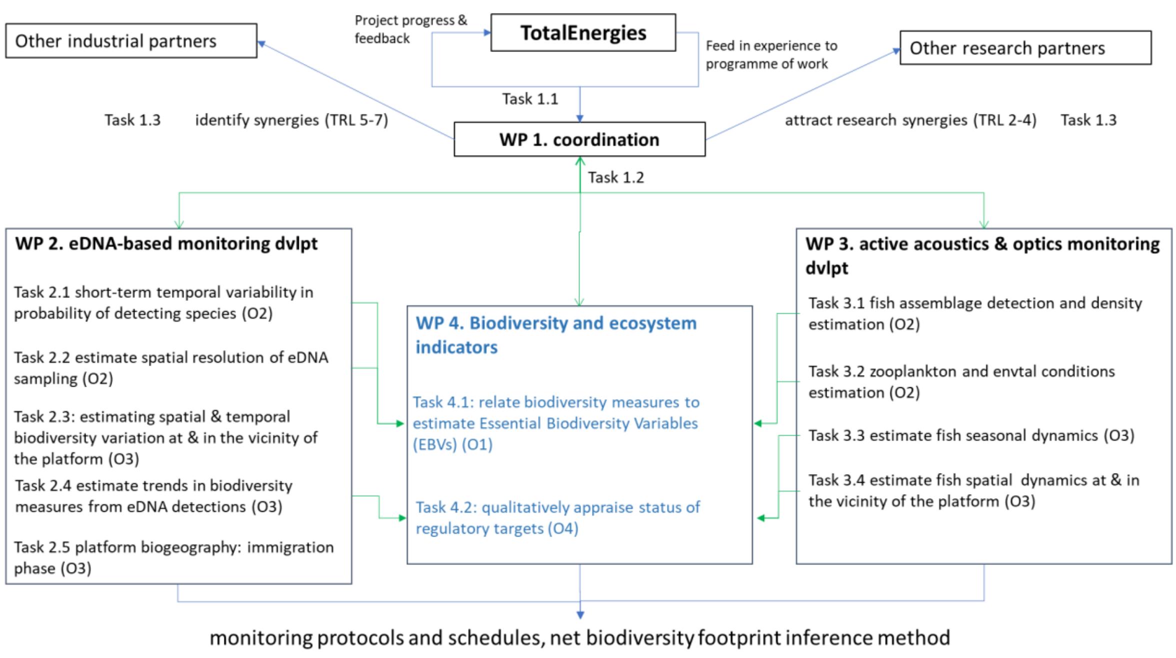
Duration: 2025 – 2030

Aim – Test and deliver an end-to-end protocol to estimate the biodiversity footprint of platforms and its consequences for local ecosystems. To do so, the project aims to advance multimodal environmental DNA, optics and acoustics data integration methods to reliably and robustly monitor local changes in ecosystem composition.

Objectives

- Identify indicators relevant to monitor changes in ecosystem service provision and multiple dimensions of biodiversity within and around offshore wind farms.
- Develop an integrated monitoring platform to reliably monitor key biodiversity indicators at a relevant spatial and temporal resolution.
- Evaluate methods to assess the impacts on local biodiversity of the floating wind turbine using existing data and newly collected data on and around the platform.
- Explore likely biodiversity and ecosystem services impacts qualitatively of offshore wind farms in different locations from the platform to farm to sea basin level

Work programme



Milestone

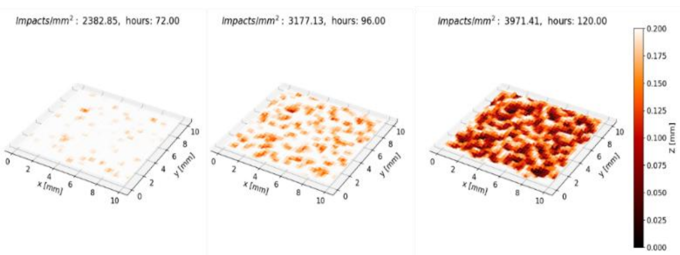
- Designed integrated multimodal sensor unit which has been integrated to the platform
- Identified candidate Essential Biodiversity Indicators

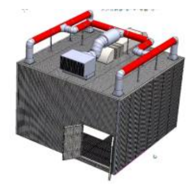
Contact: David Lusseau – Technical University of Denmark (davlu@dtu.dk)

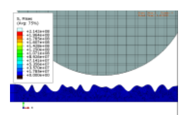
VELUX FONDEN

Velux Fonden project **PREMISE: Preventing MIcroplastics pollution in SEa water from offshore wind**

Wind blade erosion: Testing and modelling







How much microplastic is emitted ?

- 30 g per blade per year for onshore and 500 g for offshore
- 2 orders of magnitude less than paints, and 3 orders of magnitude less than car tires.

Project design

WP1. How serious is the problem? Mapping coating. Prediction of pollution volume. (DTU)

WP2. Plastic degradation and evolution in marine environment (AAU)

WP3. How large risk of the blade microplastic pollution? Effect on sensitive species (RUC) Impact

WP4. Future directions & mitigation (DTU) New generation coatings. Guidelines

WP5. Dissemination (AAU)

WP6. Management (DTU)

Project purpose:

Surfaces of wind turbines are subject to erosion due to rain and hail impacts. It causes high maintenance costs and worsens aerodynamic properties but also can lead to microplastics falling into the water. Is it a risk for marine animals, marine ecosystems, and the environment? This question will be answered in this project.

Expected results:

Evaluate the size and volume of the problem. How much plastic lands in the sea? Quantifying volume, size distributions and shape characteristics of microplastics formed from each blade coating material.

Evaluate environmental risk and toxicological effects for each group of polymers. How potentially toxic is each group of polymers? What is the fate of various microplastics coming from wind turbines?

Future solutions: promising ways to mitigate erosion and its pollution risks. Guidelines for the reduction of marine pollution.

Partners:

DTU Wind: Project coordinator: Leon Mishnaevsky Jr. Privatdozent, Sr. Researcher, Dr. habil. Technical University of Denmark. **Aalborg University:** Jes Vollertsen, Professor, PhD, Forskningsgruppeleder, Institut for Byggeri, By og Miljø, **Roskilde University**: Kristian Syberg, Head of Section, Professor PhD, Institut for Naturvidenskab og Miljø

Publications

Microplastic emission from eroding wind turbine blades,Energies 2024, 17(24)

Coating material loss and surface roughening due to leading edge erosion of wind turbine blades, Wear, 566–567, 2025

Maintenance of wind turbine blades and microplastic emission: How to mitigate environmental risks, Wind Energy, 28, 12, 2025

Wind turbine blade surface roughening and plastic emission due to leading edge erosion, Materials 2026, 19, 963

On the potential of mitigation of microplastic emission by optimizing anti-erosion coatings, Int J Mechanical Sciences, Vol. 319, 2026

Contact:
Professor **Leon Mishnaevsky Jr.**
Technical University of Denmark,
DTU Wind, Roskilde
premise.dtu.dk, lemi@dtu.dk

Offshore wind farms reshape ocean stratification and productivity differently in the North Sea and the Baltic Sea

Marie Maar et al. mam@ecos.au.dk, Ocean Sustainability 2026

Background: Planned large-scale offshore wind developments in the North and Baltic Seas are set to transform these regions into major energy hubs for northern Europe. Offshore wind farms are expected to influence the marine ecosystem through two mechanisms: a wind wake effect inducing increased stratification, and a drag effect increasing mixing around monopiles (Figure 1). We applied 3D numerical models that resolve both atmosphere-controlled wind wake effects and monopile drag to quantify their combined impacts on stratification and primary production.

Results: The North Sea showed spatially heterogeneous changes, whereas the Baltic Sea exhibited stronger stratification and reduced primary production driven by the wake effect (Figure 2). The provided knowledge that ecological effects of offshore wind farms depend on prevailing current speeds and baseline stratification can be used to minimize impacts on the environment in future spatial planning

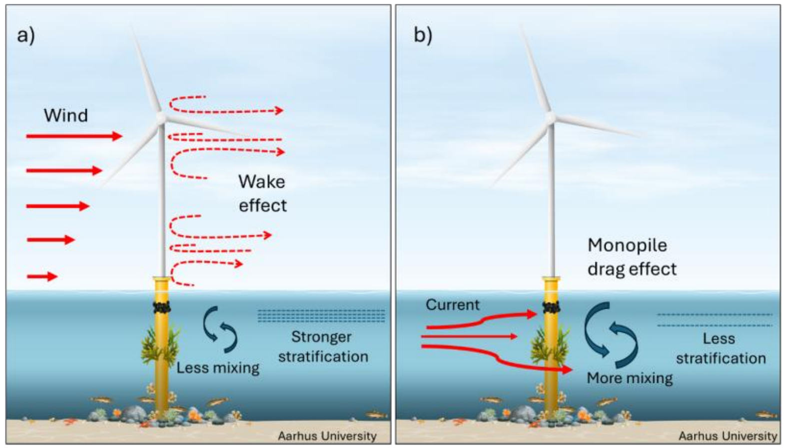


Figure 1. Offshore wind farm effects on hydrodynamics

Impacts on ecosystems:
Stratification and primary production are indicators of changes in trophic structure and overall ecosystem functioning. The found wind farm-induced changes could potentially affect higher trophic levels and conditions for co-existence between nature and offshore wind farms

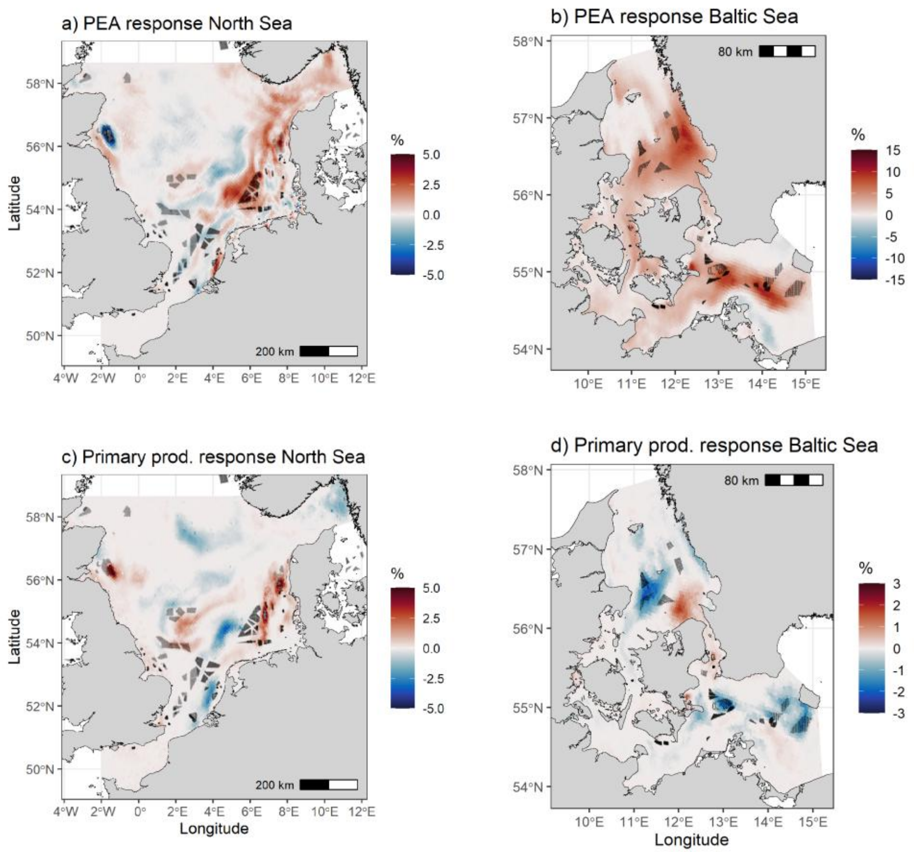
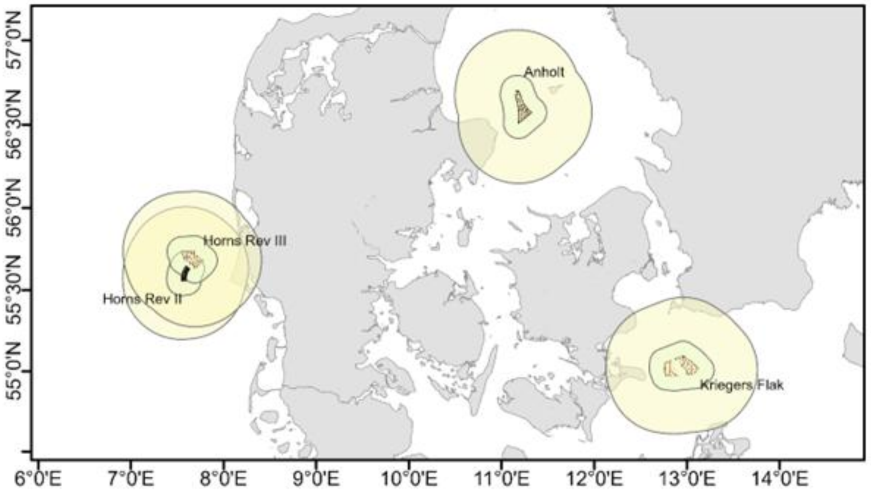


