Title (and review question)

What evidence exists on the effectiveness of nature-inclusive designs for marine biodiversity in offshore wind farms? A Systematic map protocol

Authors and affiliations

LANGRIDGE, Joseph : Joseph.langridge@fondationbiodiversite.fr. Fondation pour la Recherche sur la Biodiversité, France.

ENNOCHI-MIROUX, Jules : jules.ennochi@fondationbiodiversite.fr. Fondation pour la Recherche sur la Biodiversité, France.

PIOCH, Sylvain : sylvain.pioch@univ-montp3.fr Université Paul Valéry-Montpellier III, France

PINAULT, Mathieu : math.pinault@gmail.com. GIE MAREX, France.

DELAVAUD, Aurélie : aurelie.delevaud@fondationbiodiversite.fr. Fondation pour la Recherche sur la Biodiversité, France.

QUINARD, Aurélie : aurelie.quinard@fondationbiodiversite.fr. Fondation pour la Recherche sur la Biodiversité, France.

GABORIAU, Matthias : matthias.gaboriau@fondationbiodiversite.fr. Fondation pour la Recherche sur la Biodiversité, France.

1. Background

In December 2022, 196 countries adopted the Kunming-Montreal Global Biodiversity Framework, setting global targets to achieve a vision of living in harmony with nature by 2050 (CBD, 2022). In addition to restoration and conservation goals, the framework emphasizes the need to reduce anthropogenic pressures on biodiversity, notably, Target 15 calls upon all economic sectors to reduce negative impacts, enhance positive contributions, and promote sustainable production practices. Likewise, the Intergovernmental Panel on Climate Change (Wiser et al. 2011) has highlighted the crucial role of transitioning towards renewable energy sources, including offshore wind farms (OWF), in limiting global warming. However, while current policies are often guided by climate targets, this singular metric does not capture the full ecological footprint of energy infrastructure. Indeed, offshore wind farms, including their submerged infrastructure, such as turbine foundations and export cables, can impact a large range of marine species groups, e.g. marine mammals, fish, and benthic invertebrates, which are often considered most at risk from OWF development (Galparsoro et al 2022; Watson et al, 2024; Wawrzynkowski et al 2025). Moreover, OWF also disturb pelagic, benthic, and coastal habitats (Lindeboom et al 2011). To mitigate these effects, Nature-inclusive Designs (NiDs) have been proposed. NiDs aim to reduce ecological harm and, where possible, enhance biodiversity outcomes through adaptive construction, and improve ecosystem resilience (Pardo et al 2017). Although empirical evidence on their effectiveness is increasing, systematic literature reviews remain limited. To support evidence-based decision-making, the French Transmission System Operator (FR: *Réseau de Transport d'Electricité en France*: RTE) commissioned the French Foundation for Biodiversity Research (FRB) to assess the current state of knowledge on the effectiveness of NiDs in offshore wind farm contexts. This Map will collate, catalogue, and present outcomes of NiD comparative studies evaluating their effectiveness in mitigating offshore wind farm impacts on marine biodiversity.

1.2 Theory of change model

Implementing Nature-inclusive Designs in OWFs aims to reduce negative impacts on marine biodiversity by modifying the infrastructure. These measures—e.g. eco-designed additional structures or biodiversity-friendly cable protection—are expected to mitigate species disturbance and habitat degradation. Through such nature-optimised measures, NiDs can enhance local biodiversity, and align with international conservation targets (e.g., CBD Targets 8 and 15). Both climate change and biodiversity must be faced together. To this end, there is growing recognition that solutions are necessary to resolve this 'green-green' dilemma by better aligning these technological developments with biodiversity conservation policies.

1.3 Stakeholder engagement

The current study will be conducted with the involvement of the French Transmission System Operator (RTE). Given its role in managing existing infrastructures and future offshore wind farms, RTE is one of the principal stakeholders most directly concerned by the need to implement measures to mitigate the sector's impact on biodiversity. The project originated from a request by this stakeholder, a partner of the French Foundation for Biodiversity Research. RTE will also contribute to shaping the study's scope and questions and is free to provide feedback on various parts of the review as it progresses.

1.4 Objectives and review question

The main objective is to conduct a systematic map addressing the following primary question: "**What evidence exists on the effectiveness of nature-inclusive designs (NIDs) for marine biodiversity in offshore wind farms?**"

Secondary questions include:

- What species are most studied in the context of NIDs and which geographical areas are covered?
- Which indicators/metrics are most used, and which are under-represented or absent from the evidence base?