Figure 2. Yearly median responses of stratification (PEA) (a, b) and primary production (c, d) to offshore wind farms for the North Sea and the Baltic Sea, respectively

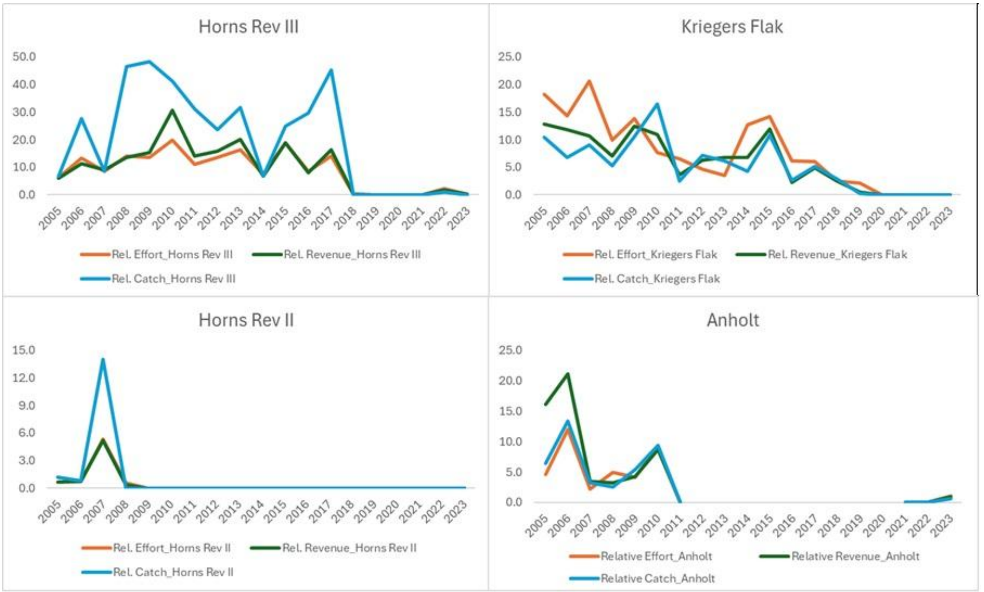
Retrospective analyses of offshore wind farm impacts on fisheries and benthic habitat interactions

The expansion of offshore wind farms (OWFs), driven by increasing global energy demands and marine spatial planning, is intensifying spatial conflicts and impacting fisheries. However, research on observed local and cumulative effects of OWFs on fisheries, especially regarding fishing effort reallocation, is limited. Retrospective analyses are crucial for informing science and policy. Denmark, a pioneer in large-scale OWFs, has over 15 operational farms totaling more than 2500 MW, with some early installations already decommissioned after 25 years. Analyses of the impacts and interactions between OWFs and various fishing fleets were conducted for four major Danish OWFs in the North Sea, Kattegat, and Western Baltic Sea from 2005 to 2023. This timeframe covers pre-, during-, and post-construction phases of the OWFs. Using available vessel monitoring system (VMS) and logbook data, we analyzed vessel-level fishing effort allocation, fishing efficiency, revenues and landings in relation to OWFs, fishing method, and benthic habitat fishing grounds, providing valuable insights into OWF-fisheries dynamics. This study identified major impacts of OWFs on Danish fisheries, as active fisheries within OWF sites generally ceased following construction. However, results indicate potential for reallocating fishing activities to surrounding areas offering similar opportunities. Most vessels are not exclusively dependent on OWF areas, as they typically have flexibility to switch between fisheries or gears and operate across wider areas due to their long range and polyvalent capabilities. Although minor gear-specific variations and localized concentrations in fishing effort were observed just outside OWF boundaries after their establishment, overall fishing patterns and efficiencies remained significantly consistent after OWF establishment – except for one OWF area. Fishing activity within and adjacent to OWFs showed in general similar gear composition, effort allocation, benthic habitat preferences, depth distributions, landings and economic efficiency, and species composition. Spatial fishing patterns associated with habitat also persisted and there was in general found continuity in fishing dynamics in surrounding areas following OWF establishment.

Future perspectives and work: As OWF expansion accelerates across coastal EEZs, further factual assessments are needed, particularly addressing cumulative effects and the cross-sectoral and multi-disciplinary consequences of growing competition for marine space and fishing grounds. In additional future studies, vessel-based models such as DISPLACE (https://displace-project.org/blog/download/) can simulate cumulative effects using historical impact patterns, as shown in this study, and assess site-specific spatial displacement compensating for lost cumulative fishing opportunities.



Overview map of location and extension of analyzed OWFs with indication of location and density of individual turbines (dots) within the borders of each OWF area (0 km zone), as well as the borders for the surrounding near-field area in a radius of 10 km outside the OWF borders (10 km zone) and the far-field area covering a 10–40 km radius outside the OWF area (40 km zone).



Distribution over time of relative effort, relative revenue and relative catch (landings) for the fishery inside the OWF zone (0 km) compared to the sum of the fishery inside and in the near-field surrounding zone (10 km radius area surrounding the OWF borders).

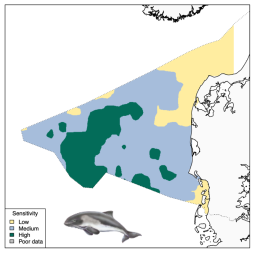
Reference and Contact and Project:
Nielsen JR, Olsen J, Nielsen A, Bastardie F and Egekvist J (2026) Retrospective analyses of offshore wind farm impacts on fisheries and benthic habitat interactions. *Front. Mar. Sci.* 13:1748431. doi: 10.3389/fmars.2026.1748431

Technical University of Denmark, National Institute for Aquatic Resources (DTU Aqua), Kgs. Lyngby, Denmark (rn@aqua.dtu.dk; +45 21314969)

EU-Danish National Government research project "Carbon-free fisheries pathways (CAFF) – Transitioning towards low-impact carbon-neutral fisheries in Denmark by 2050" Proj. Ref. EMFAF Green Transition EFMVB-23–0019 within the Programme GROFISK-24-0023-20240501–1023 under which this research has been financed.

Sensitivity mapping for marine coexistence: siting offshore wind in Danish waters

A planning tool that points offshore wind toward areas of lowest ecological cost



WHAT IS A SENSITIVITY MAP?

A spatial product that combines the relative abundance of a species with the consequence of constructing and operating a wind farm in a given area.

Marine areas are classified as low, medium or high sensitivity — giving planners, authorities and developers a transparent, evidence-based starting point for coexistence. Abundances are modelled based on survey data and consequences are often based on expert knowledge.

WHY SENSITIVITY MAPPING ENABLES COEXISTENCE

01

Spatial transparency

Sensitivities become visible at the scale of national planning, not just project sites — making trade-offs between energy expansion and biodiversity explicit.

02

Multi-taxon coverage

Layers exist for marine mammals, seabirds, bats, fish and benthic habitats. They can be stacked to expose cumulative pressure across taxa.

03

Decision support

Authorities and developers can rank candidate areas before EIA — lowering conflict and steering build-out toward the least vulnerable areas first.

EVIDENCE — DANISH SCREENING FOR OFFSHORE WIND POTENTIAL (2022–2025)

Marine mammals

Stokholm et al.

Sensitivities were mapped for seals and harbour porpoise. Porpoises are particularly vulnerable to underwater noise; OWF construction in core habitats require special attention.

Seabirds

Isojunno et al.

Relative species risks were quantified for 17 species based on conservation status. Three sources of risk were considered: habitat alteration, displacement, and collision.

Bats

Smeele et al.

Highest risk along 0–20 km coastal zone and inner Danish waters; long-distance migrants dominate.

Benthic habitats

Göke et al.

Sensitivity of benthic habitats on basin scale were mapped using a Marine Strategy Framework approach with <2% habitat loss deemed acceptable.

Reports compiled under the Danish Energy Agency's screening for offshore wind potential — Aarhus University (DCE) with NIRAS and DTU Wind.

HOW SENSITIVITY MAPPING FACILITATES COEXISTENCE

1. **Early overview of offshore wind potential.** Direct development toward low-sensitivity areas first; reserve high-sensitivity zones for stricter assessment or exclusion.
2. **Make trade-offs visible.** Use the maps to open early dialogue with stakeholders, NGOs and authorities — turning conflict into informed planning choices.
3. **Stack the layers.** Combine taxa-specific maps to expose cumulative pressure hot-spots across mammals, birds, bats, fish and benthos.
4. **Update iteratively.** Refresh sensitivity layers as new survey data, telemetry and effect studies emerge — keep the maps as living planning tools.

Authors: Jacob Nabe-Nielsen and Eva Friis Møller

References: Background reports available at https://ecos.au.dk/en/gtm/screening-for-wind-farm-potential

Funding: The Danish Energy Authority · Environmental mapping and screening of the offshore wind potential in Denmark

Center for Green Transition and Marine Ecology · Aarhus University, Department of Ecoscience

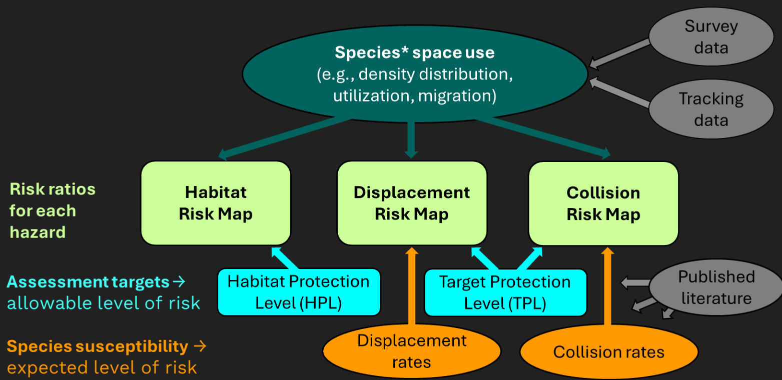
GTM Center for Green Transition and Marine Ecology

Quantifying sensitivity: a framework to map relative risk to seabirds from future offshore wind energy developments in Danish marine waters

Conceptual approach

- **Risk** = likelihood & consequence of unwanted outcomes for species
- **Sensitivity map** = spatial ranking of areas by species risks
- **Relative risk** = risks relative to assessment targets
- **Hazard** = source of risk. We considered:
  1) Overlap with core habitat
  2) Displacement
  3) Collision

$$\text{RISK RATIO} = \frac{\text{Expected level of risk}}{\text{Allowable level of risk}}$$

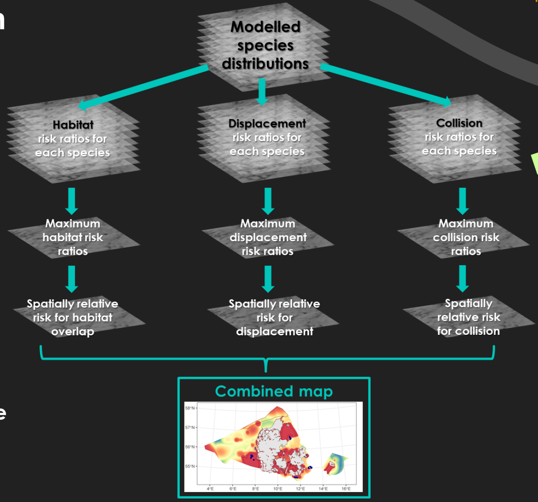


* Species or species groups comprising ecologically similar species. We grouped together divers, alcids (razorbill & guillemot), grebes (red-necked & great crested), grey gulls (herring & common), and terns (common, Sandwich, Arctic).

The algorithm

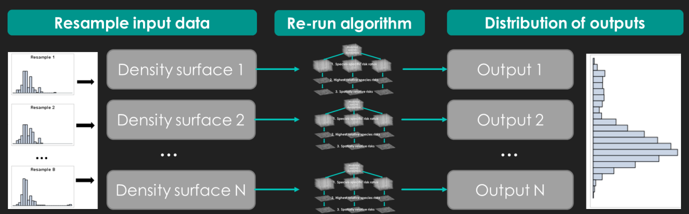
Four main steps:

1. **Species risk relative to assessment targets**
2. **Maximum species risk at each map location**
3. **Rank areas by maximum species risk**
4. **Highest-ranking areas across the three hazards**



Bootstrapping uncertainty

- Resample inputs to generate a distribution of outputs: summarize 95% percentiles and coefficient of variation (CV) to represent uncertainty



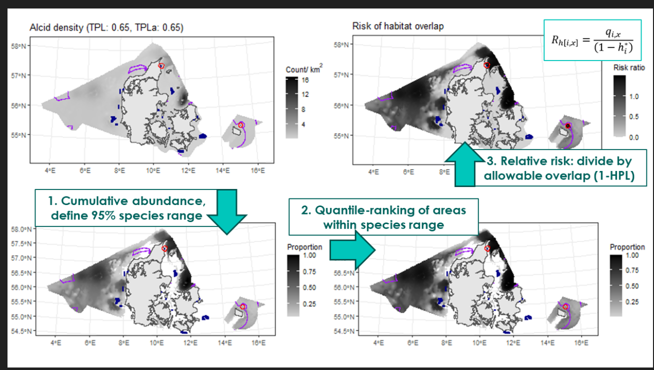
- Current implementation accounts for uncertainty in underlying density surfaces; next version to incorporate uncertainty in all inputs

Ongoing & future work

- Cumulative risk over multiple planning areas
- Shifting baselines: time-weighting historical survey data (25 yrs)
- Incorporating seasonal differences in distribution/usage
- Incorporating tracking data
  - Flight height distributions to inform CRM
  - Usage & passage rates (e.g., migration intensity)
- Interactive web-based tool (Shiny)

Calculation of relative species risks

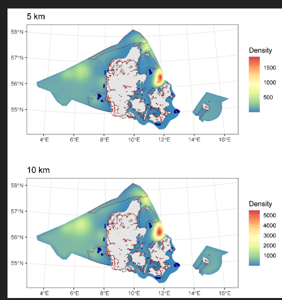
Habitat risk ratio $= \dfrac{\textit{expected overlap with core areas}_{\text{for each grid cell,species}}}{1 - \textit{habitat protection level}}$



Displacement risk $= \dfrac{\textit{expected number of birds at risk}_{\text{for each grid cell,species}}}{1 - \textit{target protection level}_{\text{outside designated SPAs}}}$

Displacement rate & extent

- Species-specific rates (/km^2) derived from a literature review
- To represent expected number of displaced birds in each 1x1 km grid cell, we accounted for bird density in adjacent grid neighbourhoods
  → Larger displacement ranges lead to smoother spatial patterns



Collision risk $= \dfrac{\textit{expected number of birds at risk}_{\text{for each grid cell,species}}}{1 - \textit{target protection level}_{\text{outside designated SPAs}}}$

Proxy collision rates:

- Derived from collision risk modelling with species-specific input parameters (avoidance rates, body size, flight speed), holding wind farm parameters constant

stochLAB

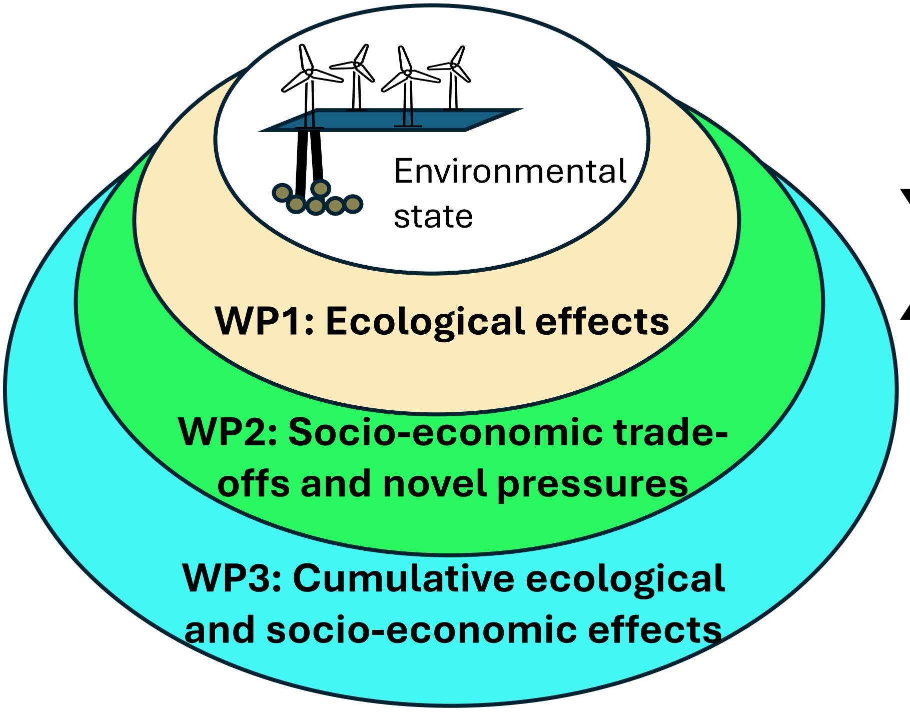
Saana Isojunno (si66@st-andrews.ac.uk)[1], Lindesay Scott-Hayward [1], Claus Lunde Pedersen [2], Heidi Maria Thomsen[2], Jordan Chetcuti[2], Morten Frederiksen[2], Thomas Bregnballe[2], Jacob Sterup[2], Rasmus Due Nielsen[2], Anthony Fox[2], Monique MacKenzie [1], Ib Krag Petersen[2]

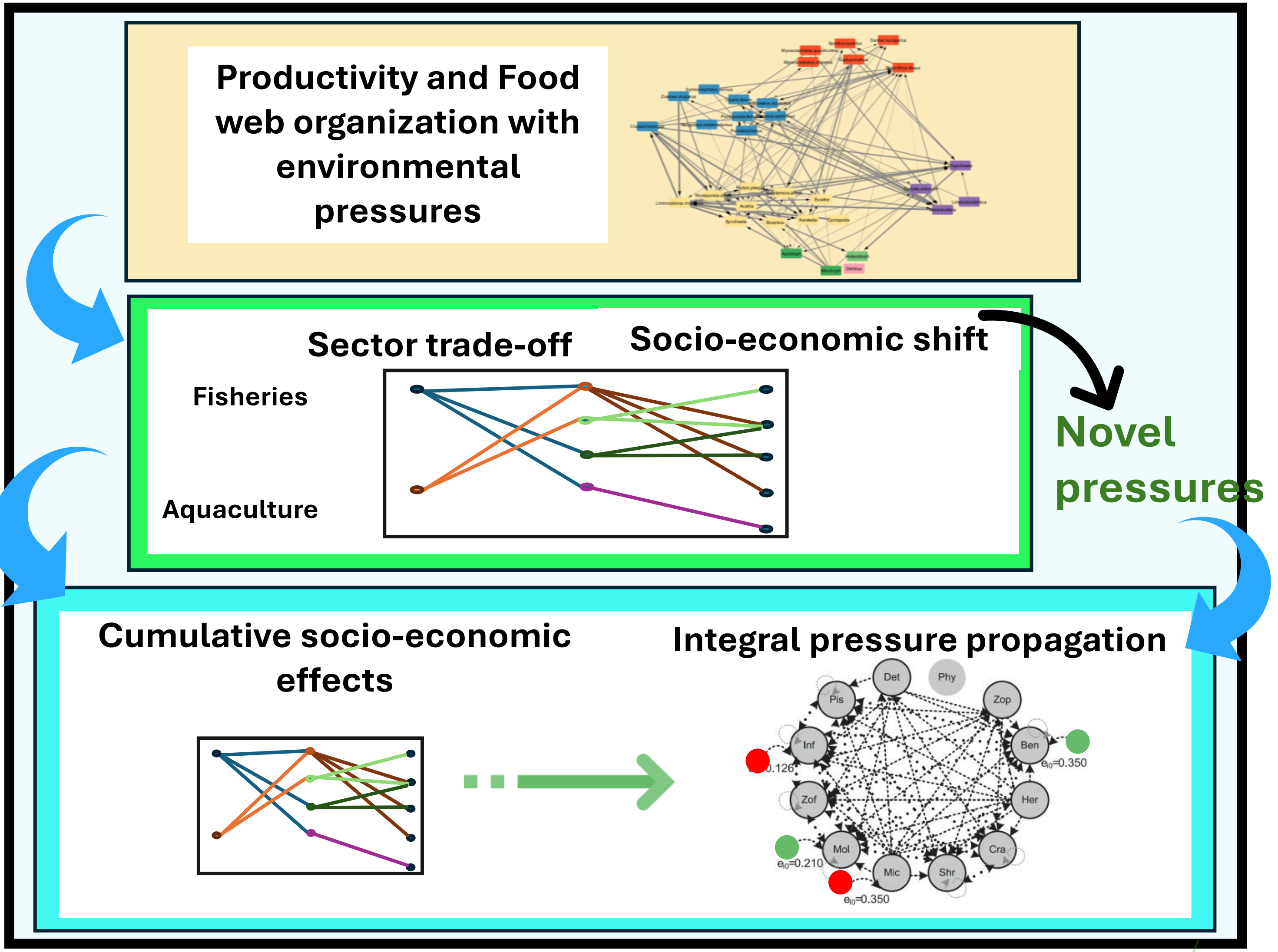
[1] CREEM, School of Mathematics and Statistics, University of St Andrews
[2] Department of Ecoscience. Aarhus University

AARHUS UNIVERSITY · CREEM · University of St Andrews · Energistyrelsen Danish Energy Agency · ENERGINET · NIRAS

Report available online https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Tekniske_rapporter_300-349/TR331.pdf

Cumulative Ecological and Economic Effects of Offshore Windfarms (C3EO)