2. Definitions of the question components

The components of the question, following a "PICO" structure, are as follows:
Population: Marine biodiversity (all species, fauna and flora)
Intervention: Nature-inclusive Design (NIDs): all measures integrated into offshore wind farms and associated infrastructure whose primary function is aimed at minimizing risks and optimising biodiversity.
Comparator: Different types of NIDs, absence of NiDs where appropriate, and/or before the installation of NIDs (spatial or temporal comparators)
Outcome: All indicators/metrics used to measure the effect of a NID, such as abundance, species richness, population density, etc.
Context: Offshore wind farms (OWF)

3. Search strategy

We will search both peer-reviewed literature and grey literature (journal articles, books, theses, non-commercial technical reports) by consulting databases, search engines, and specialized websites. We will conduct searches in two databases: **Web of Science Core Collection (WOSCC)** and **Scopus**, as well as two online search engines: **Google Scholar** and **Bielefeld Academic Search Engine (BASE)**, using a search string composed exclusively of English terms. We will also search grey literature on the websites of relevant organizations such as Tethys and Archimer. We will undertake a **'call for knowledge**' whereby domain experts and stakeholder will be solicited and send to the review team who will judge relevance of received documents based on o eligibility criteria (see 9.1). Lastly, we will perform '**backward citation chasing'**, using the tool, *Citationchaser* in lens.org (Haddaway et al 2022). Based on the elements of the research question, we have identified key terms relating to the population, intervention, and outcome. These will be combined using "OR" within each block and "AND" between the blocks, so that a publication will be retrieved if it studies the effectiveness of NIDs in offshore wind infrastructure on marine ecosystems. Review articles will not be included, as the request focuses primarily on empirical evidence. No contextual limitation will be applied; therefore, studies conducted anywhere in the world are eligible. Likewise, no date restrictions will be applied.

3.1 Bibliographic databases

First, a scoping exercise was conducted in the Web of Science Core Collection database to explore the sensitivity and specificity of the selected keywords. In line with our objectives and the PICO format, we combined all search terms related to marine wildlife (Population), NiD type (Intervention), and results demonstrating effectiveness (Outcomes). All searches were conducted using the topic field tags (i.e., enabling the retrieval of articles that contain keywords in title, or abstracts, or keywords of articles). Example of WOSCC adapted string:

TS=(((((biodiversity OR fish* OR vertebrate$ OR invertebrate$ OR bivalve$ OR mollusc$ OR crustacean$ OR echinoderm$ OR decapod$ OR cephalopod$ reptile$ OR algae OR seaweed$ OR species) AND (marine OR coast* OR estuar* OR ocean OR sea)) AND ("nature based solution$" OR "nature positive solution$" OR "nature positive design$" OR "nature inclusive design$" OR "nature based design" OR "nature derived solution$" OR "nature based feature$" OR "nature inspired solution$" OR "nature inspired design$" OR "nature derived design$" OR "ecosystem based adaptation" OR "ecosystem based mitigation" OR "nature based strateg*" OR "nature based protection" OR "nature based coastal" OR "nature based shoreline$" OR "nature based mitigation" OR "nature based infrastructure$" OR "human made" OR "man made" OR "human intervention" OR "biogenic structure$" OR "biogenic material$" OR boulder$ OR rubble OR "tubular pile$" OR "artificial surface$" OR "artificial substrate$" OR cobble OR rock* OR "artifical reef$" OR concrete$ OR biohut$ OR "fish hotel$" OR "balast bag$" OR "cable protection" OR "stand alone unit$" OR frond$ OR "scour protection" OR "gravel protection" OR "boulder protection" OR "reef ball$" OR "hybrid infrastructure" OR "hybrid technique$" OR "natural infrastructure" OR "eco* engineer*" OR "eco* friendly engineering" OR bioengineer* OR "blue engineering" OR "engineering with nature" OR "blue infrastructure" OR "eco* conception$" OR "marine infrastructur*" OR "green grey infrastructure" OR "green infrastructure" OR "multi use") AND (impact$ OR effect$ OR behavio?r OR disturbance OR mortalit* OR fatalit* OR "population size" OR "population density" OR abundance OR occurrence OR diversity OR richness OR cover* OR communit* OR recruit* OR complexit* OR "surface area" OR dispers* OR bioaccumul* OR predat* OR invasiv* OR distribut* OR composit* OR symbio* OR microb* OR "micro organism$" OR physiol* OR respir* OR metabol* OR diamet* OR stabili?* OR survival) AND (offshore AND wind OR power OR farm OR construction))))

3.2 Web-based search engines

An additional search for publications will be carried out using two online search engines, starting with **BASE**, followed by **Google Scholar**. For Google Scholar, we will use the software "Publish or Perish" (version 6) to retrieve all academic citations. The use of Boolean operators and the number of keywords permitted in Google Scholar differ from that of WOSCC and Scopus. Also, the search string will be broken down into several separate searches to achieve similar sensitivity, given that a maximum of 256 characters is permitted per search string (Haddaway et 2015). Moreover, since our main aim is to acquire academic evidence, we will limit each sub-search to the top 50 results.

3.3 Organisational websites

The following specialized organizational websites will be consulted to find relevant grey literature (i.e technical reports, etc.) containing primary data on the effectiveness of Nature-Inclusive Design on marine biodiversity:

1. The **Tethys** database, which compiles and shares content related to the environmental effects of marine energy (wave, tidal, ocean current, river, ocean thermal, salinity gradient) and wind energy (onshore, fixed offshore, floating offshore): https://tethys.pnnl.gov/
2. The institutional archive of **Ifremer (Archimer)**: https://archimer.ifremer.fr/
3. The **French Agency for Ecological Transition (ADEME)**: https://librairie.ademe.fr/2889-energies-renouvelables-reseaux-et-stockage

4. Comprehensiveness of the search

To ensure the comprehensiveness of the search, an iterative process was implemented to test the preliminary search strings against a predetermined list of benchmark articles (i.e., the test list) (Livoreil et al 2017). The test list consisted of relevant scientific journal articles identified by the review team. The sensitivity and specificity of the search strings were tested in the Web of Science Core Collection.

We tested different keyword combinations and checked whether the benchmark articles were retrieved. If any articles from the reference list were missing, the search string was refined by adding terms to increase sensitivity—without compromising specificity—until all articles were successfully retrieved.

5. Screening strategy

According to the predefined criteria for study selection and eligibility, the selection of studies will follow a three-step screening process carried out by the review team (Frampton et al 2017). First, all titles will be screened, followed by all retained abstracts, and then a full-text screening stage. During the screening, we will apply a conservative approach. Thus, if the qualifying information is not sufficiently detailed to either exclude or retain with certainty, the publication (i.e., the title or abstract) in question will be retained for evaluation at the next eligibility stage (i.e., the abstract or full text). Additionally, publications that do not include an abstract will, by default, move on to the full-text screening stage. Finally, if our search strategy identifies relevant documents published in French, they will also be included in the review process, as these are the two languages spoken and understood by all members of the review team.

5.1 Eligibility criteria

We will review the collated studies obtained from the searches using the following set of criteria:

Title and Abstract Inclusion Criteria:

Note that title and abstracts will be screened separately but will consider the same criteria. Regarding population components, titles and abstracts will be included if they contain terms corresponding to marine biodiversity.

Regarding intervention elements, title and abstract content containing terms compatible with nature-inclusive design in offshore wind energy will be included.

Title and Abstract Exclusion Criteria:

All biodiversity groups other than sub-marine flora and fauna, and any renewable energy technology other than wind energy, will be excluded.

Full-Text Inclusion Criteria:

Note that Full-text screening will be the 3rd screening step. All studies analyzing the effectiveness of nature-inclusive designs using temporal or spatial comparisons will be included. We will retain study designs such as Before-After (B-A), Control-Impact (C-I), and Before-After-Control-Impact (BACI) studies.

Regarding outcomes, only outcomes from empirical studies will be included. All publications that study the impact of nature-inclusive wind turbine designs on the populations of the aforementioned species will be included.

Regarding context element, only studies performed inside OWFs will be included. However, we will also retain studies outside OWFs in cases where studies conducted explicitly address the potential transposition of the NID to an OWF.

Full-Text Exclusion Criteria:

Similar to those applied during the title and abstract screening. In addition, any type of publication other than field studies will be excluded (e.g., discussion papers, conference proceedings, etc.).