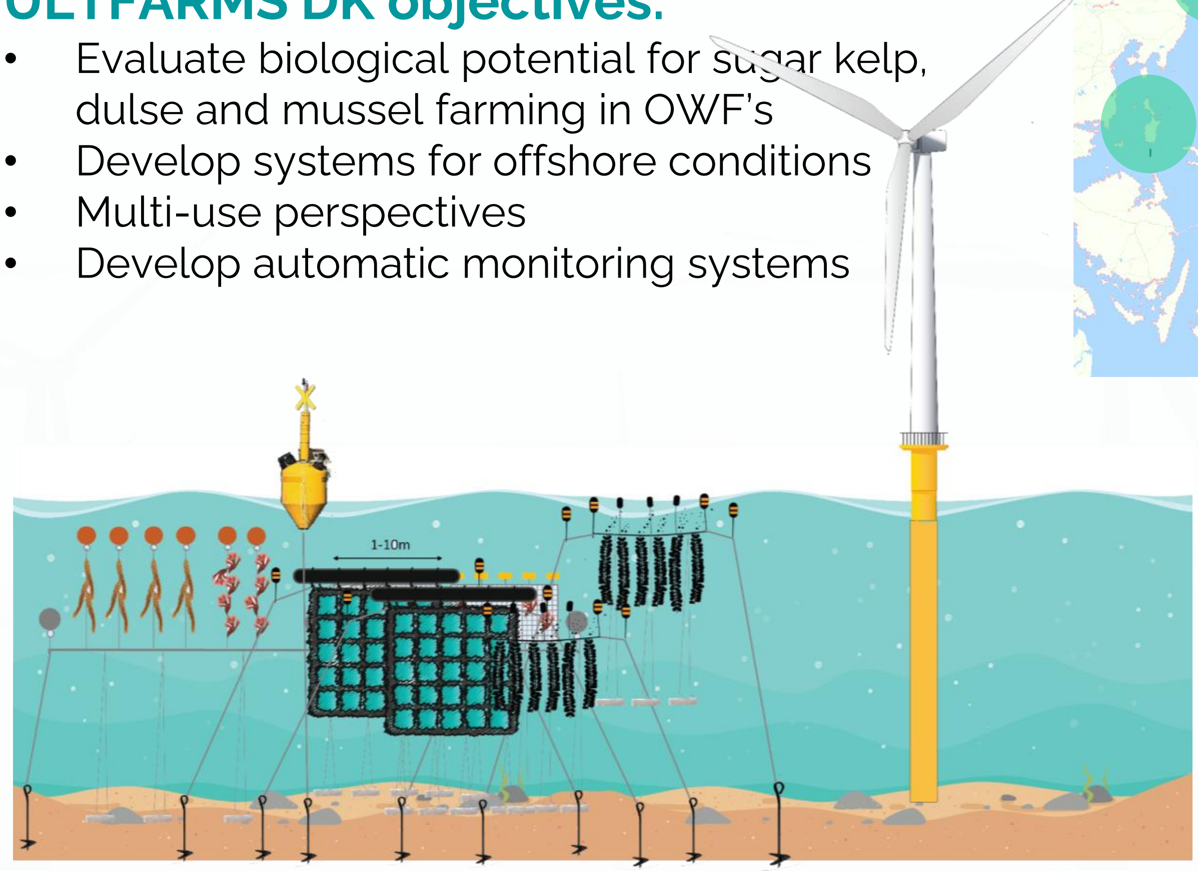
- Evaluate ecological and economic effects of OWFs
- Marine food-web changes with fisheries & aquaculture decisions
- Trade-offs between renewable energy, ecosystems, and sea-based livelihoods
- Co-develop practical policy tools with industry partners and ICES.

Contact: Ashley Hemraj (PI: adhemraj@ecos.au.dk); Adam Koziol; Doan Nainggolan; Hans Jakobsen

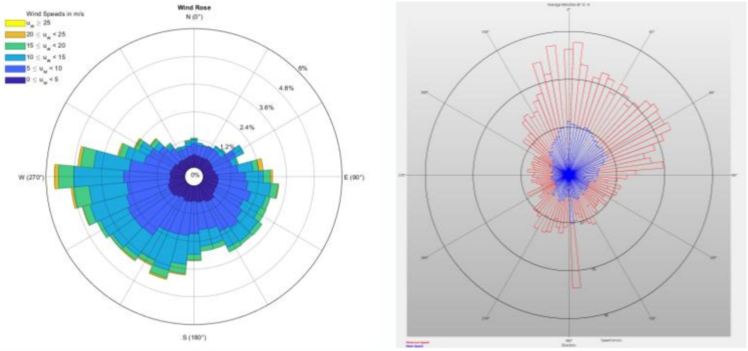
AARHUS UNIVERSITY VELUX FONDEN Center for Green Transition and Marine Ecology

ULTFARMS DK objectives:

- Evaluate biological potential for sugar kelp, dulse and mussel farming in OWF's
- Develop systems for offshore conditions
- Multi-use perspectives
- Develop automatic monitoring systems



Physical forcing



U_c = 1.36 m s^{-1}
H_s = 4.5 m

Conclusions: Technical challenges, good spatfall and growth of mussels, low growth rates of seaweed

This project has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No 101093888. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held repsonsible for them.

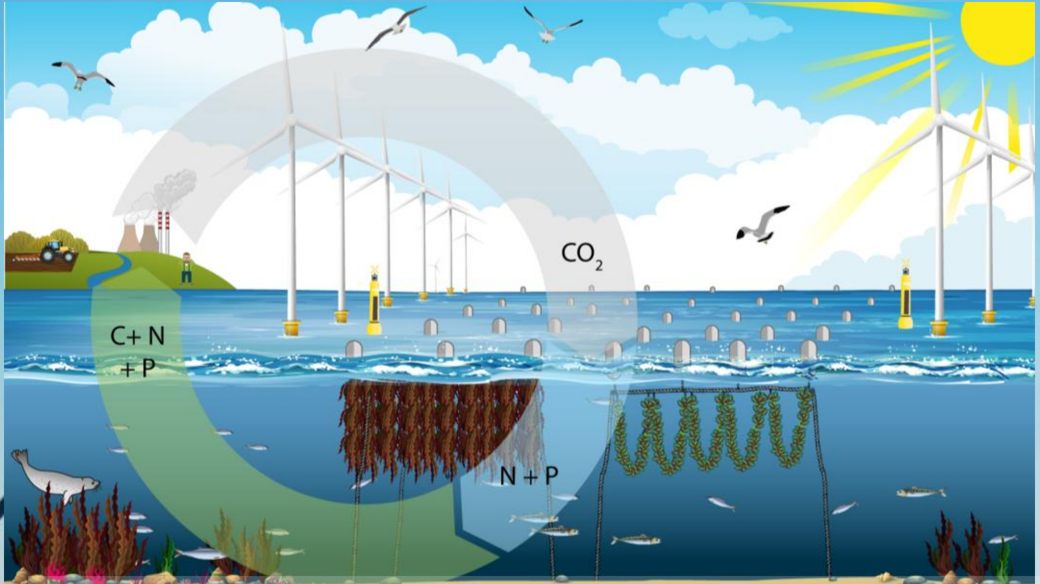
Contact: Jens Kjerulf Petersen, DTU, jekjp@aqua.dtu.dk

Contact: Annette Bruhn, Aarhus University, Department of Ecoscience. anbr@ecos.au.dk

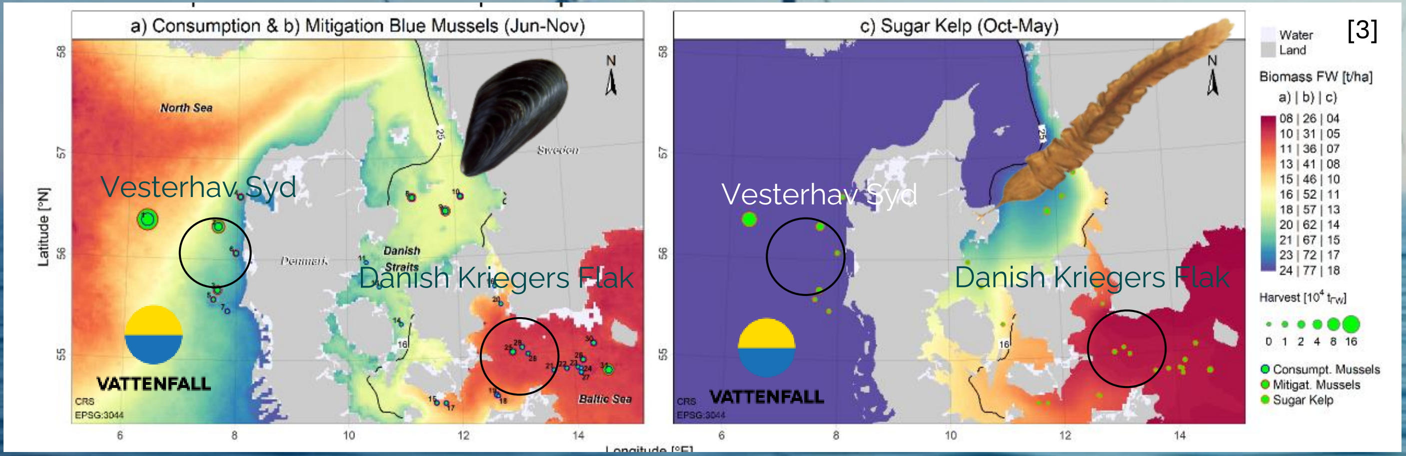
Sharing the space at sea

– co-production of renewable energy and blue food (Marine Multi-Use)

Background: Competition for space at sea is increasing. Marine Multi-Use, where actors share space, services and infrastructure, can reduce overall costs and emissions, while increasing safety of operations [1,2]. Further, by concentrating human activities in already allocated zones, other marine areas can be protected.
Mission: In the WIN@sea and OLAMUR projects, a Danish Multi-Use pilot case was pioneered in the Danish Kriegers Flak windfarm in the Baltic Sea from 2023-2025, and in Vesterhav Syd in the North Sea in 2025-2026. The Multi-Use concept included cultivation of seaweed and mussels, nature restoration and marine monitoring.
Outcomes: 1) Guidelines for Marine Multi-Use, 2) Site selection tool for optimising yields and ecosystem services, while reducing emissions and costs, 3) Life-cycle and techno-economical analyses of Marine Multi-Use scenarios confirm reduced Carbon and Nitrogen footprints, and product costs through Multi-Use, 4) Dedicating 10% of global existing and planned wind farm area for low trophic aquaculture → 132% increase in global low trophic aquaculture yield [3].



Conceptual drawing of Marine Multi-Use – production of seaweed and mussels in a wind farm, supporting a restorative circular blue economy.



[1] Schupp et al, 2019. Frontiers in Marine Science. [2] Thomsen et al, 2026. Ecosystem Services. [3] Maar et al, 2023. Nature Sustainability.

The project is funded by the European Union, grant no. 101094065. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the CINEA. Neither the European Union nor CINEA can be held responsible for them.

VELUX FONDEN

DANMARKS FRIE FORSKNINGSFOND

Ørsted

eDNA-based Monitoring of Marine Biodiversity at Offshore Wind Farms

WINDNA

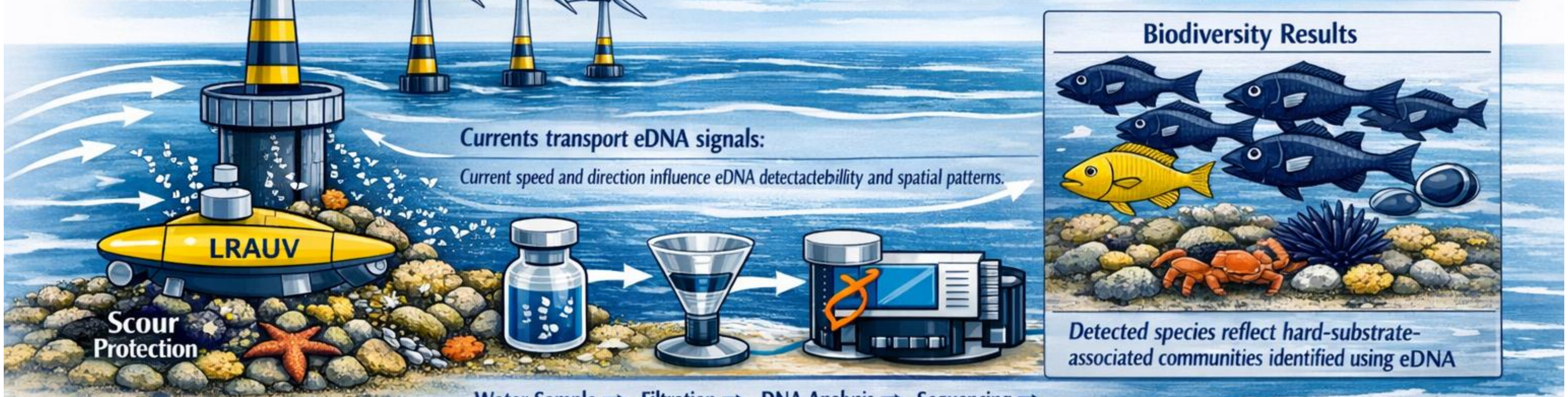
Einar Eg Nielsen, Annkathrin Dischereit, Karoline Degn, Helen Berger, Magnus Jacobsen, DTU Aqua

Project Aim: Develop a standardized eDNA platform for monitoring biodiversity at offshore wind farms

Future Use (Regulation & Monitoring):

- Input to environmental monitoring requirements in offshore wind tenders
- Support regulatory assessments (eg, fish & non-native species)
- Scalable, low-carbon alternative to conventional surveys.

Approved by the Danish Energy Agency as part of offshore monitoring programs.



Water Sample ➡ Filtration ➡ DNA Analysis ➡ Sequencing ➡

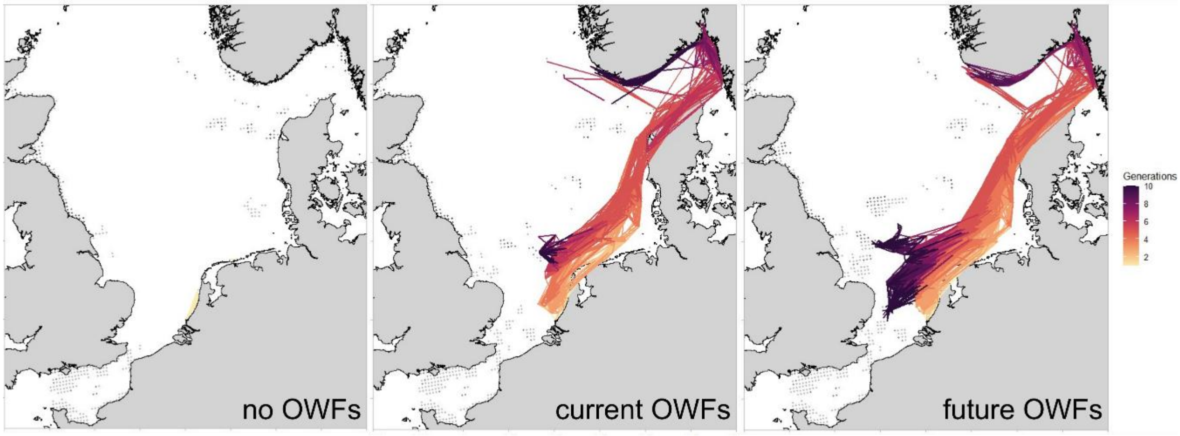
Key Scientific Results (WINDNA):

- Wind-farm eDNA signals are distinct from broader North Sea biodiversity – eDNA reliably separates local wind farm communities from regional biodiversity
- Rocky-substrate species detected primarily above Scour Protection – Hard-substrate species flourish on artificial reefs.
- Robust assessments require large sample numbers across seasons & transects – *High spatial & temporal replication captures* biodiversity dynamics
- Hydrodynamic context is essential for reliable offshore eDNA interpretation – *Current speed & direction are critical for eDNA transport pathways*

Developed in Collaboration with Authorities & Industry

een@aqua.dtu.dk | +45 4021 0231

Are offshore wind parks a "highway" for non-indigenous species to Danish protected reef sites? (WIND-NIS)



Preliminary results from a dispersal model of the non-indigenous species titan acorn barnacle, *Megabalanus coccopoma*, showing the number of generations required for the species to reach the Danish coastline. Results are shown for three scenarios: no OWFs, current OWFs (Nov 2021), and future expected OWFs in 2030.

Background: Studies show that more than 250 non-indigenous species (NIS) from the North Atlantic may be able to settle and survive in Danish waters through range expansion. The seabed surface sediments in the southern and central North Sea are dominated by soft sediments. As many NIS have a sessile life stage, and require stable hard substrate, the lack of boulders likely act as a dispersal barrier for many NIS entering the protected Natura 2000 reef sites in Skagerrak from southern reef sites along the English east coast and the British Channel.

Aim of the project: WIND-NIS will investigate the risk associated with the large-scale establishment of offshore wind turbine platforms for the enhanced dispersal and impact of NIS in Danish marine waters.

Preliminary results: We modelled the dispersal of three candidate NIS using agent-based models to assess the impact of offshore wind farms (OWFs) on NIS spread. One of these species, the titan acorn barnacle *Megabalanus coccopoma*, disperses for up to 21 days. When we modelled the multi-generational dispersal of this species from areas of known populations under no, current (Nov 2021) and future (2030) OWF scenarios, we found that, relative to the no OWFs scenario, current and future OWFs act as stepping-stones that allow *M. coccopoma* to reach previously inaccessible areas, arriving to the Danish coast within four and three generations, respectively (Figure).

We performed eDNA monitoring at two offshore windfarms in the North Sea, Vesterhav syd and Horns Rev (Winter and summer). In total, we detected 16 NIS species of different phylogenetic backgrounds and habitat preference with most hard substrate associated species only detected in the eDNA from scraping samples directly on the wind turbines. In addition, almost all NIS were found in the summer, demonstrating the importance of seasonality in NIS monitoring.

Prevention and mitigation: We are investigating potential prevention and mitigation strategies to minimise the risk of NIS using OWFs as stepping-stones, as means to support co-existence between development of offshore wind on one hand and obligations to protect marine environments according to EU regulations on the other.

Barriers: OWFs as stepping-stones for non-indigenous species is not recognised as a problem for regulation, unlike ballast water for the shipping industry. In fact, political interest has promoted the development of artificial reef elements in at least one public tender in the North Sea. Furthermore, wind parks acting as stepping-stones is an issue for all North Sea countries, but protected Danish reef habitats in Skagerrak are the first in line for potential invasions of spreading NIS.

Contacts: Karsten Dahl kda@ecos.au.dk (PL), C.H. Clubley, A.L. Koziol, M. Maar, C. Mohn, H. Buur and P.A.U. Stæhr (DCE/AU).

Financed by the Velux foundation and the Danish Environmental Protection Agency

Miljø- og Ligestillingsministeriet Miljøstyrelsen
VELUX FONDEN
Centre for Green Transition and Marine Ecology
AARHUS UNIVERSITET DCE - NATIONALT CENTER FOR MILJØ OG E

Environmental Impacts of Offshore Wind

What We Know, What We Don't. Why Does It Matter?

Elliot J. Brown, DTU Aqua, Technical University of Denmark

For the original article scan the QR code or use this link:
https://doi.org/10.1016/j.ocecoaman.2025.107853

Purpose and scope

This one-pager summarises empirical evidence on the environmental impacts of offshore wind energy and its implications for coexistence, based on an updated systematic review. Expert judgement is excluded here in favour of empirical knowledge only.

Where impacts are well established

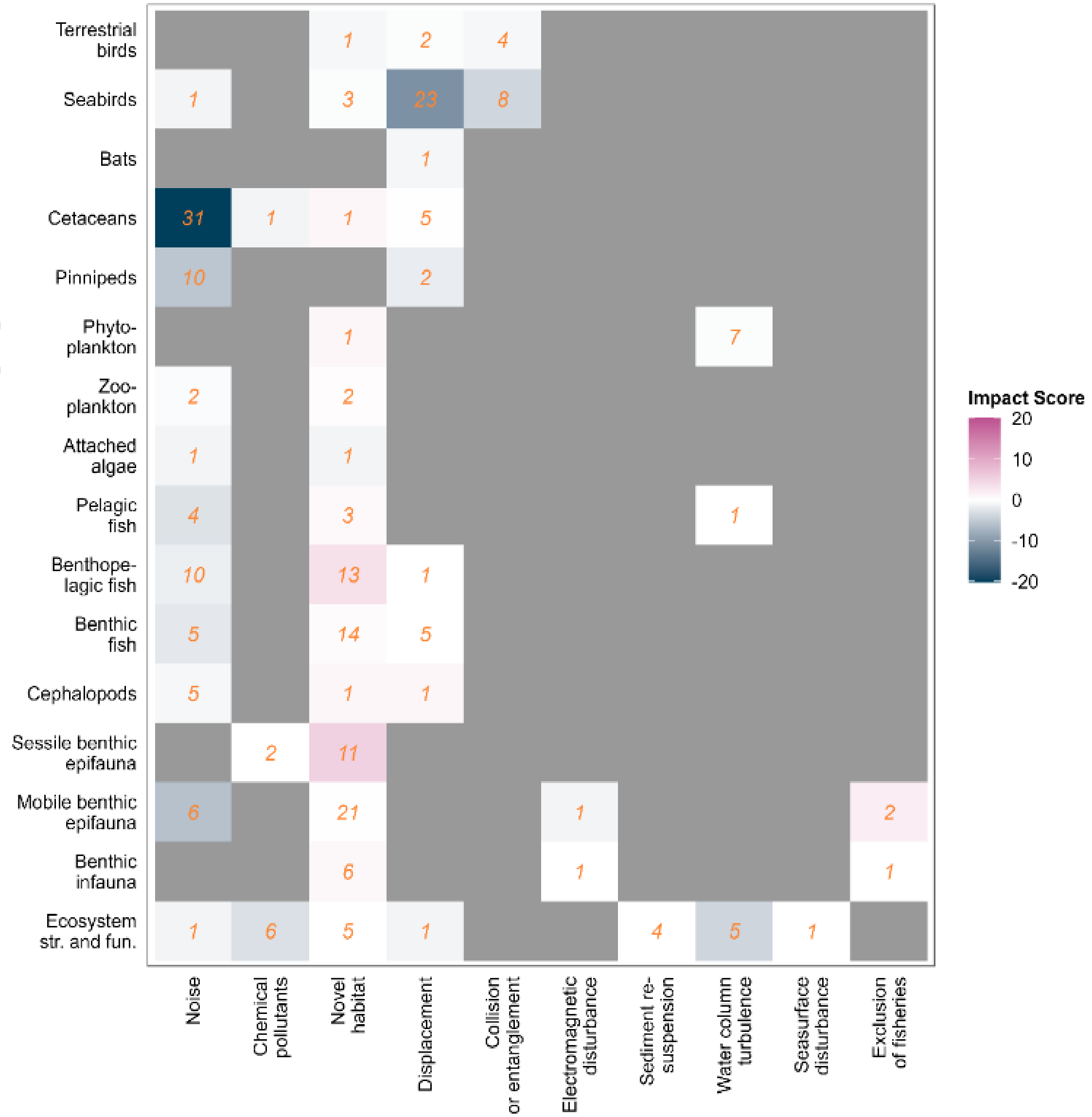
- Negative ***impacts of noise on cetaceans***, especially during foundation installation. This pressure is also seen to negatively impact a wide range of ecosystem components.
- ***Displacement and collision risks for seabirds*** from above-water structures during operation.
- ***Ecosystem structure & function*** is impacted by ***many pressures.***

Where impacts appear positive—but with caveats

- The presence of ***novel hard substrate*** (foundations, scour protection) is frequently associated with positive responses in ***benthic and benthopelagic organisms.*** However:
- These are still ***anthropogenic disturbances***, not neutral interventions.
- Apparent benefits may represent ***pseudo-restoration***, particularly where hard-bottom habitats were historically removed.
- Their ecological value ***depends strongly on context*** and conservation objectives.

Knowledge gaps:

- ***Transmission cables, maintenance activities*** and ***decommissioning*** are poorly studied
- ***Cumulative impacts*** across multiple pressures and activities are rarely addressed holistically
- ***Floating offshore wind technologies*** are almost entirely absent from the empirical literature
- Pressures such as ***chemical pollution and sediment resuspension*** are judged by experts to pose ecosystem-wide risks, despite minimal published evidence.



Biodiversity State Indicator (BSI)

A unified metric for quantifying and tracking biodiversity change

Biodiversity loss is widely recognized as a major global challenge, driven by climate change and intensified human pressures on ecosystems. However, existing frameworks often lack consistent and operational methods for measuring biodiversity. Thus, DHI has developed the Biodiversity State Indicator (BSI) (Mortensen & Schrameyer et al. 2025) to provide a transparent and science-based approach to measuring biodiversity across ecosystems.

How it works

Calculations of the Biodiversity State Indicator (BSI) capturing biodiversity change

Biodiversity is an abstraction of a multidimensional concept (Purvis and Hector, 2000). In this context, biodiversity is defined as an integrated concept that includes taxonomic diversity, functional diversity, and the degree of possible interactions between ecosystem components (such as connectivity and I-diversity). Generally, the individual diversity types are calculated for both the target and reference ecosystem, and the target ecosystem is then benchmarked against the reference ecosystem.

Definition of target & reference ecosystem

Define a clear reference baseline and collect species abundance data at both target and reference sites using consistent methods, scale, and resolution to allow comparability.

Calculate α-, β- and I-diversity

Calculate standard biodiversity indices for target and reference sites across taxonomic, functional, and interactions, capturing species composition, ecological traits, and species networks.

Standardisation and aggregation into BSI

Indices are standardised against the reference state and averaged into component scores (taxonomic, functional, and interaction), and then averaged to produce a single BSI value.

Interpretations and applications

The BSI provides a single score per site relative to a defined reference, where positive values indicate biodiversity gain and negative values indicate loss, making it both intuitive and easy to communicate across scientific and decision-making contexts. It can be applied in environmental impact assessments, offshore wind and marine spatial planning, biodiversity net gain frameworks, and long-term monitoring programmes to support consistent evaluation and reporting of biodiversity change.

References

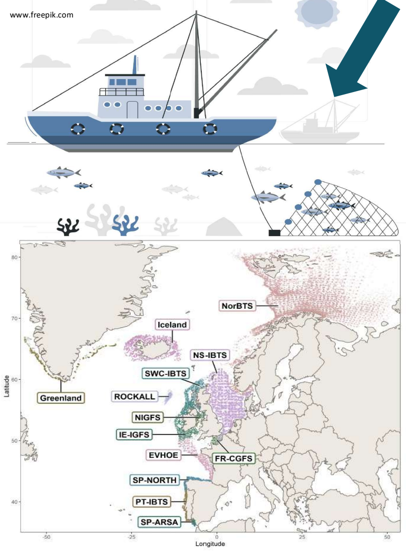
Mortensen & Schrameyer et al (2025): Biodiversity State Indicator: Integrating taxonomy, functionality and species interactions. doi: https://doi.org/10.1101/2025.05.23.655681

Purvis, A., and Hector, A. (2000). Getting the measure of biodiversity. Nature 405, 212–219. doi: 10.1038/35012221

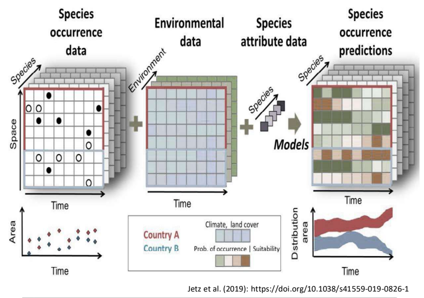
How to “B-USEFUL” in marine spatial planning and conservation: from Earth observations to decision-support tools (DST) for biodiversity protection

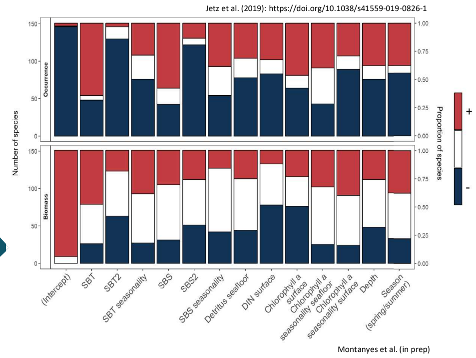
Brief intro to B-USEFUL from the project coordinator

1. Co-creation: project activities and outcomes, including DSTs are designed together with end-users to ensure uptake and future implementation fitting their specific needs in marine spatial planning (MSP) and conservation

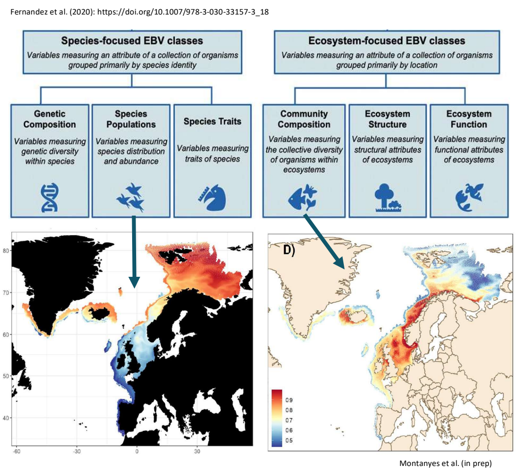


2. Data collection: high-resolution monitoring data of species abundances and traits are collected and standardized from available bottom trawls surveys throughout European shelf seas (bottom panel), covering a pronounced gradient in latitudes and environmental conditions.



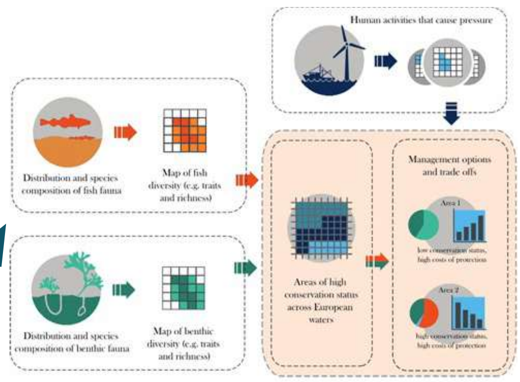


3. Modelling: joint species distribution models (JSDMs; top panel) are parametrized and validated based on available data – thus providing improved process understanding on key drivers and responses of (fish) species distribution and composition to environmental conditions (lower panel).



4. Indicator development and mapping: the validated JSDMs are used to generate maps of past, current and future patterns in multiple biodiversity indicators, i.e., Essential Biodiversity Variables (EBVs), including both species and community-level indicators (bottom panel).

5. Scenario testing and management strategy evaluation: model predictions of marine biodiversity under different scenarios are combined with available maps of current or planned human activities to prioritize protection of biodiversity (30% by EEZ), while minimizing trade-offs with other ocean sectors (e.g., fishing and offshore energy).



Conceptual figure of a DST for evaluating trade-offs and prioritizing MPAs using maps of biodiversity and other ocean use sectors as input (work still in progress)

For more information, please contact Martin Lindegren (DTU, Denmark): mli@aqua.dtu.dk

Check out our website for more info.

European Commission
This project has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement No. 101059823 (B-USEFUL)

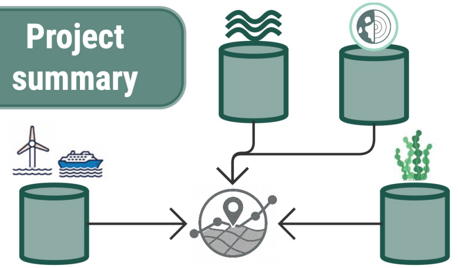
DTU

Title: Decision Support Tools for Spatial Planning and Cumulative Effects Assessment of Offshore Wind in the Greater North Sea

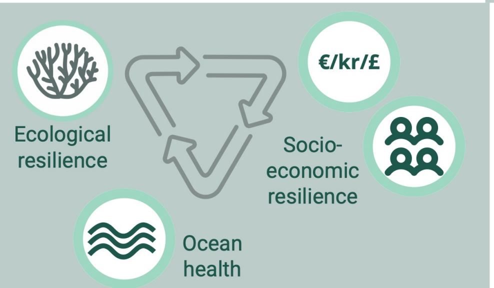
Aim: Understanding the cumulative impacts of offshore wind developments to inform marine spatial planning

: h.s.putuhena@soton.ac.uk

Project summary

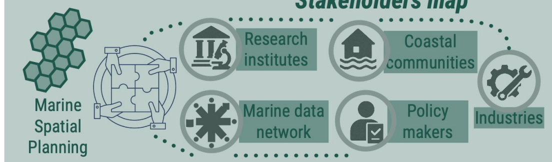


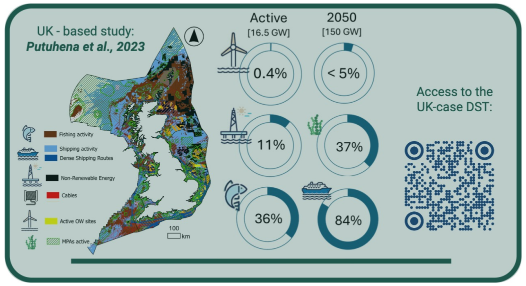
Geospatial analysis



Cumulative impact assessment

Role of stakeholders engagement





Decision support tools (DST)

How you can contribute...

You belong on this map – or you know who does.

- I AM A STAKEHOLDER

Tell us who you are and your interest and/or involvement in offshore wind.

- I KNOW A STAKEHOLDER

Nominate someone (a colleague, leader, or organisation) who should be part of this analysis.

Scan to begin your participation. Takes 2-3 minutes only.

Project timeline

2026	2027	2028	2029

Initial development of geospatial data → Initial integrated data → Development of integrated data → Decision support tools

Stakeholders engagment 1 ··· 2 ··· 3 ··· 4

1. Identification of knowledge and data gaps
2. Intedisciplinary **geospatial analysis**
3. Development of integrated data

Cumulative impact assessment → **Decision support tools**

Outreaching stakeholders

How the project results will be used in practices

Project outcome: **Decision support tools**

"Bridging the gaps between **complex marine data** and **the stakeholders** who need to make **decisions** with interactive maps, dashboards, and geospatial datasets."

- Access to assess the impact of offshore wind development alongside other human activities on the environment (e.g., marine biodiversity) in the Greater North Sea.
- Access to assess different scenarios of future offshore wind development and spatial planning and their impact to the environment in the Greater North Sea.

SOUTHAMPTON MARINE & MARITIME INSTITUTE

VELUX FONDEN

University of Southampton

EcoCorp
Biodiversity action in offshore wind energy
Reconciling ecosystem-based and corporate-driven biodiversity action across scales
Practice-oriented research project | 2025-2028 | Funded by the VELUX FOUNDATION

The challenge
Large-scale offshore wind development raises difficult questions about how marine biodiversity can be understood, assessed, and acted upon across planning, permitting, project development, and monitoring.

Marine ecosystems operate across **large spatial and temporal scales**, while offshore wind decisions often have to be made through **project-specific, legally robust, and operationally actionable procedures**. That makes it challenging to consider biodiversity consistently across scales.

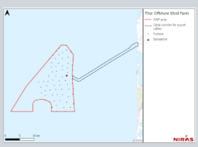
How can biodiversity action in offshore wind energy be organized more consistently across scales?

Project purpose & design
EcoCorp combines research (WP1), collaborative workshops (WP2), and learning formats (WP3) to support **more ecosystem-based use of existing planning and environmental assessment tools**.

WP1: Mapping the biodiversity data chain

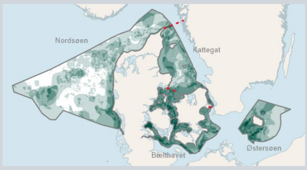
EcoCorp studies how biodiversity data, tools, indicators, and assessments are produced, interpreted, and used in offshore wind planning and project development.

Case studies of two projects


Thor OWF


Hesselø OWF

Future-oriented biodiversity considerations
- Evolving Danish and EU marine governance
- Danish Energy Agency monitoring program and sensitivity mapping



WP2: Collaborative workshops and process framework

EcoCorp brings together authorities, offshore wind developers, environmental consultants, NGOs, and other stakeholders in a **series of collaborative workshops**.

- **Placement of offshore wind areas**
- **Auction design**
- **Environmental impact assessment**
- **Biodiversity-enhancing solutions**

Output: Process framework for biodiversity action in offshore wind

WP3: Learning & reflective spaces

EcoCorp translates project insights into **educational modules** and **learning formats** for current and future practitioners at the intersection of the energy transition and nature, including a DTU master-level module and CBS executive education.

Project team
EcoCorp is led by **Copenhagen Business School** and **WWF Denmark**, in collaboration with **DTU Aqua** and **DTU Wind and Energy Systems.** The project is funded by the **VELUX FOUNDATION** (2025 to 2028).

Co-PIs
Lise Justesen, Copenhagen Business School, lj.ioa@cbs.dk
Jonathan Feddersen, Copenhagen Business School, jfe.ioa@cbs.dk
Stine Gro Jensen, WWF Denmark, stine.gro.jensen@wwf.dk

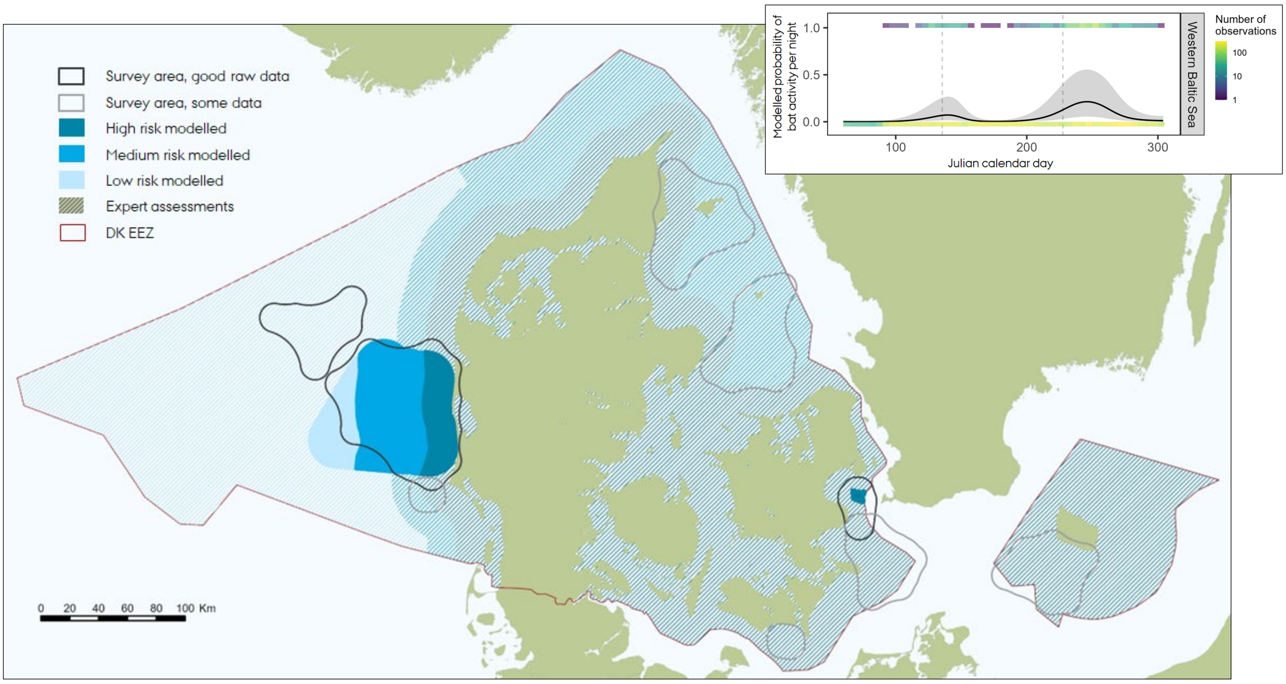
CBS WWF DTU Aqua DTU Wind VELUX FONDEN

Bat activity over Danish waters - overview and knowledge gaps

Background: Wind energy production poses a major conservation challenge for bats as wind turbines increase mortality and degrade habitat quality. Most research has focused on onshore wind turbines, but bats are also at risk when foraging or migrating over marine waters. Bat migration and foraging activity were known over the Baltic Sea, Øresund and Fehmarn Belt, but a comprehensive overview covering all Danish water lacked.

To guide evidence-based development of offshore wind turbines (OWT) we used passive acoustic monitoring data collected in OWT projects over the latest years to elucidate on offshore bat activity over different Danish marine areas. Data were obtained from Energinet, Vattenfall, Ørsted Wind Power and HOFOR.

Results: Bat activity was higher over the inner Danish waters than over the North Sea for all bat species and species groups. The differences would probably have been larger, if raw data of comparable quality had been available from all survey areas. Bat activity peaked during the autumn migration period in all areas, but a peak during spring was also evident over in the inner Danish waters. Bat activity declined with distance to the coast in the North Sea but this could not be documented in other areas. Offshore activity was dominated by Nathusius's pipistrelle, ENV-complex (noctules, parti-coloured bat and serotine) and soprano pipistrelle.



Hatched areas indicate expert assessments of the sensitivity of bat populations to OWT development in different seas. Using recorded bat activity over the southern Øresund as reference, the modelled bat activity over the North Sea fell <10% 21 km and <1% 67 km from the coast, but uncertainties on the estimates were high. The heterogeneous methodology between studies hampered advanced modelling of bat activity from all areas.

Conclusions: Overall, survey results confirmed the expert assessment of a higher risk to the conservation status of bat species from OWT in the inner Danish waters than in the North Sea, but reliable assessments of bats in all marine areas require better validated data across multiple years.

Knowledge gaps: 1/ To develop sustainable offshore wind energy, more systematic long-term monitoring of offshore bat activity and better knowledge on migration routes and flight heights in spring and autumn is required. 2/ To further elaborate on the risk to bat populations from OWT, the collision risks and mortality rates at OWTs should be researched at several turbines in several wind farms. 3/ To realistically model the risk from OWT at population levels and the cumulative effects on national and fly-way populations, basic research on population sizes and dynamics for the relevant species is also required.

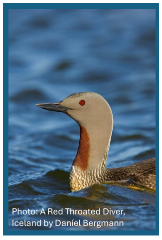
Contacts: Morten Elmeros (elm@ecos.au.dk), S.Q. Smeele, S.M.M. Brinkløv, K.J. Grethen.

Financed: Danish Energy Agency.

DEPARTMENT OF ECOSCIENCE
AARHUS UNIVERSITET

Danish Energy Agency

Center for Green Transition and Marine Ecology



Tracking a quarter century of changes in common scoter and diver species' distribution and abundance in response to the successive development of the Horns Rev I-III offshore wind farms, Denmark.

University of St Andrews · CREEM · AARHUS UNIVERSITY · ENERGINET

L Scott-Hayward, I Krag Petersen, M Mackenzie, C Lunde Pedersen, S Isojunno, R Due Nielsen, J Sterup, HM Thomsen, RS Neergaard, A Fox

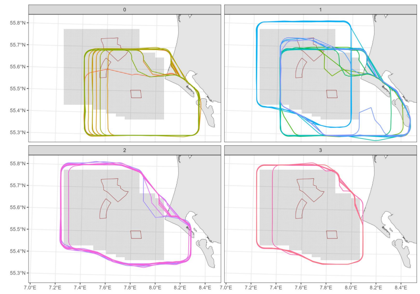
Horns Rev Study Area

- 2,818 km²
- Most of the study area falls within EU Bird Directive area (SPA113)
  - HR I; 80 turbines 560 m apart (2002)
  - HR II; 91 turbines in arcs 693-905 m apart (2009)
  - HR III; 49 irregular turbines 1-1.7 km apart (2018)
- A shallow sand bar extending west from Blåvandshuk (0-35m)

Survey Effort

- 62 visual aerial surveys, 2000 - 2025
  - Varying coverage over time

Phase	Phase number	Date range	Number of surveys
Pre-construction	0	Feb 2000 - Apr 2002	15
Post HR I	1	Aug 2002 - Apr 2007	25
Post HR I - shortened	1*	Nov 2005 - Apr 2007	10
Post HR I & II	2	Mar 2011 - Apr 2012	10
Post HR I, II & III	3	Nov 2023 - Mar 2025	12



Distance Sampling Methods

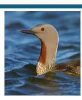
- Pooled across all surveys
- **Covariates**: Behaviour, Observer, Sea State, Group Size
- **Glare issues** - dealt with prior to distance analysis.
  - Left/right sided detection bias assessed using band A detections on each transect. Transects reduced to single side if proportion exceeded critical value.
- **Uncertainty Estimation**
  - Parametric bootstrap to generate distance corrected data.

Spatial Modelling Methods

Spatially adaptive GAM using MRSea R package for each survey separately

- **Tweedie family:**
  - Response – counts/unit area (transects segmented to ~ 500m x transect width)
- **Covariates:**
  - Bathymetry, Distance to Coast (B-spline/Natural cubic), Spatial coordinates (Gaussian basis)
- **Model selection:**
  - BIC for flexibility of terms, k-fold cross validation for selection between models.
- **Uncertainty Estimation**
  - Robust standard errors, parametric bootstrap using detection function bootstraps as input.

Diver Results

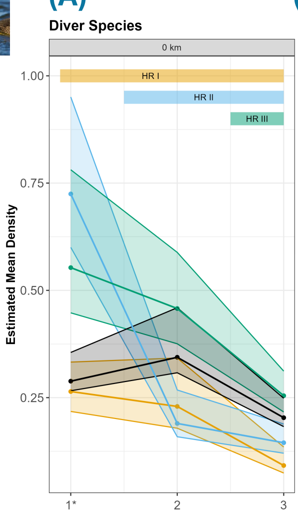


(A)
- **Density within each footprint** over time (phases 1* to 3). Black is the study area density.
- Steady with a general decline in density phases 2 to 3.
- A steep decline in the footprint of HR II post construction.

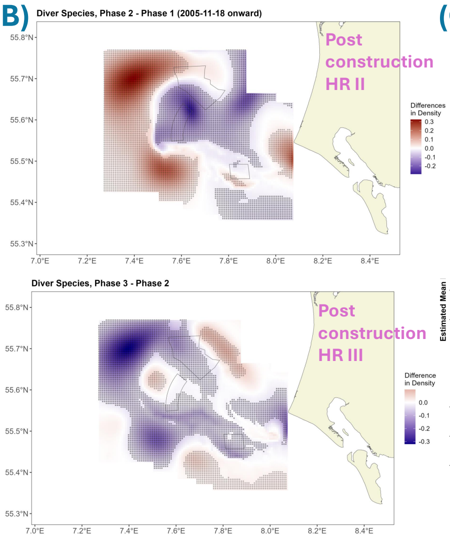
(B)
- **Spatial changes in density** between phases
- Evidence of decline in/around HR II post construction
- Some

(C)
- **Displacement from HR II.**
- Clear evidence of displacement in out to 6.5-8.5 km from HR II

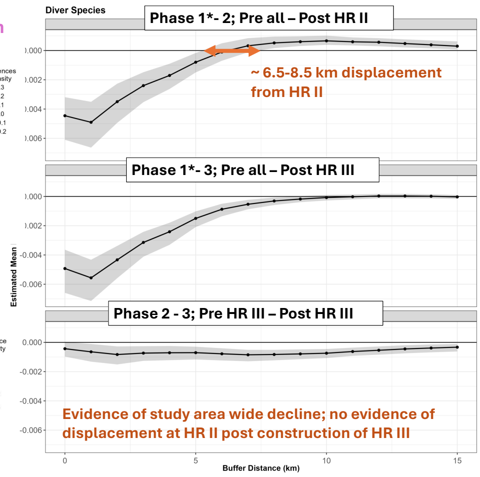
(A)



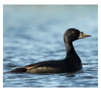
(B)



(C)



Common Scoter Results

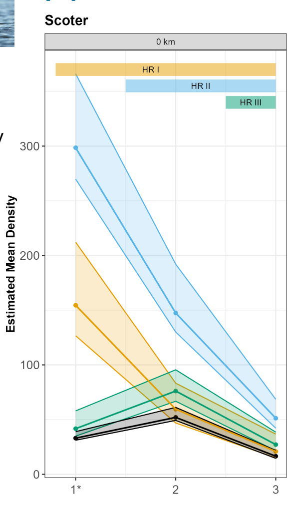


(A)
- **Density within each footprint** over time (phases 1* to 3). Black is the study area density.
- Generally, a slight increase in density phases 1-2 and then a decline.
- A steep decline in the footprint of HR II post construction continuing beyond construction of HR III.

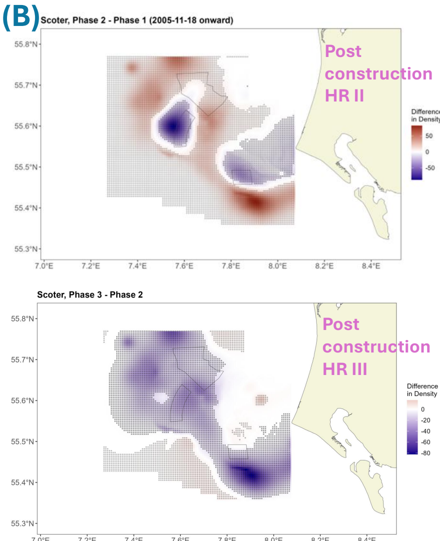
(B)
- **Spatial changes in density** between phases
- Strong evidence of decline in/around HR II post construction
- Mainly study area wide decreases in density post construction HR III.

(C)
- **Displacement from HR II.**
- Clear evidence of displacement out to 4-5 km from HR II.

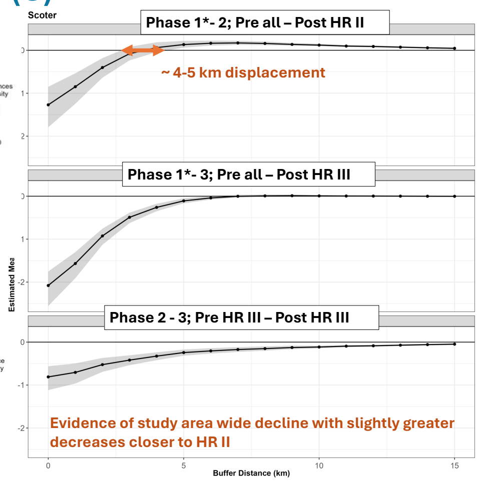
(A)



(B)



(C)



Conclusions

Horns Rev I:
- Complications of survey coverage and changes in abundance due to range changes and external shocks
- Some evidence of displacement of Divers

Horns Rev II:
- Evidence of displacement for both species following construction
- Some evidence remains (Phase 3) but complicated by wide-scale declines in the most recent surveys.

Horns Rev III:
- Mixed evidence for displacement depending on Year 1 or Year 1/2 assessment in Phase 3
- Some declines in density evident but to a lesser extent than HR II

Report: Scott-Hayward *et al (2025)*. Changes in the distribution and abundance of common scoter and diver species in the Horns Rev I, II and III offshore windfarm areas, Denmark, 2025. Commissioned by Energinet. (https://tinyurl.com/3j69h7t4)

POLICY BRIEF · CONFERENCE ON COEXISTENCE 2026 · UN OCEAN DECADE

Harbour porpoises and offshore wind: a path to coexistence

Evidence from agent-based cumulative impact assessment in Danish waters

KEY FINDING

When all current and planned wind farms are simulated together with shipping and natural foraging behaviour, offshore wind has no measurable effect on Danish harbour porpoise populations.

Disturbance is real but local and of short duration; modelled at population scale, it is offset by behavioural recovery and prey aggregation around turbine foundations. However, large-scale changes in currents and prey induced by offshore wind may affect populations.

Harbour porpoise (Phocoena phocoena)

WHY COEXISTENCE IS POSSIBLE

01

Disturbance is local

Pile-driving deters porpoises beyond 20 km — but only for a few hours. Operating turbines are nearly silent; service vessels are the main residual noise source.

02

Foundations attract prey

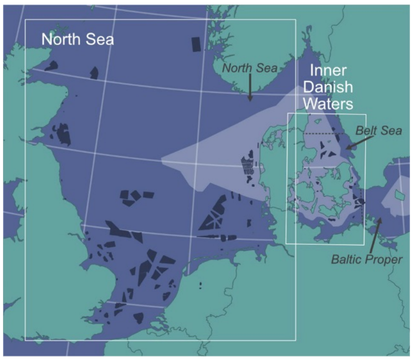
Wind-farm structures act as artificial reefs. Higher local prey availability partially compensates for energetic costs of avoidance behaviour.

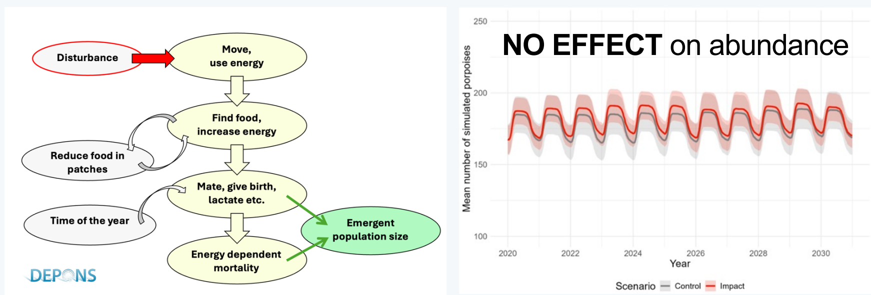
03

Population scale matters

Individual avoidance does not equal population decline. Agent-based models linking energetics, movement and reproduction reveal the true cumulative footprint.

EVIDENCE — CUMULATIVE IMPACT ASSESSMENT, DANISH WATERS





All existing and planned wind farms in 2020–2030 — North Sea & Inner Danish Waters — simulated together with vessel traffic and prey aggregation around turbine foundations. The model simulates movements, energetics and responses to disturbance for individual animals.

RECOMMENDATIONS FOR POLICYMAKERS

1. **Plan at the population scale.** Assess cumulative effects of all wind farms, vessels and fisheries jointly — not project-by-project. Use spatial population models to set thresholds.
2. **Mitigate the loudest hours.** Bubble curtains, soft-start and seasonal restrictions during pile-driving keep impacts brief and local. Route construction vessels away from key foraging areas.
3. **Manage vessel noise.** Service-vessel noise — not turbines — is the dominant operational disturbance. Speed limits and quieter propellers in and around wind farms deliver large gains.
4. **Invest in monitoring and modelling.** Testing the cumulative impact of different kinds of disturbances in an agent-based mechanistic framework is essential to minimize negative impacts on marine populations. Future analyses should account for changes in prey availability related to altered currents and climate change.

Authors: Jacob Nabe-Nielsen, Cara Gallagher & Caitlin K. Frankish

Sources: *Nabe-Nielsen et al., Conservation Letters (2018); Frankish et al., Marine Pollution Bulletin (2023); Bicknell et al., Marine Environmental Research (2025); Gallagher et al., DCE Report (2026); Stockholm et al., DCE Report (2025); Dähne et al., MEPS (2017e).*

Centre for Green Transition and Marine Ecology · Aarhus University, Department of Ecoscience

SUSTAINOW

Smarter tools for sustainable offshore wind

SUSTAINOW develops open-access tools that make it easier for planners, policymakers, and developers in Europe to design and manage offshore wind farms sustainably from start to finish.

By improving how marine data is shared and used across countries and sectors, the team is strengthening our understanding of how offshore energy affects the environment, society, and coastal communities.

The result: offshore wind projects that are better designed for people, nature, and energy networks.

OUR SOLUTION

Open access tools

Our European team of experts come together to make decision-making processes behind offshore wind planning more straightforward and sustainable.

How? By improving how data is shared between stakeholders and by integrating environmental, social, and economic assessments through a suite of open access tools.

Cross-border marine data platform

A shared marine data space to improve access and interoperability of environmental, social, and technical data across countries.

Evidence-based siting tool

Helps identify the most sustainable and technically suitable locations foroffshore wind farms.

Project design tool

Supports holistic planning by assessing environmental, social, and economic impacts across the entire life cycle.

TESTING THE WATERS

Real-world demonstration

The project will test and demonstrate these tools with the North Sea as key pilot area.

Transferability of the tools will be explored for the North-East Atlantic, Baltic, Mediterranean, and Black Sea.

SUSTAINOW responds to the ambitions of the **European Green Deal**, **REPowerEU**, and **the EU Strategy on Offshore Renewable Energy**, which together call for a rapid and sustainable scale-up of offshore wind in Europe.

Targets include reaching at least 300 GW of offshore wind capacity by 2050.

By improving how data is shared and used across borders, SUSTAINOW supports evidence-based planning that aligns with these goals and targets.

www.sustainow.eu

info@sustainow.eu

/company/sustainow-eu

Funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

Transformations of the North Sea: A Network Analysis of Marine Artificial Structures and Stepping-Stones

Ane Pastor Rollan*, Flemming Thorbjorn Hansen, Silvana Birchenough, Karen Timmermann

***contact email:** apro@aqua.dtu.dk

Background: In a changing climate and human-modified seascape, understanding how marine populations are connected, persist, and reorganize is essential for effective ecosystem management. The rapid offshore expansion of renewable energy infrastructure, alongside the decommissioning of oil & gas platforms and early-generation wind farms, is expected to substantially reshape marine connectivity over the coming decades. These man-made structures (MMS) can act as artificial habitats and stepping-stones, potentially altering dispersal pathways, gene flow, and metapopulation dynamics for species with pelagic larval stages. This study reveals the ecological implications of offshore MMS on connectivity and metapopulation dynamics in the North Sea.

Aims: Using biophysical models and network analysis we **1)** quantify the relative contributions of different habitat types to larval connectivity before and after the inclusion of MMS **2)** assess how MMS amplify stepping-stone connectivity and modify dispersal pathways and network topology; and **3)** evaluate how these connectivity patterns give rise to coherent metapopulation structure, including persistent communities and source-sink dynamics and explore management implications.

Impact: This study provides insights to support evidence-based marine spatial planning, conservation of native biodiversity, and the management of future infrastructure expansion and decommissioning in the North Sea.

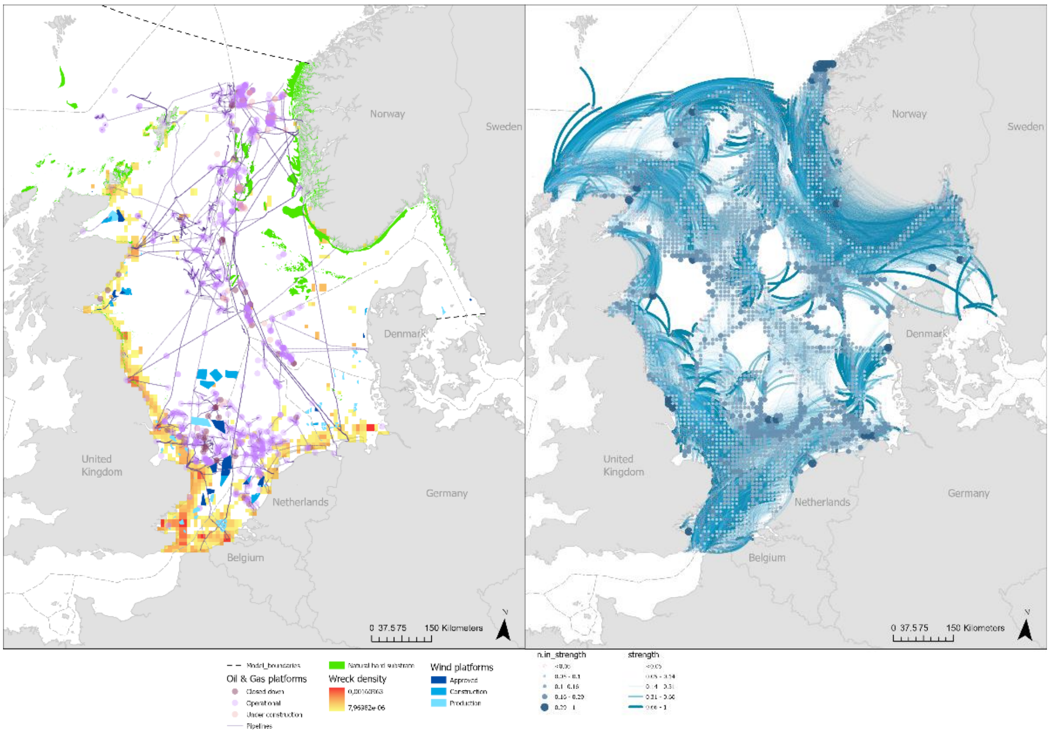


Figure 1. (right) Study area of the North Sea including all artificial structures: Wind platforms (blue), oil and Gas platforms (purple), wreck density (yellow to red), pipelines (purple lines) and natural hard substrates (green). (left) Network of hard substrate habitat patches based on dispersal simulations showing the in-strength centrality of nodes and strength of edges for 50 days of pelagic larval duration (preliminary results).

Technical University of Denmark

CARLSBERG FOUNDATION