5.2 Consistency checking

To fully assess whether screeners (MG, JE-M, JL) are adhering to the eligibility criteria, a Fleiss' Kappa test (adapted for 3 or more screeners) will be conducted at the beginning of each screening stage. Accordingly, 10% of titles, 10% of abstracts, and 10% of full texts retained will be randomly pre-selected to assess agreement. Kappa scores should be equal to or greater than 0.7 (Frampton et al., 2017; Livoreil et al., 2017). If differences of opinion arise, discussions will be held to refine the criteria; the process will be repeated with new samples until a score of 0.7 or higher is reached. Once a statistical agreement is achieved, any remaining disagreements (if any) will be discussed before beginning screening. A consistency check for metadata extraction will also be undertaken using a sample of “training articles” representing 5% of the retained corpus. Any disagreements will be discussed within the review team.

6. Data coding strategy

To map the available evidence on the effectiveness of nature-Inclusive designs for marine biodiversity in offshore wind farms, all publications retained after full-text will undergo metadata extraction for the purpose of narrative synthesis. All the articles included will be organized into an Excel spreadsheet. This work will be shared between three reviewers who will check consistency beforehand concerning all coding decisions.

6.1 Meta-data to be coded

The metadata extraction parameters will focus on the main research question. The information will include bibliographic details (title, authors, year, journal), the study context (country, location, sea/ocean name), details on study design (BA, CI, BACI), and methodological details (study duration). Information about the population, i.e., the study subjects, will be extracted (species name, species group), along with the type of intervention (i.e. type of NIDs) will also be extracted. Likewise, the outcome measured (i.e. indicators such as abundance, richness, etc.). Data will be extracted into a customized Excel spreadsheet.

6.3 Consistency checking

Prior to commencing data extraction, reviewers (MG, JE, and JL) will perform a pilot extraction on a ‘training sample’ of 5 studies. Then discuss all discrepancies between reviewers and clarify variable descriptions to ensure consistent implementation of the data extraction method. This process will be repeated until all three reviewers extract data in the same way, and consensus is reached. This will allow verification and discussion of consistency in data interpretation. Additionally, a post “cross-check” will be carried out by two reviewers (MG, JL) once data extraction is complete to ensure absence of errors, i.e. to check for heterogeneity between coders (see Langridge et al., 2021).. Regarding missing data, if the information is not sufficiently detailed or simply unknown, it will be coded as such, “Unknown”.

7. Type of mapping

A “long map” will be produced as the primary database (spreadsheet) (Haddaway et al 2021). This means extracting all articles and prioritising specific comparative cases per article (hereafter referred to as “case studies”), potentially multiplying the number of lines of data entries in the spreadsheet (hence “long map”). As such, several case studies may be extracted per article and a *case-study id* will be attributed accordingly. All included articles with their coded and extracted information at the case study level will be made available with the map report. We will follow similar methods to Langridge et al 2021.

7.1 Narrative synthesis methods

The evidence included in the map review will be described by the frequency distribution of case studies (i.e. comparative studies) across the relevant variables describing the various issues associated with Nature-inclusive designs. And the narrative synthesis will answer the secondary questions of the review. We will do this by using a combination of visualisations and tables. For instance, heat maps will be used to present the number of comparative studies in the evidence base categorised over 2 to 3 categorical variables. We will also present the evidence base cartographically, illustrating the distribution of articles and comparative studies by country or sea regions. Using such visualisation methods will allow the review team to identify knowledge clusters (i.e. topics where a lot of evidence exists, and which may allow for the exploration of quantitative analysis), but also knowledge gaps (i.e. topics that are un- or under- represented with few studies).

7.2. Knowledge gap identification strategy

We will identify knowledge gaps and clusters using frequency distribution tables and cross-tabulating (heat maps) key variables of interest. For example, we will examine the distribution of case studies by research theme, crossed with document type or geographical location. For instance, we expect that certain issues relating to Nature-inclusive design have been specifically addressed in certain geographical areas.

Competing interests
We declare having no competing interest

Funding information
This work was funded within the partnership between the FRB and RTE.

Author's contributions
MG discussed and assured the terms of the project with the stakeholder partner. Accordingly, MG designed and clarified the scope of the review in discussion with the partner and subject experts. MG, JE, and JL wrote the protocol. SP and MP provided subject guidance and expertise ensuring policy relevance. JL provided method expert guidance and reviewed all stages of the protocol. All authors proof-read and approved the protocol.

Acknowledgements
The authors thank Marjolaine GARNIER for assuring preliminary discussions with the stakeholder.

References
- CBD (2022) *Kunming-Montreal Global Biodiversity Framework*. Secretariat of the Convention on Biological Diversity. Available at: https://www.cbd.int/article/cop15-final-text-kunming-montreal-gbf-221222
- Frampton, G.K., Livoreil, B., Petrokofsky, G., 2017. Eligibility screening in evidence synthesis of environmental management topics. Environmental Evidence 6, 27. https://doi.org/10.1186/s13750-017-0102-2
- Galparsoro, I., Menchaca, I., Garmendia, J.M., Borja, Á., Maldonado, A.D., Iglesias, G., Bald, J., 2022. Reviewing the ecological impacts of offshore wind farms. npj Ocean Sustain 1, 1. https://doi.org/10.1038/s44183-022-00003-5
- Haddaway, N.R., Grainger, M.J., Gray, C.T., 2022. Citationchaser: A tool for transparent and efficient forward and backward citation chasing in systematic searching. Research Synthesis Methods 13, 533–545.https://doi.org/10.1002/jrsm.1563
- Haddaway, N.R., Collins, A.M., Coughlin, D., Kirk, S., 2015. The Role of Google Scholar in Evidence Reviews and Its Applicability to Grey Literature Searching. PLOS ONE 10, e0138237.https://doi.org/10.1371/journal.pone.0138237
- Haddaway, N.R., Gray, C.T., Grainger, M., 2021. Novel tools and methods for designing and wrangling multifunctional, machine-readable evidence synthesis databases. Environmental Evidence 10, 5. https://doi.org/10.1186/s13750-021-00219-x
- Langridge, J., Sordello, R., Reyjol, Y., 2021. Existing evidence on the outcomes of wildlife translocations in protected areas: a systematic map. Environmental Evidence 10, 29. https://doi.org/10.1186/s13750-021-00236-w
- Lindeboom, H.J., Kouwenhoven, H.J., Bergman, M.J.N., Bouma, S., Brasseur, S., Daan, R., Fijn, R.C., de Haan, D., Dirksen, S., van Hal, R., Hille Ris Lambers, R., ter Hofstede, R., Krijgsveld, K.L., Leopold, M., Scheidat, M., 2011. Short-term ecological effects of an offshore wind farm in the Dutch coastal zone; a compilation. Environ. Res. Lett. 6, 035101. https://doi.org/10.1088/1748-9326/6/3/035101
- Livoreil, B., Glanville, J., Haddaway, N.R., Bayliss, H., Bethel, A., de Lachapelle, F.F., Robalino, S., Savilaakso, S., Zhou, W., Petrokofsky, G., Frampton, G., 2017. Systematic searching for environmental evidence using multiple tools and sources. Environmental Evidence 6, 23. https://doi.org/10.1186/s13750-017-0099-6
- Pardo, J.C.F., Aune, M., Harman, C., Walday, M., Skjellum, S.F., 2023. A synthesis review of nature

positive approaches and coexistence in the offshore wind industry. ICES Journal of Marine Science fsad191.https://doi.org/10.1093/icesjms/fsad191
- Watson, S.C.L., Somerfield, P.J., Lemasson, A.J., Knights, A.M., Edwards-Jones, A., Nunes, J., Pascoe, C., McNeill, C.L., Schratzberger, M., Thompson, M.S.A., Couce, E., Szostek, C.L., Baxter, H., Beaumont, N.J., 2024. The global impact of offshore wind farms on ecosystem services. Ocean & Coastal Management 249, 107023. https://doi.org/10.1016/j.ocecoaman.2024.107023
- Wawrzynkowski, P., Molins, C., Lloret, J., 2025. Assessing the potential impacts of floating Offshore Wind Farms on policy-relevant species: A case study in the Gulf of Roses, NW Mediterranean. Marine Policy 172, 106518. https://doi.org/10.1016/j.marpol.2024.106518
- Wiser, R., Z. Yang, M. Hand, O. Hohmeyer, D. Infi eld, P. H. Jensen, V. Nikolaev, M. O'Malley, G. Sinden, A. Zervos, 2011: Wind Energy. In IPCC Special Report on Renewable Energy Sources and Climate Change. Mitigation [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA