REPORT

Macro-avoidance of Seabirds: Key Findings from a Specialist Workshop

Mechanisms, Drivers, and Uncertainties in Seabird Responses to Offshore Wind Farms

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Executive Summary

Offshore wind development in the North Sea is expanding rapidly, increasing the urgency to understand its ecological implications. One key uncertainty concerns the macro-avoidance behaviour of seabirds during the operational phase of offshore wind farms (OWFs): the tendency of some species to reduce their presence within or around wind-farm areas. Macro-avoidance may reduce collision risk but can also lead to displacement, increased energetic costs to move around the perceived barrier, or reduced access to foraging habitat. The underlying causal factors and mechanisms of this behaviour remain poorly understood, limiting the accuracy of ecological impact assessments and habitat-loss modelling.

In the Netherlands, the Offshore Wind Ecological Programme (Wozep) plays a central role in generating the knowledge needed to assess and manage ecological impacts of offshore wind development. Together with the Framework for Assessing Ecological and Cumulative Effects (KEC), Wozep provides the scientific evidence base for evaluating effects on marine ecology and informs environmental assessments and policy decisions for Dutch OWFs. To address the lack of knowledge on macro-avoidance, Rijkswaterstaat (RWS) commissioned Haskoning Nederland B.V. to organise an expert workshop. The workshop brought together specialists from the Netherlands and Belgium and aimed to generate a shared understanding of the causal factors, mechanisms, knowledge gaps, and potential mitigation opportunities related to seabird macro-avoidance. Focus was placed on a predefined set of seabird species that have ecological relevance and sensitivity to offshore wind development, as indicated by national impact-assessment results.

Seven themed sessions structured the workshop, during which experts engaged in a series of guided exercises—including sticker-based allocation, Analytic Hierarchy Process (AHP) pairwise comparisons, facilitated discussions, and future-scenario exploration—to share insights on how various species interact with offshore wind-farm environments and the processes that may lead to macro-avoidance.

The outcomes show that visual disturbance is generally perceived as the most influential causal factor across species, often followed by changes in food availability and changes in habitat structure. For some diving species, sound disturbance also emerged as an important factor. Experts consistently emphasised that these causal factors are interrelated, with multiple disturbances acting simultaneously. The experts also identified various mechanisms that may explain how a causal factor can lead to avoidance behaviour. Frequently mentioned mechanisms included increased vigilance, masking of prey detection, changes in prey concentration, shifts in prey composition. It was noted that a lack of an attracting stimulus can also result in behaviour that is perceived as avoidance, adding complexity to the interpretation of observed patterns. The workshop also produced an extensive overview of ongoing national and international research, highlighting opportunities to link existing datasets, strengthen monitoring programmes, and coordinate between ecological and physical disciplines.

Experts identified several critical knowledge gaps, including the influence of OWF characteristics (e.g., turbine density, rotor movement, minimal tip height), the ecology and distribution of fish prey, species-specific responses to sensory disturbances, and the energetic consequences of macro-avoidance. The experts worked on formulating concrete steps for resolving four priority knowledge gaps, and elaborated on which factors could help or hinder this process in the coming five years.

Finally, the workshop generated a wide range of potential mitigation opportunities, such as adjusting OWF locations, turbine design characteristics, changes in fishing and shipping activities, and modifications to

underwater habitat. Experts noted that some measures may reduce macro-avoidance, while others may risk increasing attraction and thereby elevate collision risk, highlighting the need for careful evaluation.

Overall, the workshop provided a structured and comprehensive overview of current expert understanding of seabird macro-avoidance during the operational phase of OWFs. The insights collected in this report will support the development of Wozep's future research strategy.

1 Introduction

This chapter contains the background, aims and approach for this report.

1.1 Background

Offshore wind development is expanding rapidly, driven by national and international climate and energy ambitions. As the number and scale of offshore wind farms increase, so does the need to better understand their ecological impacts. One area of particular concern is the macro-avoidance* behaviour of seabirds. While such behaviour reduces immediate collision risk, it may also lead to ecological costs, such as displacement, increased energy expenditure, and reduced access to resources. Although several studies indicate that certain species no longer occur in or around operational wind farms, the underlying mechanisms driving these patterns remain poorly understood. This knowledge gap poses challenges for ecological assessment, impact prediction, and the development of effective mitigation measures.

To address these issues, Rijkswaterstaat (RWS) has asked Haskoning to organise an expert workshop focused on improving insights into the causal factors and mechanisms that lead to the avoidance of entire wind farm areas by seabirds, rather than individual turbines. This workshop forms part of the broader Wozep (Windenergie op Zee Ecologisch Programma) initiative, which investigates ecological impacts of offshore wind developments and supports evidence-based policy and monitoring strategies.

1.2 Objectives and scope

The objective of this assignment is to improve understanding of the causal factors of seabird macro-avoidance of offshore wind farms using a multi-session workshop approach. The workshop aims to gather expert knowledge on:

- The relative importance of the different macro-avoidance causal factors (including a ranking)
- The mechanisms through which these causal factors lead to macro-avoidance
- The identification of knowledge gaps relevant to understanding macro-avoidance behaviour
- Possible mitigation options and actionable management perspectives

Special attention is given to:

- Species specific differences in macro-avoidance or sensitivity-specific differences in macro-avoidance or sensitivity
- Current or upcoming national and international research relevant to the topic
- The feasibility of addressing identified knowledge gaps through new studies

The workshop outcomes will contribute to Wozep model development, but their primary purpose is to guide the design of targeted field studies that clarify key ecological processes. Additionally, the findings will contribute to broader research lines assessing habitat loss, wind farm configuration, and potential habituation effects.

Ideally, all potential ecological effects and behavioural responses of seabirds to offshore wind farms would be investigated comprehensively. However, given the complexity of the system and the wide range of possible influencing factors, it is necessary to establish a focused scope for this phase of the research. Within Wozep, **macro-avoidance during the operational phase** has been identified as one of the least understood components of seabird–wind farm interactions, whilst the large and rapidly increasing scale of offshore wind development means that its potential ecological consequences could be substantial. Existing studies support this, suggesting substantial macro-avoidance effects for several species, but the underlying causes, species differences, and long-term implications remain highly uncertain. Because this knowledge gap currently limits the ability to model impacts, assess habitat loss, and develop effective mitigation, this topic requires clearer direction and prioritisation. Implications of macro-avoidance during the operational phase remain highly uncertain.

For this reason, the present workshop and analyses deliberately focus on three key elements:

- Macro-avoidance: the avoidance of entire wind farm areas at a broad spatial scale, rather than fine-scale responses around individual turbines.
- The operational phase of offshore wind farms (OWF's), during which macro-avoidance patterns are most consistently observable.
- A predefined set of seabird species, selected for their ecological relevance and sensitivity to offshore wind development, specifically in the Dutch part of the North Sea. (Lesser Black-backed Gull, Northern Gannet, Razorbill, Common Guillemot, Sandwich Tern, Black-legged Kittiwake, Great Black-backed Gull, Red-throated Diver).

Although the workshop was organized around the selected focus areas, the discussions occasionally expanded beyond them. These broader insights are included in this report when they meaningfully contribute to the overall objectives of this project.

1.3 Approach

In preparation of the expert workshop, we conducted a broad literature review (see: paragraph 6.1.2) addressing macro-avoidance of wind farms by birds to design the contents of the workshop. In close consultation with RWS, we selected experts from the Netherlands and Belgium, known for their extensive experience in and knowledge of seabirds and their behaviour at sea. The workshop was held on Thursday, January 29th 2026, at the Haskoning office in Delft. This document describes the outcomes and discussions of the workshop. An international panel of experts on the topic have been approached to review this document. Comments and ensuing additional information will be included in green italic font.

Table 1 Workshop participants

Organisation	Attendees	Role
Wageningen University & Research (WUR)	3	Subject matter expert
Royal Netherlands Institute for Sea Research (NIOZ)	1	Subject matter expert
Deltamilieu Projecten	1	Subject matter expert
Waardenburg Ecology	2	Subject matter expert
Research Institute for Nature and Forest (INBO)	1	Subject matter expert
Haskoning	3	Workshop facilitation and reporting
Rijkswaterstaat	3	Wozep

2 Methods

The preparation of the workshop included several methodological phases, starting with a literature review, early expert engagement, and a pre-workshop assignment to ensure participants arrived with a shared understanding of the central concepts and issues.

The second phase was the expert workshop itself, which was structured by a division into different sessions to collect targeted input on causal factors, mechanisms, knowledge gaps, and potential mitigation measures. The expert workshop took place on 29 January 2026.

The third phase will entail a thorough review process, with an internal review by Rijkswaterstaat, an expert review (by the workshop participants), and a review by an international expert panel. This final external review will help to refine and validate the findings.

As a result, the Results chapter reflects an integrated synthesis of three sources:
1. input gathered through the preparatory assignment;
2. input collected during the expert workshops;
3. input and feedback from the multi-layered review process.

2.1 Preparatory work

The pre-work (literature review and the pre-workshop assignment) validated our conceptual understanding of the problem and the project's underlying reasoning, helping ensure that the workshops were aligned with the intended focus. Given the project's limited scope, clear and consistent terminology was essential to keep discussions aligned with the project aims and the purpose of the workshop. Experts were also asked to provide feedback on the proposed focus species. Several immediate discussions emerged regarding the most appropriate terminology for certain processes and factors. These semantic considerations, and how they were addressed, are described in Chapter 3.

2.2 Species selection

For the workshop, a predefined set of seabird species was selected based on their ecological relevance and sensitivity to offshore wind development. The selection followed a structured, multi-step assessment that combined a literature review (see 6.1.2), national impact modelling, and key ecological considerations. First, a review of existing studies identified species with documented avoidance behaviour around offshore wind farms. These included Lesser Black-backed Gull, Northern Gannet, Razorbill, Common Guillemot, Sandwich Tern, and Black-legged Kittiwake. Next, results from the Programma Noordzee 2022–2027 were examined, in which population-level collision risks were modelled using the stochastic Collision Risk Model (sCRM). The analyses indicated that several species exceeded the Acceptable Level of Impact (ALI) under one or more national offshore wind scenarios, specifically Black-legged Kittiwake, Northern Gannet, Great Black-backed Gull, and Herring Gull. Consequently, the Great Black-backed Gull was added to the list. Further assessment of displacement and habitat loss highlighted substantial impacts on species such as the Razorbill and Common Guillemot, while also identifying major data gaps for divers.

Given the uncertainty surrounding avoidance behaviour and displacement mortality in divers, the Red-throated Diver was included as a priority species for expert consultation. Although avoidance rates from KEC 5.0 were reviewed, species with high avoidance but limited presence in the North Sea were not added. Finally, findings on migrating non-seabirds were incorporated by acknowledging this broader group without selecting individual species. Through this process, a set of focus species was defined, representing those most relevant to collision risk, displacement effects, and ecological vulnerability in relation to offshore wind development:

- Black-legged Kittiwake (*Rissa tridactyla)*
- Common Guillemot (*Uria aalge)*
- Great Black-backed Gull (*Larus marinus)*
- Lesser Black-backed Gull (*Larus fuscus)*
- Northern Gannet (*Morus bassanus)*
- Razorbill (*Alca torda)*
- Red-throated Diver (*Gavia stellata)*
- Sandwich Tern (*Thalasseus sandvicensis)*

Addition after review:

- *One expert added the recently published report that contains a scoring system and proposed a few additional KEC-species: Using sensitivity scoring to identify marine bird species for KEC assessments (Heße & Melis, 2025).*

During the preparatory phase, experts provided additional reflections on the proposed list of focus species. Several experts indicated that the selection formed a strong and appropriate starting point for examining macro-avoidance, noting that the chosen species are ecologically relevant, relatively abundant in Dutch waters, and have documented sensitivities to offshore wind development. At the same time, experts highlighted a number of species that were not included but may warrant consideration depending on the scope and future context of the project.

Some experts pointed out that several seabird species with lower abundance in the Netherlands, such as Northern Fulmar, Great Skua and Arctic Skua, also exhibit behaviours that could be relevant for macroavoidance studies, although their lower numbers reduce their immediate priority. Other experts mentioned that certain nearcoastal species (e.g., Great Crested Grebe, Common Scoter, Great Cormorant, European Herring Gull or Common Gull) were not included but noted that their more coastal distribution likely explains their omission within the current offshore-focused scope.

Addition after review:

- *One expert noted that lower population size does not necessarily reduce a species' priority. On the contrary, small or declining populations, such as that of the Arctic Skua (Parasitic Jaeger), may be particularly vulnerable to increased mortality. The expert also pointed out that less numerous species may be less suitable for studying the mechanisms underlying macro-avoidance, as obtaining sufficiently large sample sizes is more challenging.*

One species repeatedly mentioned as potentially missing from the selection was Little Gull. Experts noted that the Netherlands is an important migration corridor for this species, with high peak numbers passing through Dutch waters. Although it is uncertain whether macro-avoidance of offshore wind farms would have a substantial impact on this migratory species, experts suggested that, under a precautionary principle, its relevance may increase, especially if offshore wind development expands closer to the coast in the future.

Addition after review:

- *One expert added that for Little Gull, the impact of OWF is particularly uncertain due to the unavailability of basic population parameters.*

Experts also commented on the inclusion of Lesser and Great Black-backed Gulls. While these species often show low levels of avoidance or even attraction to wind-farm areas, their contrasting behaviour compared to strongly avoiding species was seen as valuable for understanding species differences and for comparative analysis.

Finally, some experts raised a broader point about migratory non-seabirds. They noted that expanding offshore wind development will increasingly affect long-distance migrants such as geese, swans and waders, particularly in relation to lighting and large-scale spatial barriers. While including all migrant groups was considered beyond the current scope, experts emphasised the importance of acknowledging these species groups when considering the wider ecological context of offshore wind development.

Addition after review:

- *One expert confirms the importance of this statement, and adds that this may also apply to species such as Shelduck (Green et al., 2019)*
- *One expert agrees that migratory non-seabird need to be acknowledged and adds that research projects employing radars to study seabirds can also be used to detect flocks of migrating birds. Large flocks can even be detected with weather radars. Using this existing infrastructure for the additional purpose of studying migratory behaviour can yield important information at relatively low cost.*

Overall, expert feedback confirmed that the selected set of focus species is suitable for the aims of this project, while also highlighting several species and species groups that may become relevant as offshore wind development expands or as new research questions emerge.

2.3 Workshop design

This paragraph provides an overview of the workshop, describing the structure and objectives of the each of the separate sessions. It explains how the exercise unfolded and reports the direct outputs. The outcome will be discussed in chapter 4 (Results).

Session 1: Species and causal factors

This session was aimed at identifying which causal factors play the greatest role in causing macro-avoidance behaviour for each of the focus species. The causal factors covered were habitat, visual, sound, food availability, light and electromagnetic field and each were displayed at the top of a blank poster. Participants were given a sticker sheet with images of the different bird species (three stickers per species) and were asked to allocate the different species to three of the most important causal factors contributing to that species macro-avoidance. Discussion was allowed but experts were encouraged to make the selections individually. The results were discussed plenary.

How it went

The discussion surrounding the choices made by participants generated valuable insights, which are incorporated into Chapter 4 (Results). The workshop was considered successful, as it became evident that some causal factors are regarded as more important than others, and that species differed notably in how they were allocated by the participants across the causal factors.

The exercise was intended to identify factors that cause birds to avoid offshore wind farms. However, during the final step of the exercise, it became apparent that stickers were also used to indicate how these factors may influence the degree of avoidance. In some cases, this influence was understood to reduce avoidance to the point where it effectively becomes zero, resulting in an apparent attraction to the area rather than avoidance. A frequently cited example concerned fishing vessels. Species such as Gulls are often strongly attracted to fishing activity, and this attraction may offset or override avoidance of wind-farm structures. Consequently, when fishing vessels are present, birds may not avoid wind farms, whereas their absence may lead to lower densities within wind-farm areas even in the absence of strong disturbance effects.

Addition after review:

- *One expert added that similar attraction effects may also occur in association with maintenance vessels, as comparable observations were made at the Hywind Tampen floating offshore wind farm in Norway.*
- *One expert added that lower densities of gull species within offshore wind farms should not automatically be attributed to the absence of fishing vessels. Although reduced fishing activity is frequently mentioned in the report, there is increasing evidence that these patterns may reflect genuine avoidance behaviour rather than fisheries effects alone. Recent and forthcoming work, such as a submitted study by Kentie et al. on Lesser Black-backed Gull in the Borssele wind farm, suggests avoidance that cannot be explained by fisheries-related mechanisms. More broadly, the expert stressed that what is often labelled as macro-avoidance is usually inferred from observed differences in bird densities inside versus outside wind farms, rather than from direct evidence of behavioural motivation. Changes in density may result from a complex interplay of attraction and avoidance processes, including food availability, resting opportunities, and visual or acoustic disturbance. The expert therefore recommended avoiding overly deterministic interpretations and explicitly acknowledging these uncertainties and limitations in a concluding section of the report.*

Outcome

An overview of the most relevant causal factors influencing macro-avoidance behaviour per species was achieved.

Session 2: Species and Mechanisms

This session focused on identifying which underlying mechanisms best explain macro-avoidance behaviour for each focus species. Participants received a new sticker sheet and reviewed the mechanisms displayed on the posters. For each species, three stickers were allocated to the mechanisms they considered most influential. Discussion was encouraged, but experts made their selections individually. A plenary discussion followed to review the outcomes.

How it went

Experts expressed that it was very difficult to determine which underlying mechanisms are most likely to explain macro-avoidance behaviour. The experts emphasized that the proposed underlying mechanisms could not be meaningfully assessed as isolated factors as these factors are often interlinked. They highlighted that multiple disturbances frequently occur simultaneously, interact with one another, and may jointly influence seabird behaviour. As a result, experts found it challenging to attribute macro-avoidance responses to a single causal factor and stressed the importance of considering these causal factors in combination rather than as strictly separate mechanisms.

Despite this, the distribution of stickers revealed clear differences in how strongly each mechanism was supported. Experts also indicated missing possible underlying mechanism and added this to the posters.

Outcome

An overview of the most relevant underlying mechanisms that possibly explain macro-avoidance behaviour per species was achieved.

Session 3: Ongoing Research

This session aimed to compile an overview of ongoing research related to causal factors, mechanisms, and related factors influencing seabird macro-avoidance of offshore wind farms. Participants were asked to place post-its next to the relevant causal factors or mechanisms, with information about e.g. the project name, the research institute or group involved, the method used, and the species addressed. Studies that directly focus on macro-avoidance or on disturbance sources, co-factors, or modifiers were included.

How it went
This session went smoothly; a lot of ongoing research projects were identified.

Outcome
A consolidated overview of ongoing research relevant to seabird macro-avoidance behaviour.

Session 4: Identifying Knowledge Gaps
This session aimed to jointly determine where the most important knowledge gaps lie. A plenary discussion was held in which experts contributed their views and the key knowledge gaps were documented collaboratively.

How it went
The group was able to compile a clear list of knowledge gaps. Some of these extend slightly beyond the intended scope of this project, for example when they touch on broader aspects of species ecology. Nevertheless, all identified gaps are relevant and connect back to the overall aim of understanding seabird macro-avoidance of offshore wind farms.

Outcome
A shared overview of the most critical knowledge gaps identified by the expert group.

Session 5: Prioritization of causal factors
The Analytic Hierarchy Process (AHP) is a structured decision-making method that breaks complex choices into a hierarchy of criteria and alternatives, then uses pairwise comparisons to quantify their relative importance. It calculates priority weights to determine the best option based on both objective data and subjective judgments. An overview of the calculation steps to obtain the relative weights can be found in appendix 6.1 AHP calculations. The objective of this session was to determine the top three most important causal factors for each focus species. Participants were divided into two groups. Each group compared pairs of causal factors for a number of species (for example: “For Common Guillemot, is noise more important than visual disturbance in causing macro-avoidance?”). For each comparison, the group selected one of five predefined statements ranging from “much more important” to “no difference / entirely uncertain.” These paired comparisons were used to derive a ranked order of causal factors (AHP-methodology), which was then discussed in a plenary session.

How it went
The experts initially found the pairwise comparisons challenging to perform, but ultimately the exercise progressed well. Once it became clear that completing the statements would generate a ranking that could be used to compare species, the task became more manageable. The resulting rankings aligned well with the experts’ intuitive understanding of how different species experience and respond to avoidance-related causal factors. During the plenary feedback session, several interesting differences in perspective between the two groups emerged. This will be discussed further in the chapter 4 (Results).

Outcome
A ranked top three of the most relevant causal factors for each focus species.

Session 6: Pathways to addressing Knowledge Gaps
This session explored what would be required to resolve the knowledge gaps identified earlier. In groups of two, experts selected the gap they considered most urgent. They were asked to imagine a scenario in which this gap had been successfully resolved in the period 2026–2031, and to describe what this future situation

would look like and what had been necessary to achieve it. On their worksheets, they listed the selected knowledge gap, three enabling factors, three hindering factors, and three major steps needed to reach the envisioned solution. At the end, each group was asked to share some thoughts on how they experienced the exercise.

How it went
Each of the four groups addressed a different knowledge gap they considered important. The experts generated many valuable ideas, and filling the worksheets proved easy. If anything, the greatest challenge lay in narrowing to only three key action steps.

Outcome
Concrete pathways and potential challenges for addressing the most important knowledge gaps.

Session 7: Mitigation Opportunities
The final session aimed to gather ideas for mitigation measures informed by the insights from the previous sessions. Each participant wrote one idea at the top of a sheet of paper. Participants walked around the room and, at a signal, exchanged sheets with someone nearby. The participants were then asked to add comments or suggestions below the idea they had just received. This process was repeated in several rounds. Finally, each expert read what was on the paper that they were holding in the end.

How it went
A range of ideas for potential mitigation measures was collected. During the plenary discussion, it became clear that the experts were largely aligned in their views on which measures might hold promise. At the same time, several experts expressed a degree of hesitation about proposing mitigation measures at this stage, noting that the current state of knowledge may not yet be sufficient to determine whether such measures are appropriate or advisable. Despite this, they engaged fully with the exercise and contributed thoughtful and constructive suggestions.

Addition after review:

- *One expert adds that Prey availability and spatial distribution were repeatedly identified during the workshop discussions as key factors influencing bird distribution, and several experts highlighted that offshore wind farms may affect these patterns indirectly by altering prey distribution. Addressing uncertainties around prey dynamics was therefore considered an important prerequisite for assessing whether and how mitigation measures might reduce avoidance or displacement.*

Outcome
A diverse set of mitigation ideas, complemented by expert feedback and reflections.

2.4 Reviewing process

The information and preliminary results have been compiled in this document and reviewed by Rijkswaterstaat.

Subsequently, the experts who participated in the session were invited to evaluate the findings. At the same time, an independent panel of international experts provided external review. Each review round contributed to refining, validating, and contextualizing the outcomes, ensuring both robustness and transparency.

To encourage open and honest contributions, all expert inputs have been anonymised throughout the process. This approach was intended to create a safe environment in which experts could share their views freely, including diverging perspectives. Where there was clear agreement among experts, the information has been integrated directly into the main text of this report. However, in cases where opinions differed, or when individual experts added points that are not universally supported, these contributions have been preserved as separate bullet points in green beneath the main text. This ensures that no information is lost and that the full range of expert perspectives is represented.

Experts have been encouraged, during each review step, to substantiate their statements with scientific literature and to provide relevant sources where possible. As a result, the method used in this project allowed not only converging viewpoints to be captured, but also areas of disagreement. These differences in expert opinion will be valuable: they may highlight topics where scientific evidence is still limited, inconsistent, or insufficiently explored, and thus help identify where knowledge gaps persist.

3 Terminology

To support clarity and consistency throughout this project, a structured terminology was proposed to describe pathways leading to macro-avoidance. During the workshop, it became clear that similar concepts were sometimes used interchangeably or interpreted differently by experts. Introducing a common set of terms helps to disentangle causes, processes, and outcomes, and facilitates clearer discussion of mechanisms, uncertainties, and knowledge gaps.

The proposed terminology distinguishes between the source of disturbance, the driver through which this disturbance acts, and the ecological outcome, while explicitly recognizing the role of cofactors and modifiers that can influence the strength or expression of responses. This structure allows complex interactions to be described in a transparent and reproducible way, without implying that causal relationships are fully established.

Macro-avoidance

Following the review, it became clear that the term macro-avoidance has been used in slightly different ways throughout this project. During the workshop and subsequent discussions, experts expressed differing interpretations of what they considered macro-avoidance to entail, reflecting broader ambiguities in how the concept is applied in both the scientific literature and practice. These interpretations, as well as proposed ways to address the resulting inconsistencies, are summarised below.

In the KEC framework, proposed in May (2015), macro-avoidance is defined as large-scale displacement, whereby birds avoid wind-farm areas altogether, resulting in reduced habitat use at the scale of the wind farm or the surrounding landscape. This definition focuses on habitat selection and disturbance responses and is explicitly distinguished from meso- and micro-avoidance, which operate at finer spatial scales.
During the workshop, however, the terms positive and negative avoidance were at times used inconsistently. In particular, negative avoidance was occasionally used to describe attraction to offshore wind farms, while in other contexts it referred to a reduction in the strength of avoidance. This indicates that two conceptually different processes were sometimes conflated under the same terminology.

To reduce ambiguity and better reflect underlying mechanisms, it was suggested to replace the terms positive and negative avoidance with direct and indirect avoidance, respectively. This distinction more clearly separates behavioural responses directly related to disturbance from changes in density or distribution that arise indirectly through other processes, such as altered food availability or habitat conditions.

In compiling this report, we have sought to apply terminology as consistently as possible. Where used in a strict sense, macro-avoidance is intended to refer to the avoidance behaviour itself, namely, the act of large-scale avoidance of a wind-farm area. At the same time, we deliberately chose not to extensively reinterpret or standardise the language used by experts during the workshop sessions. Preserving the original phrasing was considered important to accurately reflect expert reasoning and existing uncertainties. Consequently, some terms may appear in the report with more than one possible interpretation, reflecting both ongoing conceptual ambiguity and the exploratory nature of the discussions.

Pathway
If we consider the situation where sound disturbance leads to macro-avoidance, the pathway may look like this:

An operational wind turbine (*source of disturbance*) generates sound (*driver*). Wind conditions can influence the intensity of this sound and thereby modify its effect (*cofactor*). Birds may respond to the sound by exhibiting macro-scale avoidance of the wind farm (*outcome*). The magnitude of this response may vary among age classes (*modifier*). The perception of sound causes the bird to avoid the windfarm, due to the sound masking acoustic communication between birds (*underlying mechanism*).

In this project, the aim is to collect targeted information on why seabirds avoid offshore wind farms and the mechanisms that drive this behaviour. To achieve this, we want to focus as much as possible on drivers and underlying mechanisms. Circumstances that might strengthen or weaken a response, here named cofactors and modifiers, are not the main gain to gather information about.

While the framework provided helpful structure, it was not perfect. Several experts noted limitations and offered suggestions for refinement.

Drivers
During the workshop, we used the term drivers as a working label for a set of factors that may play a part in causing macro-avoidance behaviour, such as Electro-magnetic fields (EMF), sound, visual, habitat, and food availability. As the discussions progressed, it became clear that some of these terms do not represent drivers in the classical ecological sense but rather describe modalities. Modalities are the different ways in which birds may perceive or experience a disturbance.

Part of the confusion that arose during the session stemmed from terms such as ‘visual’. Participants noted that this label can be interpreted as referring to the sensory system through which a bird perceives its environment, rather than the disturbance factor itself. This highlighted that some workshop terms unintentionally blended the mode of perception with the nature of the disturbance.
To resolve this ambiguity, we have refined several terms in the results presented in the next chapter (see Table 2 Updated terminology.). These adjustments clarify that the discussion centred around causes of macro-avoidance behaviour, and not sensory perception of the focus species. Due to this revision, the terminology used in the workshop differs slightly from the terminology used in this report. However, the underlying meaning and conceptual structure have not changed.

Table 2 Updated terminology.

Terminology used in preparatory work and during workshops	Updated terminology for following chapters
The driver behind avoidance behaviour could be…	*The causal factor of avoidance behaviour could be…*
Visual	Disturbance resulting from visually perceiving physical objects (Visual disturbance)
Light	Disturbance caused by artificial or reflected light (Light disturbance)
Sound	Disturbance caused by anthropogenic sound (Sound disturbance)
Electromagnetic fields	Disturbance caused by electromagnetic fields (EMF disturbance)

Food availability	Changes in food availability (Changes in food availability)
Habitat	Changes in habitat structure or quality (Changes in habitat structure)

Structure of framework

Several experts commented on the internal structure of the framework. One suggestion was to insert an additional step between the source of disturbance and the modality, describing the primary modality mechanism that converts a disturbance characteristic (e.g. contrast, light spectrum, sound frequency) into a sensory cue perceived by the bird.

Another expert proposed replacing the term driver altogether with dose–response factors, arguing that this would better capture how the intensity of a disturbance translates into behavioural outcomes and would provide clearer links to potential mitigation measures.

These remarks add useful nuance to how avoidance pathways can be interpreted and highlight the complexity of such processes. As the framework's purpose was primarily to structure discussion rather than to function as a definitive model, we have not aimed to refine its design further here. Instead, the focus in the following chapters shifts to the insights gathered during the workshop, which form the core outcomes of this project.

Summary of feedback on the terminology and framework by reviewing experts

Terminology

- *The terminology used is not always aligned with established frameworks and current literature. For example, the term "driver" has a specific meaning in the DPSIR framework that differs from its usage here. The revised terminology presented in Table 2 is considered more appropriate.*
- *The use of the term "disturbance" is unclear. It is not evident whether it refers to the source of a stimulus (e.g. sound or light) or to a more general effect, leading to potential misinterpretation.*
- *The terminology used in the report to describe the workshop outcomes does not clearly reflect the terminology that was adjusted and applied during the workshop itself. As a result, the final agreed framework remains insufficiently clear (see paragraph 3.1).*
- *It is unclear whether the category "Light" also includes indirect effects such as moving blade shadows on the water surface.*
- *In several instances, "disturbance" appears to refer to the resulting bird behaviour rather than the causal stimulus, which adds to the terminological confusion.*

Completeness

- *The absence of wake effects (e.g. changes in wind or uplift conditions) is not explained, despite their potential relevance.*
- *Potential effects of the presence of maintenance and service vessels are not explicitly addressed.*
- *In addition, loss or reduced availability of soft-substrate prey species, such as sandeel, may further contribute to observed changes in bird densities within offshore wind farms.*

Sound

- *Low-frequency underwater sound propagates over long distances with relatively little attenuation. Depending on the sound level and spectral characteristics of the source, such as offshore wind farms and associated shipping activity, as well as the auditory sensitivity of the species involved, underwater sound may therefore represent a relevant environmental factor.*
- *Physiological sensitivity to underwater sound has been investigated in only a small number of seabird species, all of which are relatively shallow divers, including Cormorants, Guillemots, Gentoo Penguins, and three species of Duck. Ducks appear to be relatively insensitive to underwater sound, whereas cormorants show similar sensitivity in water and air, although within the typical avian frequency range and without particular sensitivity to low frequencies.*
- *Beyond physiological studies, behavioural responses to underwater sound have been demonstrated in some species. Guillemots have been shown to respond to underwater sound exposure (Hansen et al., 2020), and gentoo penguins have been observed to actively swim away from sound sources during experimental trials (Sørensen et al., 2020).*
- *Overall, however, empirical knowledge remains limited, and considerable uncertainty persists regarding the potential effects of offshore wind farm–generated sound on the behaviour of diving seabirds. Further species-specific research is therefore required before firm conclusions can be drawn (Hansen et al., 2020; Sørensen et al., 2020).*

3.1 Author's note on terminology

We acknowledge the feedback provided by reviewers regarding the use of terminology in this report. The results presented in this chapter are based on expert opinions expressed during the workshop and subsequently the review rounds. Throughout this process, we have aimed to remain faithful to the original wording, reasoning and nuance of the experts' contributions.

As a result, terminology used throughout this report may not always be fully consistent or alignment with other existing frameworks or literature. In particular, terms such as "driver" were recognised during the review process as potentially suboptimal. However, these terms formed an integral part of the discussions during the workshop and contributed to generating valuable insights and exchanges between experts. Retrospectively standardising or replacing such terminology throughout the report would risk altering the original context and interpretation of these discussions.

It is also important to note that this report was developed through multiple stages, including preparatory input (pre-workshop), workshop discussions, and iterative review rounds leading to this final version. Given this layered process, it is not feasible to fully revise terminology in the final stage without modifying the substance of earlier expert contributions.

For this reason, we have chosen to prioritise the accurate representation of experts' perspectives over complete terminological uniformity. Where relevant, reflections on terminology and its limitations are provided, and uncertainties are acknowledged.

4 Results

This chapter contains mainly the insights gathered during the workshop sessions. Insights gathered from the preparatory work have been incorporated.

Experts commented that it is important to keep in mind that many of the views expressed during the workshop were not directly supported by established scientific evidence, as the exercise explicitly aimed to explore existing knowledge gaps. Without this clarification, some outcomes may read as definitive conclusions, whereas they should instead be interpreted as tentative hypotheses about how processes may operate and which still require further investigation.

4.1 Causal factors

This paragraph contains insights gathered during the preparation of the sessions and the feedback received through the preparatory work of the experts.

Causal factors used in this project
Based on the preparatory work, six potential causal factors were identified as relevant pathways through which offshore wind farms may lead to macro-avoidance behaviour in seabirds. These are:

1. Disturbance resulting from visually perceiving physical objects (visual disturbance)
2. Disturbance caused by artificial or reflected light (light disturbance)
3. Disturbance caused by anthropogenic sound (sound disturbance)
4. Disturbance caused by electromagnetic fields (EMF disturbance)
5. Changes in food availability
6. Changes in habitat structure or quality (changes in habitat structure)

These categories emerged from the pre-workshop literature review and were used to guide expert discussions during the workshop sessions.

Addition after review:

- *One expert adds that an additional causal factor which doesn't seem to have been considered is changes in air flow/movements due to the wind farm/turbines themselves and the associated change in the energetics of flight in potentially more turbulent air. This is being considered by the BIRDWAKE-project[1].*
- *One expert notes that the method described in (Wade et al., 2016). Could have been beneficial here, as it allows for a distinction to be made between the topics which have been researched rather than those which might potentially be important but are difficult to study.*
- *One expert noted that although six factors are listed as potential drivers of macro-avoidance behavior, they are presented inconsistently. Some factors are framed as uni-directional (e.g. disturbance), while others are implicitly bi-directional (e.g. changes in food availability). In practice, many of these factors can operate in both directions. For example, offshore wind farms may have both negative and positive effects on food availability, potentially decreasing or increasing seabird presence. Similar considerations apply to habitat changes, visual effects, and light, which can be repellent for some species but attractive for others. Moreover, individual factors may simultaneously induce both attraction and avoidance within the same species, with the observed changes in seabird density reflecting the net outcome of these opposing effects. Treating these factors as strictly uni-directional therefore risks oversimplifying the underlying mechanisms shaping seabird distribution.*

[1] https://www.nina.no/english/Sustainable-society/Renewable-energy/BIRDWAKE

Concerns related to categorization
Experts noted several considerations when using this set of causal factors:

- Overlap between habitat and food availability:
  Multiple experts pointed out that food availability is often a direct consequence of habitat structure, making the two difficult to separate conceptually. At the same time, maintaining them as distinct categories was considered useful because habitat characteristics may influence birds either directly or indirectly (via prey), and because it remains uncertain whether birds detect food cues or habitat cues more strongly.

- Visual, light and sound effects may interact:
  Experts highlighted that birds often respond to combinations of sensory cues, making it seem artificial to treat visual disturbance, light disturbance and sound disturbance as entirely separate pathways. In particular, “visual” and “light” were seen as closely related, and sound can amplify or modify the effect of visual cues. Nonetheless, separating them helps identify what type of sensory information might initiate a macro-avoidance response.

- Uncertainty around EMF effects:
  EMF was recognised as a possible causal factor, especially for species such as Red-throated Diver, but experts emphasised that evidence is extremely limited and effects may operate indirectly via prey species.

Purpose of using these causal factors
Despite the limitations and overlaps noted by experts, this set of causal factors provided a practical structure for discussion. It allowed participants to consider what kinds of disturbances or environmental changes might trigger macro-avoidance in different species, without requiring the framework itself to be fully optimised or definitive. The goal was not to resolve all conceptual boundaries, but to create a shared language for identifying which causal factors may be most important for which species, thereby supporting the interpretation of workshop results and guiding future research priorities.

4.2 Causal factors and species

This paragraph contains insights gathered during session 1: Species and causal factors. See chapter 2.3 for an overview of the session. It describes the structure and objectives of the session and explains how the exercise unfolded in practice.

The aim here was to make the identified causal factors specific to each species. Experts individually assigned three stickers to the causal factors they considered most important for each species, after which the group discussed the patterns and reasoning behind these choices. Figure 1 reflects how the different species were assigned to the different causal factors according to the experts.

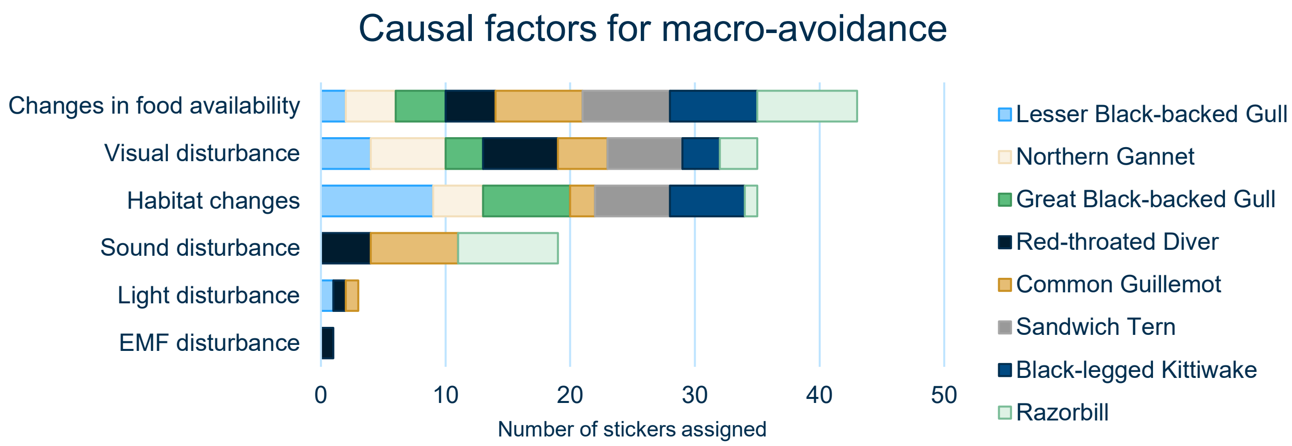

Figure 1 Results of session 1: species and causal factors.

Addition after review:

- *One expert adds that “changes in food availability” are strongly overemphasized in this figure. The expert emphasizes that we should only consider negative effects of food availability here (since the focus is on avoidance not on attraction) and not positive effects. In fact, most studies on changes in fish communities indicate that there are no strong effects, except immediately around the pilings (Bergström et al., 2013; Stenberg et al., 2015; Van Hal et al., 2017). The latter can even have positive effects, for example, that Herring Gulls forage on benthic communities growing on the pilings during low tide. The expert strongly doubts that the main causal reason that less seabirds occur within offshore windfarms compared to outside is a decrease in food availability.*
- *One expert added that, although some species have previously been reported to be attracted to offshore wind farms, such as Lesser Black-backed Gull, recent work shows that attraction is not consistent across all periods or individuals. At the population level, based on breeding birds, avoidance was observed, even though some individuals did show attraction. The expert emphasized that attraction and avoidance can therefore coexist within a single species, which complicates interpretation but also adds important nuance to the discussion. Such individual-level analyses, however, are currently lacking for other species, limiting the extent to which these patterns can be generalized.*

Methodological caveats

The following methodological caveats should be considered when interpreting these results:

- Some experts interpreted the task (partly) as attraction rather than exclusively macro-avoidance, which may have influenced sticker placement.
- Terms like changes in habitat structure and changes in food availability have ecological overlap and may have not been interpreted identically by all participants.
- Stickers were placed individually; results reflect informed expert judgement rather than a formal consensus.
- The aim of this session was to collect information by discussing the choices made, the stickers alone shouldn’t be used as a stand-alone result.

Changes in food availability

Changes in food availability emerged as a relevant causal factor for all focus species. Clearly, changes in prey abundance are widely perceived as influencing macro-avoidance behaviour. With regards to the diving species, experts explained that offshore wind farms may increase competition for prey: turbines introduce hard substrate that can attract predatory fish communities, which also consume the small fish and invertebrates targeted by diving seabirds. As a result, altered prey dynamics within wind farm areas may reduce food availability for these species.

Participants debated whether both attraction and avoidance should be considered when evaluating food-related mechanisms, as increased prey availability could attract birds, while reduced availability could result in macro-avoidance.

Addition after review:

- *One expert adds that 'Changes in food availability' is markedly different from the other factors, since it requires that the birds remember having visited the site and here observed a change in food availability. They cannot decide on fish abundance until they have been on site and remember the state. In contrast, the other factors can be sensed at a distance from the source and the birds react accordingly, for instance by changing flight direction.*

Visual disturbance

Visual disturbance proved to be a relevant causal factor for every focus species. All species were assigned multiple stickers in this category, suggesting that visual changes are commonly recognised as influencing macro-avoidance behaviour.

Discussion arose among the experts about whether the absence of visible fishing activity inside wind farms could be causing seabirds to remain outside these areas. However, this line of reasoning treats visual cues as a factor that attracts birds rather than one that drives avoidance. As such, it falls under the discussion of “positive avoidance” (see Chapter 2.3, Session 1).

Changes in habitat structure

Changes in habitat structure was considered relevant for several species, although the placement of stickers revealed some ambiguity in how participants interpreted this category. Some species, such as the Red-throated Diver , received no stickers under changes in habitat structure because offshore wind farms fall largely outside their coastal distribution range. In addition, participants noted that offshore wind farms primarily provide habitat for flying species rather than for species that spend extensive time resting on the water surface, which influenced some of the allocation choices.

Addition after review:

- *One expert expressed that they did not fully understand this last statement. They mentioned that offshore windfarms have been built and will be built in areas with high densities of Guillemots and Razorbills. Furthermore, seabird counts show that species, which are considered as flying birds (Gulls, Fulmars etc.), spend most of their time swimming instead of flying. The expert emphasizes that it is an assumption that decreased densities of some species are related to the absence of fisheries, at least for Gulls this seems not to be the case.*

Conversely, other species were placed under this category based on expert interpretation of habitat-related processes. For example, some experts included the activity of fisheries as part of habitat structure, drawing on previous studies showing that certain species avoid wind farms due to the absence of fishing vessels. The Sandwich Tern was placed here due to its preference for foraging in strong tidal currents, which may be altered by wind farm structures. Although the Northern Gannet was mostly associated with visual disturbance, experts also linked its presence to fishing activity, as Gannets are often attracted to vessels and their associated foraging opportunities.

Addition after review:

- *One expert adds that changes in turbidity and stratification are important to mention as alterations of habitat structure. The first probably affects visually hunting diving species, the latter affecting prey availability (or accessibility or both).*
- *Another expert finds it difficult to separate changes in habitat structure from changes in food availability. It is not clear what is exactly meant by changes in habitat structure. The expert assumes it refers primarily to changes on the seabed. Yet there are also important changes above the water surface, for example new resting areas and sheltered spots with reduced wind. The pilings themselves are new habitat structures that support the growth of food and provide shelter for fish. Additionally, there are seabed modifications caused by scour protection, sand displacement, and similar interventions. The expert is not aware of any literature indicating that seabirds respond directly to such underwater habitat structures. Correlations are often found between habitat features and seabird presence, but these are likely not causal and instead reflect indirect effects, for instance via food availability. The expert does not believe that the new habitat features (such as scour protection) have strongly negative effects on seabird presence, even indirectly through food. If anything, the effect may be positive. In other words, the negative impact of habitat modifications, which some experts consider important, is in their view marginal.*
- *One expert notes that it does not seem logical that Loons are included, as OWFs are placed outside their range.*

Sound disturbance

Sound disturbance received fewer stickers overall, indicating that participants considered it a relatively minor factor in causing macro-avoidance behaviour for most species. Experts distinguished clearly between airborne sound (above water) and underwater sound, which differ strongly in both propagation and potential ecological relevance.

Airborne sound disturbance (above water)

Several experts questioned whether operational turbine sound represents a sufficiently clear stimulus for seabirds, given that offshore environments already have high ambient noise levels. Many species may therefore experience limited disturbance from airborne noise at the surface.

Addition after review:

- *One expert agrees with this statement and notes that seabird behaviour is likely only minimally influenced by airborne sound from offshore wind farms unless birds are in close proximity to the source. But also adds that if high level low frequency sound or infra-sound is produced by these sources, it may disturb species that are sensitive to low frequencies. Seabird species investigated so far, however, do not deviate from the majority of birds with no particular low frequency sensitivity to airborne sound.*

Underwater sound disturbance

Underwater sound, however, was seen as potentially relevant for diving species. Participants highlighted that the primary concern is the low-frequency vibrations generated by rotating turbine blades, which can travel underwater. These vibrations may also indirectly affect prey species, thereby influencing seabirds through changes in food availability.

Experts further discussed the cumulative offshore soundscape, which includes (maintenance) vessel traffic and other maintenance noise. As wind farms expand, vessel routes may become more concentrated, increasing overall underwater noise levels. Foghorns were also mentioned as an additional but poorly understood sound source. As with other causal factor, uncertainties remain about the relative importance of sound disturbance.

Addition after review:

- *One expert agrees with this statement, adding that underwater sound produced by turbines is less loud than sounds of ship traffic and active fishing vessels. Under some circumstances even Guillemot and Razorbill actively feed behind fishing vessels (Camphuysen, 1993) and many other seabirds do so as well. Sound levels around those vessels are way higher than around offshore turbines, and still seabirds are attracted and manage to catch fish.*
- *One expert adds that USBL (ultra-short baseline) communication systems may also be relevant sources of underwater noise if used in OWF.*

Light disturbance

Light disturbance received relatively few stickers, reflecting the limited knowledge available regarding the effects of artificial or reflected light on seabirds. Experts noted that light-related mechanisms are unlikely to operate in isolation and are probably intertwined with other causal factors rather than functioning independently. It remains unclear whether artificial light may in some cases have an attractive effect, especially on migrating birds. Observations of Gulls rafting near wind farms raised questions about whether light could play a role, although no empirical evidence currently supports this. Experts mentioned research conducted on Common Guillemots in Blijdorp Zoo, where the birds appeared to respond to a flickering light on an underwater camera. However, the disturbance effect was uncertain, and the relevance of such small-scale, captive observations to large offshore environments is highly limited.

Addition after review:

- *One expert adds that many studies (excluding tracking studies) are based on data gathered during the daytime and therefore fail to reflect reaction to artificial light.*

EMF disturbance

Electromagnetic fields received relatively few stickers. Substantial uncertainty surrounds the ecological relevance of EMF disturbance for seabirds. Measuring EMF effects in the marine environment is challenging, and little is known about whether and how seabirds might detect or respond to such fields. Experts suggested that any potential effect would most likely be indirect, occurring through changes in prey species or other ecological interactions. Possible impacts on diving birds were mentioned, but overall, participants emphasised the high degree of uncertainty associated with this mechanism. Some participants noted that if any species were likely to respond to EMF disturbance, it would be the Red-throated Diver because it is a diving species and is perceived as a very vigilant and sensitive species.

Addition after review:

- *One expert adds that theoretically, EMF from OWF might interfere with navigation in night migrating birds such as European robins passing above the OWFs but so far, such potential interference has not been investigated. However, this is not a seabird and therefore not part of the scope of this report.*
- *One expert added that the strength of typical EMF is less than 5 micro-Tesla (max in export cables, less in inter-monopile cables). Furthermore, there is a strong decrease at 20 m from cable, therefore the effect is probably small.*

General remarks

Participants emphasised that macro-avoidance is often misinterpreted. In their experience, it reflects reduced densities rather than total absence. They noted that the system is highly dynamic: any species may be present in wind-farm areas, and bird numbers can rise sharply when food resources increase.

4.2.1 Ranking

This paragraph contains insights gathered during session 5: Prioritization of causal factors. See chapter 2.3 for an overview of the session. It describes the structure and objectives of the session and explains how the exercise unfolded in practice. An overview of the calculation steps to obtain the relative weights can be found in appendix 6.1 AHP calculations.

Table 3 Top three avoidance-related causal factors identified for each focus species based on expert pairwise comparisons using the Analytic Hierarchy Process (AHP). Rankings reflect the relative importance. ([>] more important than, [=] no difference), relative weights are indicated with the %.

Species	Ranking
Lesser Black-backed Gull	Visual disturbance (61%) > Changes in food availability (30%) > Changes in habitat structure (9%)
Northern Gannet	Visual disturbance (68%) > Changes in food availability (21%) > Changes in habitat structure (10%)
Razorbill	Visual disturbance (60%) > Changes in food availability (20%) = Sound disturbance (20%)
Common Guillemot	Visual disturbance (60%) > Changes in food availability (20%) = Sound disturbance (20%)
Sandwich Tern	Visual disturbance (66%) > Changes in food availability (16%) = Changes in habitat structure (19%)
Black-legged Kittiwake	Visual disturbance (63%) > Changes in food availability (26%) > Changes in habitat structure (11%)
Great Black-backed Gull	Changes in food availability (61%) > Changes in habitat structure (30%) > Visual disturbance (9%)
Red-throated Diver	Visual disturbance (48%) = Sound disturbance (41%) > Changes in food availability (11%)

The prioritization exercise revealed clear patterns in how experts believe different seabird species respond to avoidance-related causal factors. For most species, including Gulls, Gannets, Kittiwakes, Guillemots, Razorbills, and Terns, visual disturbance emerged as the dominant causal factor, often followed by changes in food availability and habitat structure. In several cases (Razorbill, Common Guillemot, Red-throated Diver), sound disturbance was judged equally important as one of the other key causal factors, highlighting species-specific sensitivities to acoustic cues. Notably, the Great Black-backed Gull stood out as the only species for which changes in food availability outweighed visual disturbance, reflecting its opportunistic foraging behaviour. Overall, the rankings revealed subtle differences between species in how they prioritize visual disturbance, sound disturbance and changes in habitat structure and food availability on macro-avoidance behaviour.

Across species, the experts frequently emphasized how difficult it was to distinguish the degree of difference between causal factors, especially when changes in food availability and habitat structure are closely intertwined. For several species, such as the Black-legged Kittiwake and Lesser Black-backed Gull, the two groups initially reached different conclusions, illustrating how perceptions of food–habitat relationships can shift depending on ecological interpretation, particularly the influence of fisheries and multi-species foraging associations. The two groups discussed if those are linked to food availability or habitat structure, which therefore influenced their ranking. In the end the two groups agreed on the ranking shown in Table 3. Species-specific ecology also shaped the rankings: the Sandwich Tern was considered strongly coastal, making changes in habitat structure a more influential factor than changes in food availability offshore, while the Great Black-backed Gull was the only species for which changes in food availability dominated. For diving species such as Razorbill and Common Guillemot, uncertainties around the role of underwater sound led to discussions about its potential local significance relative to visual disturbance.

For the Northern Gannet, experts highlighted particularly complex trade-offs. Although visual disturbance ranked highest, there was substantial debate over whether changes in food availability or habitat structure should take second place. Participants noted that Gannets can forage effectively across a wide range of habitats, making the separation between food and habitat inherently difficult. Their responses may also be seasonally dependent: during the breeding season, Gannets exhibit high site fidelity, whereas outside breeding they tend to disperse more broadly and may closely track fisheries operations. Some experts questioned whether recent changes in Gannet distribution could be linked to factors such as avian influenza or changing prey dynamics, which complicates the interpretation of macro-avoidance behaviour. The discussion ultimately reflected a shared uncertainty about how Gannets balance visual disturbance with the pursuit of food in and around wind farm areas.

The Red-throated Diver was unanimously viewed as highly sensitive to visual cues, consistent with its reputation as an easily disturbed species. Overall, the dialogue revealed both shared understanding and nuanced differences in expert reasoning, enriching the interpretation of the final AHP-derived rankings.

4.2.2 Underlying mechanism

This paragraph contains insights gathered during session 2: Species and Mechanisms. See chapter 2.3 for an overview of the session. It describes the structure and objectives of the session and explains how the exercise unfolded in practice.

Table 4 Underlying mechanisms, indicating which underlying mechanisms best explain macro-avoidance behaviour for each focus species. Underlying mechanisms with a [*] were additions from the experts. The numbers indicate the number of stickers (votes) the experts placed, indicating that avoidance behaviour of the species may be influenced by the factor.

Mechanism	Lesser Black-backed Gull	Northern Gannet	Great Black-backed Gull	Red-throated Diver	Common Guillemot	Sandwich Tern	Black-legged Kittiwake	Razorbill
Changes in habitat structure								
Habitat structure changes -> prey communities shift -> indirect effect on predator	-	-	-	-	3	-	-	-
Perceived habitat quality	-	-	-	-	2	-	-	2
Changed underwater visibility	-	-	-	-	1	-	-	3
*Changes in anthropogenic activities e.g. servicing	6	1	3	1	1	-	1	1
Visual disturbance								
Habitat recognition	-	1	-	-	-	-	1	-
Predation risk perception/vigilance	-	3	-	4	3	1	2	4
Barrier	-	-	-	4	1	4	-	-
Habituation	-	1	-	-	3	1	-	-
*Absence of visible attractors (e.g., fishing vessels or other seabirds)	1	1	1	-	-	1	1	-
Sound disturbance								
Disturbance	-	-	-	1	-	-	-	-
Distraction	-	-	-	-	1	-	-	-
Hearing damage	-	-	-	-	-	-	-	1
Increased vigilance	-	-	-	-	-	-	-	-
Masking communication	-	-	-	-	-	-	-	-

Mechanism	Lesser Black-backed Gull	Northern Gannet	Great Black-backed Gull	Red-throated Diver	Common Guillemot	Sandwich Tern	Black-legged Kittiwake	Razorbill
Deterrence	-	-	-	-	-	-	-	-
*Masking prey detection	-	-	-	2	5	-	-	6
Changes in food availability								
Direct change in prey concentration	4	7	5	-	5	6	7	5
Change in olfactory	-	-	-	-	-	-	-	-
*Prey compostion, prey sizes	-	-	-	-	-	4	5	-
Light disturbance								
Disorientation	-	-	-	-	-	-	-	-
Navigation cue conflict	-	-	-	-	-	-	-	-
*Visible perching sites. Safety	1	-	1	-	-	-	-	-
*Disturbance/attraction	3	-	-	1	1	-	-	-
Electromagnetic fields disturbance								
Interference magneto-navigation	-	-	-	-	-	-	-	-
*Interference prey detection	-	-	-	1	-	-	-	-

In the review process, experts provided the following feedback on table 4:

- *Lesser Black-backed Gull should be included under habitat recognition and predation risk perception/vigilance. There seems to be no clear ecological or behavioural reason why this species would not be concerned by the presence of turbines.*
- *The table makes it clear that an important factor was omitted: the effect of maintenance vessels and servicing activities. These activities can occur frequently and may have significant behavioural effects that deserve explicit consideration.*
- *The category "direct change in prey concentration" likely encompasses both avoidance and attraction processes. This duality should be clarified, as these mechanisms have very different implications for bird distribution.*
- *I do not understand why "changes in anthropogenic activities, e.g. servicing" were grouped under changes in habitat structure. This further blurs the definition of what is meant by habitat structure and makes interpretation difficult.*
- *While I strongly agree that increased shipping activity, helicopter operations and similar activities around wind farms can substantially affect seabird occurrence, the causal mechanism is not a change in habitat, but rather visual and acoustic disturbance caused by vessels and aircraft.*
- *Similarly, the presence of humans during maintenance activities primarily constitutes visual disturbance. Treating this as habitat modification rather than disturbance is conceptually misleading.*
- *Since the analysis appears to focus on negative effects (macro-avoidance), it is unclear why substantially more stickers were assigned to gull species than to other species. This pattern requires explicit explanation and guidance in the text.*
- *It is unclear why underwater visibility would change within wind turbine parks. Even if such changes occur, it is not evident whether diving birds are affected, nor whether the relevant species rely strongly on vision during underwater foraging.*

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- *The mechanism "habitat recognition" is difficult to understand in an open-ocean context. It would only seem plausible if birds actively respond to concentrations of other plunge-diving birds or to fishing vessels, which should be clarified.*
- *Habituation is treated as a mechanism leading to avoidance, but it could equally indicate reduced sensitivity or even attraction. This ambiguity should be acknowledged rather than assuming a negative outcome.*
- *Sound distraction is listed only for the Common Guillemot. It is unclear why the Razorbill, which is ecologically and functionally very similar, would not be equally affected. The same issue applies to hearing damage, which is listed only for Razorbill. If this mechanism is plausible, it would presumably affect other deep-diving species as well, including the Common Guillemot.*
- *For the mechanism "masking prey detection," it is unclear what evidence supports the assumption that diving birds locate prey using sound. I am not aware of studies demonstrating auditory prey detection in these species, and this assumption should therefore be justified or reconsidered.*

Experts consistently emphasized that selecting individual mechanisms was inherently difficult. Many of the proposed mechanisms are ecologically or behaviourally interlinked, and multiple types of disturbance often occur simultaneously at sea. As a result, experts stressed that macro-avoidance cannot easily be attributed to single factors in isolation. Instead, mechanisms are likely to act in combination, creating cumulative or interacting effects. This point is crucial for interpreting the results: the sticker counts reflect relative relevance rather than independent causal explanations.

Several experts also noted that the meaning of "avoidance" can be both positive and negative. It became clear during discussion that this distinction was not always interpreted consistently during sticker allocation and should be considered when evaluating the numbers.

Throughout the session, experts added several mechanisms that were missing from the original list (see the mechanism with a [*] in the table above. These additions highlight areas where current understanding remains incomplete.

- Electromagnetic fields – interference with prey detection:
  Added because seabirds may rely on sensory cues that could theoretically be disrupted by electromagnetic fields, although experts stressed that evidence remains limited and uncertain.
- Light disturbance – visible perching sites; disturbance/attraction
  Participants discussed differences between disturbance and attraction effects around lighting and emphasized that light may shape movement patterns through both mechanisms.
- Visual mechanisms – lack of attractors
  Some species may be influenced by the presence or absence of visual cues such as other seabirds or fishing vessels.
- Food availability – prey composition and prey size
  Added to distinguish between direct changes in prey composition and shifts in prey suitability.
- Masking prey detection
- Changes in anthropogenic activities e.g. servicing

Participants indicated these as missing.

Changes in habitat structure
Experts highlighted that structural changes in the habitat (such as turbine foundations, scour protection, and exclusion of fisheries) may alter prey communities, thereby influencing foraging conditions. Some species

(e.g., Common Guillemot, Razorbill) received stickers on changed underwater visibility or perceived habitat quality, reflecting the possibility that birds either do not recognise altered areas as suitable habitat or encounter shifts in prey availability due to altered conditions.

Visual disturbance
Visual mechanisms attracted substantial attention from the experts, especially vigilance, which received high support for multiple species. Experts described this as heightened alertness caused by moving blades and shadow flicker. The role of habitat recognition, habituation, and the lack of visual attractors also arose, particularly where seabirds are known to respond strongly to the presence of other birds or fishing activity. Several experts questioned whether “barrier” effects represent a true mechanism or an emergent outcome of other causal factors such as disturbance or unfamiliarity. After the session, a few experts noted that Lesser and Great Black-backed Gulls were missing from predation risk perception/vigilance.

Sound disturbance
Sound-related discussions focused primarily on masking of prey detection, especially for diving species such as Guillemot and Razorbill. Experts noted that although direct evidence remains limited, underwater noise could interfere with prey detection or foraging efficiency. Some stickers had been placed on “hearing damage,” but experts later clarified that this would be relevant mainly during construction phases rather than the operational phase. The role of peak versus continuous noise, cumulative sound exposure, and interactions with ship traffic was also debated.

Changes in food availability
Mechanisms related to prey availability received some of the highest sticker totals across species. Direct changes in prey concentrations are perceived as a likely causal factor for several species, particularly Gulls, Gannets, and Auks. Experts also discussed that windfarms may create both positive and negative effects depending on local conditions. For example, temporary increases in prey abundance through tidal mixing, or reduced suitability due to changes in prey composition.

Addition after review:

- *One expert adds that changes in stratification and mixing in the wake of OWF cause changes in primary production, ultimately affecting the food supply for birds (Daewel et al., 2022).*

Light disturbance
Although few stickers were allocated, experts discussed research from industrial areas indicating that artificial light can both attract and disturb seabirds. The added mechanism of visible perching sites was noted for species that may use structures for resting, though experts generally did not expect strong macro-avoidance driven by lighting alone.

Electromagnetic Fields disturbance
Experts expressed uncertainty about potential effects. While EMF could theoretically interfere with prey detection in diving species, evidence is lacking. Sound was considered more important and better supported by current knowledge.

Despite the inherent difficulty of isolating mechanisms, the session produced an overview of which underlying mechanisms are currently considered most relevant for each species (Table 4). The sticker distribution reveals differences between species and highlights domains where mechanisms are perceived as particularly important, most notably changes in food availability, visual vigilance, and specific sensory processes such as sound masking. Importantly, experts emphasized that these mechanisms should not be interpreted as independent causal factors; rather, they represent interacting processes that jointly shape seabird macro-avoidance in and around windfarms.

Addition after review:

- *One expert noted that the strength of typical electromagnetic fields associated with offshore wind farms is generally well below 5 microtesla, with the highest levels occurring near export cables and lower levels around inter-monopile cables. As field strength decreases rapidly with distance and is strongly reduced within approximately 20 metres from the cable, any ecological effects are considered likely to be small or negligible.*

4.3 Ongoing research

This paragraph contains insights gathered during session 3: Ongoing Research. See chapter 2.3 for an overview of the session. It describes the structure and objectives of the session and explains how the exercise unfolded in practice.

Here, the aim was to compile an overview of ongoing research related to causal factors, mechanisms, and related factors influencing seabird macro-avoidance of offshore wind farms. Table 5 shows an overview of the compiled ongoing research during the session.

Table 5 Overview of compiled ongoing research related to causal factors, mechanisms, and related factors influencing seabird macro-avoidance of offshore wind farms.

Subject/project	Species	Research institute	Method	Study period
Calculation impact populations 'disturbance' (vs. ecosystem change model train)	-	Wageningen Marine Research, Waardenburg Ecology	Applied models for habitat loss – KEC (Kader Ecologie en Cumulatie) seabirds	
No regrets - Hotspot seabirds	Focus on Lesser Black-backed Gull	University of Amsterdam, NIOZ	Using GPS tracking of Gulls and at sea observations during research cruises. This is part of NO-REGRETS where a 'whole-ecosystem approach' is used to better understand ecological and economical trade-offs of upscaling OWFs.	
Effects of Wind turbines on water species - visibility and food availability				
Ecowende: Presence in wind farms	-	Waardenburg Ecology	-	
MonElia – monitoring seabirds on the Elia energy-island (EVINBO) (project till 31/12/28)	-	INBO (Research Institute for Nature and Forest)	The INBO monitoring will assess the environmental impact of the construction, operation, and decommissioning of the energy island. Part of this program measures the impact on seabirds. We have two components in this program: investigating any disturbance effects and investigating the presence and behaviour of (sea)birds on and around the island.	

Subject/project	Species	Research institute	Method	Study period
			By means of counts from ships, observations with fixed cameras, and possibly also GPS and radar techniques, we will study whether the Princess Elisabeth platform has a disruptive or attractive effect on seabirds. [2]	
Applied modelling – Sea birds and pelagic fish.	-	Waardenburg Ecology	Individual based modelling -> dynamic species distribution model. Input parameters from field studies. Ecosystem changes.	
Influence of park density on displacement	Razorbill, Common Guillemot, Northern Gannet, Lesser Black-backed Gull and Black-legged Kittiwake	WinMon (The Belgian monitoring program on the environmental impacts of offshore wind farm), INBO (Research Institute for Nature and Forest)	INLA (Integrated nested Laplace approximations) method	
Visual cues: effect of orientation, rotation speed on avoidance.	All species	University of Amsterdam, Waardenburg Ecology	Digital Aerial surveys, radar/camera data and GPS data.	
Ecowende. Species interactions	Black-legged Kittiwake, Razorbill	University of Amsterdam, Waardenburg Ecology	Digital aerial surveys before and after construction of the wind farm, and GPS tracking of wintering Greater Black-backed Gulls. Furthermore, observational and camera/radar studies are performed.	
Macro-avoidance & attraction to fisheries	-	Maasvlakte 2- Waardenburg Ecology & NIOZ	-	
Habituation C-Powerpark & Belwind park Belgian North sea	Razorbill, Common Guillemot, Northern Gannet, etc.	INBO (Research Institute for Nature and Forest)	BACI (Before-After Control-Impact) / INLA (Integrated nested Laplace approximations) method	There is not yet a study period available, but the plan is to conduct these analyses in the near future.
Ecowende habituation in OWEZ/PAWP	Common Guillemot, Razorbill	University of Amsterdam, Waardenburg Ecology	Ship based surveys	
Research into underwater vocalisations	Done on Guillemots in captivity	Waardenburg Ecology	Program and thus methods are in an early stage of development	

[2] *Instituut Natuur- en Bosonderzoek (2024). MONELIA-Monitoring seabirds on the Elia energy island (EVINBO). https://pureportal.inbo.be/en/projects/monelia-monitoring-seabirds-on-the-elia-energy-island-evinbo/*

Subject/project	Species	Research institute	Method	Study period
Research into link between soundscape and seabird distribution	-	Waardenburg Ecology	-	
No regrets - Soundscapes	-	University of Groningen (RUG)	To map underwater soundscapes. Does not relate to (sea)bird avoidance	
NWA Power. Impact of underwater noise on Common Guillemots	-	University Leiden, TU Delft, Wageningen Marine Research	Experimental work in Blijdorp. Offshore. Observational research. Aerial surveys	
Research into the influence of fishing distribution on wind turbine avoidance by birds	-	Waardenburg Ecology, NIOZ	-	
MONS (Monitoring en Onderzoek Natuurversterking en Soortenbescherming) Pelagic fish. Species distribution modelling	-	Rijkswaterstaat, Wageningen Marine Research	ICES data. New targeted surveys + seabird distribution simulation.	
MONS Zeevogels: 1) Diet, food availability 2) Movement ecology 3) Breeding success of coastal breeding seabirds	-	Rijkswaterstaat, Wageningen Marine Research, Waardenburg Ecology, SOVON	Including transmitting individuals	
Tree-reefs for seafloor habitat variation				

Upon request, reviewers provided the following references related ongoing research mentioned in table 5:

- *Beyond Local Footprints: Disentangling Large-Scale Redistribution and Local Abundance Responses to Offshore Wind Farms (Mercker et al., 2026).*
- *Seabirds and offshore wind farms in European waters avoidance and attraction (Dierschke et al., 2016);*
- *Assessing vulnerability of marine bird populations to offshore wind (Furness et al., 2013);*
- *Large-scale effects of offshore wind farms on seabirds of high conservation concern (Garthe et al., 2023);*
- *A synthetic analysis of post-construction displacement and attraction of marine birds at offshore wind energy installations (Lamb et al., 2024);*
- *Population level effects of displacement of marine birds due to offshore wind energy developments, KEC5 (Soudijn et al., 2024);*
- *Seabird avoidance and attraction at an offshore wind farm in the Belgian part of the North Sea (Vanermen et al., 2015);*
- *Displacement of seabirds by an offshore wind farm in the North Sea (Welcker & Nehls, 2016)*
- *Mapping relative risk to seabirds from offshore wind energy developments in Danish waters (isojunno et al., 2025).*
- *Satellite telemetry and digital aerial surveys show strong displacement of Red-throated Divers (Gavia stellata) from offshore wind farms (Heinänen et al., 2020).*
- *Operational offshore wind farms and associated ship traffic cause profound changes in distribution patterns of Loons (Gavia spp.) (Mendel et al., 2019).*
- *Effects of offshore windfarms on seabird abundance : Strong effects in spring and in the breeding season (Peschko, Mendel, et al., 2020)*

- *Telemetry reveals strong effects of offshore wind farms on behaviour and habitat use of Common Guillemots (Uria aalge) during the breeding season (Peschko, Mercker, et al., 2020).*
- *Northern Gannets (Morus bassanus) are strongly affected by operating offshore wind farms during the breeding season (Peschko et al., 2021).*
- *Cumulative effects of offshore wind farms on Common Guillemots (Uria aalge) in the southern North Sea - climate versus biodiversity? (Peschko et al., 2024).*
- *Offshore wind farms in German waters: Cumulative effects on different seabird species range from attraction to strong avoidance (Peschko et al., 2025).*
- *Dodging the blades: new insights into three-dimensional space use of offshore wind farms by Lesser Black-backed Gulls Larus fuscus (Thaxter et al., 2018).*

- *One expert added:*
  - *For the new concession zone for wind energy in the Belgian part of the North Sea that still needs to be developed, a monitoring program will be conducted using ship-based surveys. One of the goals will be to study macro-displacement. The start data is not yet known, but the hope is to do some T0 surveys in the upcoming years.*

4.4 Knowledge gaps

This paragraph contains insights gathered during session 4&6: Identifying and addressing Knowledge Gaps. See chapter 2.3 for an overview of the session. It describes the structure and objectives of the session and explains how the exercise unfolded in practice. In this session, the aim was first to jointly identify the most important knowledge gaps, and then to explore what would be required to address them.

4.4.1 Identifying knowledge gaps

A clear list of knowledge gaps was compiled during the workshop. Some of these extend slightly beyond the intended scope of this project. Nevertheless, all identified gaps are relevant and directly relate to the overarching goal of understanding seabird macro-avoidance of offshore wind farms. The identified gaps were categorized as follows;

Species and behaviour

- Influence of age, learning behaviour, individual variation and experience on seabird behaviour and macro-avoidance.

Addition after review:

- *One expert stated that apart from age, many other factors strongly influence how willing an animal is to take risks or behave boldly. Migrating birds may behave differently from wintering birds, and birds commuting to and from a colony may respond differently compared to non-commuting individuals. Hunger state is likely to be particularly important; during periods of food scarcity, birds may be more willing to enter a wind farm despite potential risks. Wind conditions may also play a crucial role. Most studies tend to report some form of average avoidance rate, but this may obscure important context-dependent variation. For example, Terns are generally considered to avoid wind farms, yet during migration they have been observed actively foraging within wind farms, likely under favorable wind conditions (van Bemmelen et al., 2024).*

- Influence of (underwater) noise on diving birds (pursuit divers like Auks).
- Energetic expenditure and temporal implications of macro-avoidance.

Addition after review:

- *One expert stated that the implications of macroavoidance are not only temporal, they highlighted the implications for fitness.*

- Limited understanding of why some species occur at lower densities than others in and around offshore wind farms.
- Research on underlying mechanisms is lacking; while some information exists for many species, the mechanisms themselves remain poorly understood.
- Little is known about the wintering Red-throated Diver. The Netherlands is not the most important wintering area for the species.
- For certain species, research has not progressed beyond initial surveys, and further study is lacking.
- Although certain species are relatively well-studied, the available data are inconsistent and do not provide a clear picture
- Causal factors and mechanisms behind these patterns are not yet well understood.
- Current knowledge of the ecological and environmental drivers of species' spatial patterns and habitat choice remains limited.
- Avoidance and collision rates of Northern Gannets.

Addition after review:

- *One expert added that mesoscale patterns are not very well understood and remain very poorly studied. Lesser Black-Backed Gulls are attracted to the outer turbines but do not dare to enter the windppark itself (Vanermen et al., 2020). Some species seem to use small corridors through wind farms, but almost nothing is known about this.*

Characteristics of offshore wind farms/turbines

- Effects of density of offshore wind farms (OWFs), distance between turbines and turbine size.
- Effects of cumulation: a combination of number of wind farms, fishing, farm densities and turbine size.

Changes in food availability

- Forage-fish movements: Insufficient understanding of their spatial and temporal patterns makes it difficult to interpret seabird habitat choices.

Addition after review:

- *One expert added that the effects of OWFs on these patterns are poorly understood.*
- *One expert stated that they missed the urgency of identifying (changes in) prey availability and distribution in relation to OWF. This came out as key issue in most of the topics.*
- *One expert stated that forage-fish movements are important, but basic knowledge on composition and species abundance is lacking.*

Other topics

- The effects of poor visibility (e.g. darkness or fog) on seabird behaviour and vigilance levels are insufficiently understood.
- The consequences of anthropogenic influences on seabird behaviour and distribution
- The effects of disturbance from vessels, including fishing and maintenance ships, on seabird behaviour and avoidance patterns.
- There is insufficient understanding of whether macro-avoidance can be effectively mitigated, how such mitigation would influence collision risk, and whether resulting changes would benefit seabird populations.
- The effects of electromagnetic fields around cables in windfarms on diving seabirds.

Addition after review:

- *One expert stated that an important knowledge gap is potential demographic impacts of macro-avoidance on seabird populations. Therefore, the expert advised to include the origin of the affected individuals in future research, i.e. where do they come from; which varies seasonally. Seabirds which are present in the Dutch/Belgian North Sea in a given season may very well breed/overwinter somewhere completely different along the NE Atlantic coasts (e.g. Scotland, Norway). So the expert concluded, it is not just 'Dutch/Belgian' birds that are affected.*

4.4.2 Pathways to addressing knowledge gaps

The experts selected knowledge gaps they considered most urgent. The experts were asked to imagine a scenario in which this gap had been successfully resolved in the period 2026–2031, and to describe what this future situation would look like and what had been necessary to achieve it.

The knowledge gaps that are considered most urgent are:

- Effect characteristics of OWFs/turbines
- Understanding species' spatial distribution patterns and habitat choice
- Effects of ecology and distribution of forage fish on the habitat choice of seabirds
- Energetic expenditure and temporal implications of macro-avoidance

Effect characteristics of offshore wind farms/turbines
Imagined scenario: by 2031, the visual disturbance effects of OWFs will be fully quantified. In addition, the trade-off between habitat loss and collision risk will be understood, enabling the design of optimal OWFs.

To close the current knowledge gap, it is necessary to study how different OWF designs influence the trade-off between habitat loss and bird collisions. This requires testing a range of design variables, including turbine density, turbine height, orientation and rotor movement (e.g., avoidance behaviour versus status turbines), field of vision, colour vision, and the extent to which relevant bird species rely on vision while foraging.

Several enabling factors will support this work: access to OWFs with diverse characteristics combined with detailed bird data, improved understanding of the physiological and mechanistic vision of relevant species, and modelling tools that can evaluate the trade-off between collision risk and habitat loss. At the same time, some challenges remain, such as the fact that truly "invisible" OWFs do not exist and bird species cannot simply be considered "blind". This makes it difficult to compare a control group and a research (experimental) group.

For this knowledge gap, the experts did not identify three major steps needed to achieve the envisioned solution.

Addition after review:

- *One expert added that a possible addition will be the sharing of both technical and ecological (e.g. EIA data) freely across OWF developers. This is likely crucial to close this gap, but hard to realize due to competition.*

Understanding species' spatial distribution patterns and habitat choice
Imagined scenario: by 2031, we will know where the most important foraging grounds for seabirds are located and how to position and design OWFs so that macro-avoidance behaviour by birds is minimized.

To close this knowledge gap, several factors must be considered. These include changes in food availability, the characteristics of existing OWFs—such as turbine density, the age of OWFs, turbine height, and the distance between individual wind farms—and the distance between bird colonies and their foraging and roosting sites. In addition, major shipping routes and environmental factors such as water depth, frontal systems, and turbidity also need to be considered.

Several enabling conditions support progress in this area: large amounts of seabird count data are available, many OWFs of varying types can be studied, and a substantial team with sufficient time and a long-term perspective can be mobilized. However, there are also hindering factors. Prey availability is difficult to study, highly variable, and takes a long period to study. Collaboration with many partners introduces issues related to data quality, data sharing, and consistency. Furthermore, numerous confounding factors—and the sheer number of variables involved—make it difficult to isolate individual effects.

Reaching the envisioned solution requires three major steps:

1. First, coordinated before-and-after surveys must be carried out across a wide range of locations, following a control–impact design. This involves conducting systematic bird counts both prior to and after the construction of offshore wind farms, and bringing together all available datasets, including international sources, into a single integrated database. To support this, it is also essential to document relevant OWF characteristics and to carry out additional high frequency surveys.

2. The second step is to quantify changes in food availability before and after OWF construction. This requires assessing changes in fish abundance and distribution using methods such as echo sounders and, where feasible, eDNA sampling, although the latter remains technically challenging.

During the review, experts were asked to share their opinion on eDNA sampling.
Addition after review:

- *One expert explained why eDNA sampling remains technically challenging. At sea, eDNA gets quickly diluted and degraded and can be transported far from its source. This makes it hard/impossible to quantify how many fish are present, where the fish actually are, and whether they are resident of just passing by. Species detection also does not provide information about the age/size class or biomass of the fish, which is very important to determine whether they are possible prey for seabirds. Also sampling design is a big challenge as weather, currents, sampling depth etc all need to be considered. Spatial and temporal coverage are likely very limited.*
- *Another expert agreed and added that collecting and analyzing water or soil samples for eDNA is quite straight-forward. What would be a limitation is while a rough indication of relative abundances (i.e. proportional amount of DNA found per species in the sample) can be obtained, but direct abundances can't be obtained. While for birds, mammals and fish good reference materials exist, for benthic communities this may prove to be harder. Also, if eDNA sampling is to be done to gather information of seabirds, also aerial eDNA can be sampled, but this is only at a piloting stage (Sullivan et al., 2025).*
- *One expert added that ideally you would have some sort of continuous auto-samplers. That equipment is in development, but maybe not available yet. It would make the collection of samples a lot quicker and therefore cheaper.*
- *One expert noted that eDNA sampling is technically feasible in most locations; however, the ecological interpretation of the results is not yet sufficiently resolved to fully understand their relevance.*

3. The third major step is to determine whether fish relocate because of OWF presence. To gain insight into how offshore wind farms influence fish dynamics, targeted studies are needed to track the

movements of fish. Tagging programs can help reveal whether fish move into, out of, or around OWF areas, and how such movements may subsequently affect the foraging behaviour and spatial use of seabirds.

Addition after review:

- *One expert added that the following research might be relevant: Mapping relative risk to seabirds from offshore wind energy developments in Danish waters (Isojunno et al., 2025).*
- *One expert commented that the current emphasis on survey data may limit the robustness of the conclusions and suggested that individual-based tracking would provide more detailed and reliable insights. While tracking of Guillemots is mentioned in Paragraph 7, the expert noted that existing data are not yet available at an appropriate spatial and temporal scale. Although a substantial amount of light-based geolocator data exists, its positional uncertainty (approximately ±200 km) restricts its usefulness, and high-resolution GPS tracking during the non-breeding period remains largely lacking.*

Effects of ecology and distribution of forage fish on the habitat choice of seabirds
Imagined scenario: by 2031, the influence of forage fish availability on impact of macro-avoidance behaviour will be fully understood.

To achieve this, the survey design must be based on repeated measurements that capture the relationship between changes in food availability and relevant abiotic changes, including water clarity, currents and tides, weather conditions, and underwater acoustic measurements. Resolving this knowledge gap requires collecting parallel data on seabirds and pelagic fish, both inside and outside OWFs. It is also essential to compare the windward and leeward sides of turbines to understand wake effects. Measurements should include echo-sounder data and targeted fish catches for calibration, allowing researchers to determine species composition, body size, and energy content.

Progress in this area is facilitated by the availability of a sufficiently large budget, as well as the ability to work without restrictions inside OWFs, including taking measurements near turbines and operating equipment such as cameras. Favourable working conditions, without major weather related interruptions, further support the research. However, several factors can hinder progress. Insufficient funding limits the scope and duration of fieldwork, while operational restrictions within OWFs can impede access to key locations.

The envisioned solution can be reached through three major steps:

1. First, extensive empirical fieldwork is required to collect high-quality data on forage fish availability, seabird behaviour, and environmental conditions both inside and outside offshore wind farms. These field measurements form the foundation for understanding how forage fish dynamics influence macro-avoidance behaviour.

2. The second step involves in-depth analysis and modelling, including species distribution modelling (SDM). These modelling efforts provide broader ecological insight and make it possible to estimate how forage fish availability and seabird responses may shift under future scenarios, including the potential effects of climate change.

3. The final step is to translate the combined empirical and modelling results into concrete mitigation advice for future offshore wind development.

Addition after review:

- *One expert questioned whether the most important seabird feeding grounds are not already well known, noting that these areas are clearly identifiable from long-term distribution maps. The expert further observed that, in many cases, offshore wind farm site selection appears not to have sufficiently accounted for this existing ecological knowledge.*

Energetic expenditure and temporal implications of macro-avoidance
Imagined scenario: by 2031, it should be feasible to determine how avoidance-induced declines in body condition affect seabird population numbers.

Achieving this will require a survey design that, in combination with the existing hydrological sea model based on sea currents, can estimate daily, across a range of environmental conditions, how much extra time birds spend swimming away from offshore wind farms and the extent to which this reduces their available foraging time.

It also necessitates an assessment of the foraging effort required to sustain a stable body condition, considering foraging efficiency and both the quality and quantity of available prey.

To achieve this, a survey design is needed that, using a current-based model, estimates for each day and under varying current conditions how much additional time birds spend swimming away from offshore wind farms, and how this reduces the time available for foraging. This also requires determining the foraging effort needed to maintain stable body condition, taking into account foraging efficiency, prey quality, and prey quantity.

When addressing this knowledge gap, various factors must be considered. Competition outside wind farms has not yet been included in the research design, and to gain insight into the condition of seabirds, molting scores from both inside and outside wind farms are needed. Consideration must still be given to whether it is useful to continuously study a small area.

Progress is enabled by the increasing availability of detailed individual movement data, for example from tracked seabirds such as Common Guillemots, using devices like trackers, cameras, and unmanned aerial devices (UAVs). These data can be combined with information on the energetic expenditure of individual birds and with assessments of changes in food availability, shed light on how birds acquire the energy they need.

Addition after review:

- *One expert explained in their perspective where and how the usage of the mentioned cameras is most helpful. They thought cameras may be useful on buoys and/or turbine platforms for studying foraging behavior within the OWF. UAVs may quickly disturb seabirds in their activities. However, besides cameras, trackers that include GPS, accelerometers, and depth recorders could be useful tools. Just as well as bird radar and echosounders (recording dives).*
- *Another expert added that (in the context of macro-avoidance) cameras on planes make more sense than on turbines, as macro-avoidance acts at spatial scales too large to capture from camera's mounted on the turbines itself. Cameras on turbines might be useful to study meso-avoidance instead.*
- *Another expert added that if these cameras are deployed on the birds, they can gather information on foraging, foraging efficiency and diet.*
- *One expert noted that UAVs will not collect data on the individual level.*
- *One expert emphasized that movements away from offshore wind farms should not only consider swimming but also flying. Given the large spatial extent of offshore wind farms projected in the future, birds may need to undertake long flights to avoid these areas, which entails substantially*

higher energetic costs than swimming. The expert noted that a spatial projection for Guillemots in German waters indicates that suitable replacement areas are scarce (Mercker et al., 2026) *and therefore recommended that additional energy expenditure associated with increased flying should be explicitly considered when assessing potential impacts.*

Several hindering factors remain. The research itself is technically challenging and depends heavily on technological developments. Competition among conspecifics is poorly understood, and it is unclear how to model these interactions reliably. In addition, the variability introduced by other (environmental and ecological) processes is not yet sufficiently accounted for.

Reaching the envisioned solution requires three major steps:

1. First, the necessary technology must be developed to continuously track individual birds.

2. Second, models must be created that can predict bird movements in the absence of wind farms, providing a basis for comparison with actual movements observed in the presence of wind farms.

3. Finally, an energy model will need to be created to calculate the effects on physical condition and survival. This will then enable the consequences of macro-avoidance to be estimated.

4.5 Mitigation opportunities

This paragraph contains insights gathered during session 7: Mitigation Opportunities. See chapter 2.3 for an overview of the session. It describes the structure and objectives of the session and explains how the exercise unfolded in practice. The aim was to gather ideas for mitigation measures. The mitigation opportunities should reduce macro-avoidance and are not compensatory measures.

Locations of new OWFs

When selecting locations for new OWFs, consideration should be given to areas with low sensitivity. These are areas with, for example, low densities of seabirds and/or prey species.

Characteristics OWFs

There are opportunities for mitigation through the design and physical characteristics of OWFs. Technical innovations, such as modifications to turbine rotor blade design, may help reduce macro-avoidance behaviour in seabirds.

However, several questions arise when considering such design changes. It is important to understand how adjustments to rotor blades influence sound and vibration levels, as these may create new disturbance effects. Design changes may also affect turbine power output; if energy production per turbine decreases, additional turbines might be required to meet the same energy targets. Lower turbine density could increase the spatial footprint of an OWF, while higher density could concentrate impacts within a smaller area, raising the question of which approach leads to the least ecological disturbance. Furthermore, it remains unclear whether OWFs with lower turbine density truly result in less disturbance to seabirds, or whether other processes dominate macro-avoidance responses.

Question for reviewers: What kind of design would help reduce macro-avoidance behaviour in seabirds? Is there information available?

Addition after review:

- *One expert notes there is a range of OWF/turbine design aspects that could have an affect on seabird macro-avoidance, such as turbine density, turbine size, configuration of turbine placements, etc). However, there is evidence only for turbine density and for a single species. The* *expert also emphasizes that it is not clear yet whether reducing macro-avoidance really leads to a lower ecological impact.*

- *Another expert agrees and adds that not much is known on the effects of turbine design on macro-avoidance. Few studies that have been carried out focus on meso-avoidance and collision risk. In terms of windfarm design and configuration there are some studies that suggest lower levels of macro-avoidance for lower turbine density, but again it is not clear how large these effects are and how this relates to the footprint of OWF's as well as how this affects seabirds on a large spatial scale.*
- *One expert added that it needs a proper analysis of seabird avoidance observed at OWF with different designs of wind farm and turbine characteristics, selecting both OWF with good data availability and appropriate methods (e.g. BACI).*
- *One expert suggested that attraction to offshore wind farms could potentially be reduced by adjusting operational and service regimes, for example by modifying the timing of service vessel departures from port.*

Changes in food availability

The food availability in and around OWFs can be increased, for example by reducing fishing activities. Bottom trawling in particular should be restricted. Zonation, whereby no fishing takes place in a large zone around OWFs, could offer a solution. In addition, the presence of forage fish can be increased by making the OWF more attractive to forage fish (e.g. sand eels and herring). This can be achieved by increasing underwater habitat diversity. This bottom habitat should be designed to be as natural as possible, for example with oysters instead of stones. This is only possible with species that depend on hard substrates. Species that depend on soft substrates are (more) difficult to control. Other ideas that can offer variation include placing poles with mussels, reefs between sandy areas or so-called “tree reefs”. The latter are primary habitats for herring to lay their eggs. Research into these “tree reefs” is currently ongoing.

Nonetheless, some issues still require clarification, including the degree to which the measures support the main prey species of seabirds. In addition, experts pointed out that no nature-based solutions exist that can increase food availability for birds.

Addition after review:

- *One expert noted that ecologically it may be doubtful to give even more hard substrate into a soft bottom ecosystem.*
- *The same expert also noted that fishing in/near OWF not only takes away potential forage fish, but there can also be an extra risk when bottom-touching gear are used that disturbs the habitat of many forage fish.*
- *The same expert noted that unless it can be shown that foraging problems are the reason for avoidance, fishing should be reduced in the areas the seabirds go to when avoiding OWF. I.e. the mitigation would be to offer replacement foraging areas which do not need to be very close to OWF.*
- *Another expert agreed and was cautious about the suggestion to increase food availability in or near OWFs. They thought it should be noted that this could increase mortality due to collisions. The alternative would be to try to increase food availability away from OWFs.*
- *Another expert also agreed and added that a good mitigation would be to create protected areas where no disturbance takes place outside OWFs.*

Shipping traffic

Various mitigation opportunities related to shipping traffic can help reduce visual and sound disturbance within and around OWFs. One option is to restructure shipping routes so that vessel traffic is directed away from the most sensitive areas. Disturbance from maintenance vessels operating inside OWFs can also be reduced by establishing designated, fixed routes that limit the spatial footprint of vessel movement (canalization of traffic). Other mitigation opportunities focus on reducing the acoustic impact of ships. Reducing vessel noise through the use of electric propulsion or other low-noise technologies can significantly decrease (underwater) sound levels and vibration. Reducing vessel speed is another opportunity, as slower ships generate less noise and create less disturbance overall.

Other activities
Mitigation can also be achieved by reducing non-OWF-related activities, such as floating solar farms and oyster farming. Although OWFs can provide suitable structures for the natural growth of oysters, additional commercial activities can increase shipping traffic and thus increase disturbance. The development of floating solar farms in combination with OWFs also leads to increased shipping activity due to the maintenance required by these farms. To limit such effects, activities within OWFs must be carefully channeled and spatially restricted.

4.6 Other emerging issues

During the workshop, two themes emerged that were not part of the original scope but recurred frequently in discussions. Both issues highlight areas of uncertainty that warrant explicit attention in future research and assessment frameworks.

Recurrent discussion on “positive” versus “negative” avoidance
A recurring discussion throughout the workshop concerned the distinction between negative avoidance and positive avoidance. In negative avoidance, birds actively avoid wind-farm areas due to disturbance or altered habitat. Positive avoidance is a term some experts used to describe the absence of birds in OWFs because attractors are missing, and not because e.g. turbines repel them. For example, several species, especially Gulls, are strongly associated with fishing vessels and mixed-species feeding flocks. When such attractors are absent inside OWFs, lower densities may reflect lack of attraction rather than a behavioural response to disturbance.

This distinction was especially relevant in the sticker exercises, where some experts placed species under visual disturbance or changes in habitat structure even though their reasoning related to the absence of fisheries or other seabirds. The terminology used in the sessions did not always explicitly separate these interpretations, which may have influenced how experts categorised certain drivers or mechanisms. As a result, part of the variation in sticker patterns likely reflects differences in how experts conceptualised avoidance itself.

The repeated emergence of this topic highlights the need to treat positive and negative avoidance as analytically distinct processes. Clarifying this distinction in future workshops, analyses, and modelling efforts will help ensure that displacement patterns are interpreted correctly and not conflated with distributional changes driven by foraging ecology or multi-species associations.

Attraction to OWFs and uncertainty about potential negative effects
In addition to avoidance, experts raised the possibility that some species may experience attraction to offshore wind farms, although this was outside the formal scope of the workshop. Attraction may arise through increased resting or perching opportunities, changes in water movement, or artificial lighting. Experts also noted anecdotal observations of rafting behaviour near turbines for some gull species.

While attraction might seem beneficial from a habitat-use perspective, experts stressed that the ecological consequences could be negative. Birds drawn into the wind-farm area may face elevated collision risk, altered foraging behaviour, or increased exposure to anthropogenic activities such as shipping and maintenance vessels. Some experts described this as the risk of creating ecological traps, where birds are attracted to an area that ultimately reduces their fitness.

This tension also arose in discussions on mitigation. Measures aimed at increasing food availability may unintentionally increase attraction, potentially bringing sensitive species closer to turbines. As one expert noted: increasing food availability within OWFs can also have a negative effect by attracting species that subsequently become collision victims. This highlights the need for careful consideration of unintended consequences when designing nature-inclusive or habitat-enhancement measures.

Overall, both attraction and the distinction between positive and negative avoidance represent important conceptual considerations. They illustrate how seabird presence or absence in OWFs can result from multiple interacting processes that are not solely driven by disturbance. Future research, monitoring, and mitigation planning should therefore explicitly address these phenomena to avoid misinterpretation of observed patterns and to ensure that management measures do not increase ecological risk.

5 Conclusion and next steps

This chapter contains the next steps required following this workshop and the results captured in this report.

5.1 Achievement of goals

This project aimed to advance understanding of seabird macro-avoidance during the operational phase of offshore wind farms (OWFs) by synthesising expert knowledge. The workshop focused on identifying key avoidance causal factors, understanding their underlying mechanisms, exploring mitigation options, and highlighting critical knowledge gaps for future research. Below, we describe the extent to which each of the predefined goals was achieved.

Goal 1: Determine the relative importance of macro-avoidance causal factors (including a ranking)
A ranked overview was developed to reflect expert judgements on potential macro-avoidance drivers for the selected focus species. It is important to note that this ranking does not represent empirically established causal relationships, but rather a synthesis of expert perceptions based on current knowledge and experience, acknowledging that many underlying mechanisms remain insufficiently studied. Across species, visual disturbance was consistently identified as a potentially important driver, followed by possible changes in food availability and habitat structure. For some diving species, sound disturbance was also considered a potentially relevant factor. However, these outcomes should be interpreted as indicative rather than definitive, given the limited scientific evidence available for several drivers and species. The primary value of this exercise lies in identifying areas of agreement among experts, highlighting divergent interpretations, and revealing key knowledge gaps and research priorities. The plenary discussions were instrumental in providing ecological context to the rankings and in clarifying uncertainties. As such, the results offer a starting point for prioritising future research rather than firm conclusions on macro-avoidance causality.

Goal 2: Identify the mechanisms through which causal factors lead to macro-avoidance
An overview was made of underlying mechanisms that may explain macro-avoidance behaviour across species during the operational phase. Mechanisms such as vigilance, masking of prey detection, lack of visual attractors, and changes in prey concentration were frequently identified. Nuanced insights were provided into how sensory, behavioural, and ecological processes interact, and clarified that macro-avoidance is shaped by combinations of mechanisms rather than single causal pathways. This mechanistic overview can guide targeted research on species-specific responses.

Goal 3: Identify knowledge gaps relevant to understanding macro-avoidance behaviour
A set of knowledge gaps in seabird–OWF interactions was identified that requires further research to reduce uncertainties in macro-avoidance assessment. The list covers key themes such as species behaviour, underlying mechanisms, the effects of OWF characteristics, forage-fish ecology, cumulative impacts, and energetic consequences of macro-avoidance. For four priority knowledge gaps, experts outlined both enabling and hindering factors, as well as the steps required to address them. This provides a roadmap for future research and identifies where coordinated data collection, methodological innovation and long-term monitoring are most urgently needed. The identified gaps will refine the focus of ongoing research efforts.

Goal 4: Explore potential mitigation options and actionable management perspectives
A broad set of feasible mitigation ideas or management measures were identified that could reduce avoidance-related impacts or refine assessments of habitat loss. These ranged from strategic site selection for new OWFs to technological innovations and adjustments in operational practices. Opportunities were identified to reduce disturbance via turbine design characteristics, underwater habitat enhancement, limitations on fishing and shipping activity, and improved management of vessel routes within OWFs. Experts also provided critical reflections on the feasibility, ecological relevance and potential unintended consequences of these measures, especially concerning food availability and attraction. While several ideas

require further evaluation before implementation, a diverse set of concepts were captured that can help shape future mitigation research and policy development.

5.2 Concluding workshop remarks

The workshop was experienced as both productive and enjoyable by all participants. The atmosphere was constructive, and all experts contributed to the discussions and exercises. Their engagement was essential to the success of this project, and we gratefully acknowledge their efforts and participation. Despite the full workshop schedule, all sessions proceeded as planned, and each successfully yielded information required for this project. The expert workshop provided a foundation for advancing our understanding of seabird macro-avoidance during the operational phase of offshore wind farms. The sessions generated a set of insights across causal factors, underlying mechanisms, ongoing research, and knowledge gaps, and showed where expert views are aligned and where uncertainty remains.

5.3 Synthesis after expert review

Following the completion of the workshop and the review process, this section provides a synthesis of how the outcomes were received by both workshop participants and international experts. It also reflects on how the collected insights relate to the original research questions and an interpretation of what can be derived from the results.

Reflection on feedback from workshop experts
The feedback received from the workshop participants (session experts) was overall positive and largely confirmed the direction and interpretation of the report. Experts recognised their contributions in the text and indicated that the report reflects the discussions and key themes that emerged during the sessions.

The review primarily resulted in further elaboration rather than fundamental changes. Experts added examples and refined interpretations. Importantly, the topics that were emphasised during the workshop discussions, such as the role of visual disturbance, the importance of food availability, and the complexity of interpreting avoidance behaviour, remained central in the reviewed version.

The review reinforced the initial findings and highlighted that the expert group shares a similar understanding of the key processes, while recognising the uncertainties that remain.

Reflection on feedback from international experts
The international experts' review provided validation, as well as critical reflection. Overall, the international experts acknowledged that the report brings together a wide range of insights and provides a synthesis of current expert knowledge on seabird macro-avoidance. Some differences in tone were observed compared to the workshop experts. These were attributable to the challenge of interpreting workshop outcomes based on written descriptions alone, without direct participation in the discussions. As a result, some international experts raised questions regarding interpretation, scope, and intended application.

Key points raised by international experts included:
- The evidence base underlying some statements, particularly where expert judgement is presented in a way that may appear factual (this has been rewritten);
- The use of terminology, especially where terms differ from established frameworks;
- The broader context, including questions about how the results should be used in relation to mitigation or offshore wind development.

These reflections did not contradict the findings but emphasised the need for careful framing. Overall, international experts were aligned with the main insights and recognised the value of the approach.

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Synthesis in relation to the research questions
The central research question guiding this study was:

Which causal factors and mechanisms explain macro-avoidance behaviour of seabirds in offshore wind farms, and how do these differ between species?

A key overall finding is that no single causal factor or mechanism can explain macro-avoidance behaviour in isolation. Experts consistently emphasised that multiple stimuli can act simultaneously and interact. Despite this complexity, several consistent patterns emerged:

- Visual disturbance is perceived as the most important factor across species;
- Changes in food availability are also considered relevant, although often difficult to separate from broader habitat effects;
- Sound disturbance, particularly underwater sound, may play a more important role for diving species such as Razorbill and Common Guillemot;
- Species-specific differences are evident, for example the stronger role of food availability for Great Black-backed Gull.

Similarly, while identifying underlying mechanisms proved challenging, experts repeatedly pointed to changes in prey concentration, behavioural responses such as increased vigilance, barrier effects, and the influence of anthropogenic activities (e.g. servicing and vessel presence).

At the same time, the discussions highlighted a fundamental interpretational challenge: observed macro-avoidance often reflects changes in density rather than true absence and may result from both avoidance processes and the absence of attracting factors.

Implications and recommendations
Based on the collected input, several cautious recommendations can be formulated. First, the results underline that understanding seabird distribution and habitat selection is key for interpreting macro-avoidance. Without this baseline, it remains difficult to determine whether offshore wind farms are altering natural patterns or reinforcing existing dynamics.

Second, the findings suggest that future research should prioritise:

- linking seabird distribution to prey dynamics and environmental drivers;
- improving understanding of species-specific responses to combined stimuli.

Finally, the results highlight that attempts to mitigate macro-avoidance should be approached with caution. Increasing attractiveness of wind farms, for example through enhanced food availability, may introduce trade-offs such as increased collision risk.

Overall, the results confirmed that while substantial uncertainties remain, there is a pathway forward. The combination of expert knowledge and targeted future research will enable Wozep and its partners to take steps toward reducing these uncertainties. This will contribute not only to improved impact assessments, but also to the development of practical and ecologically informed approaches for offshore wind expansion in the North Sea.

5.4 Acknowledgements

We would like to express our gratitude to all experts who contributed their time, knowledge, and insights to this study. Their expertise and constructive input, both during the workshop and throughout the review process, have been valuable for this report. The diversity of perspectives, reflections, and open discussions have improved the quality of the work.

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Their collective input has been valuable in understanding seabird macro-avoidance of offshore wind farms.

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6 Appendices

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6.2 AHP Calculations

To evaluate the relative importance of different drivers influencing bird behaviour in offshore wind farms, the Analytic Hierarchy Process (AHP) was applied across multiple species. AHP is a structured multi-criteria decision-making method that translates qualitative expert judgements into quantitative weights, allowing different drivers to be compared in a transparent and internally consistent way.
For each species, a set of relevant drivers was defined based on expert knowledge and workshop discussions. These drivers may include, for example, visual disturbance, sound disturbance, and changes in food availability, but the relative importance of these drivers can differ among species.

The AHP analysis followed the same procedure for all species and consisted of the following steps:

1. **Definition of drivers**
   For each species, the key drivers potentially influencing presence, behaviour, or distribution within and around offshore wind farms were identified.
2. **Pairwise comparisons**
   Drivers were compared in pairs, with experts judging which of the two drivers was more influential for a given species, and to what degree (e.g. equally important, slightly more important, or clearly more important). These judgements were converted into numerical values using the standard AHP comparison scale.
3. **Construction of the comparison matrix**
   The pairwise judgements were compiled into a species-specific comparison matrix, in which each driver was compared against all others. Reciprocal values were used to ensure internal consistency.
4. **Normalization and calculation of weights**
   The comparison matrix was normalised by dividing each value by the sum of its column. The average value of each row in the normalised matrix represents the relative weight of that driver for the species concerned.
5. **Ranking and interpretation**
   The resulting weights were used to rank drivers according to their relative importance. The weights reflect the proportional contribution of each driver to the overall effect and allow comparison of dominant drivers within and between species.

By applying this approach consistently across species, the AHP analysis provides a structured framework for synthesising expert judgement while explicitly acknowledging species-specific differences. The results highlight which drivers are considered most relevant for each species.

<table>
<tr><th>Species</th><th>Razorbill</th></tr>
<tr><td>Drivers</td><td>A – Visual
B – Sound
C – Food availability</td></tr>
<tr><td>Choices in comparisons</td><td>A vs B – A little bit more important
A vs C – A little bit more important
B vs C - Equal</td></tr>
<tr><td>Resulting matrix</td><td><table><tr><th></th><th>A</th><th>B</th><th>C</th></tr><tr><td>A</td><td>1</td><td>3</td><td>3</td></tr></table></td></tr>
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<tr><td>B</td><td>0,333333333</td><td>1</td><td>1</td></tr>
<tr><td>C</td><td>0,333333333</td><td>1</td><td>1</td></tr>
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<tr><td>Normalized matrix</td><td>
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<tr><td>B</td><td>0,2</td><td>0,2</td><td>0,2</td></tr>
<tr><td>C</td><td>0,2</td><td>0,2</td><td>0,2</td></tr>
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</td></tr>
<tr><td>Weights per driver</td><td>
<table>
<tr><td>Driver</td><td>Gewicht</td><td>Label</td><td>Weights (%)</td><td>%</td></tr>
<tr><td>A</td><td>0,6</td><td>Visual</td><td>0,6</td><td>60</td></tr>
<tr><td>B</td><td>0,2</td><td>Sound</td><td>0,2</td><td>20</td></tr>
<tr><td>C</td><td>0,2</td><td>Food availability</td><td>0,2</td><td>20</td></tr>
</table>
</td></tr>
<tr><td>Ranking</td><td>
<table>
<tr><td>Rank</td><td>Driver</td><td>Label</td><td>Weight(%)</td></tr>
<tr><td>1</td><td>A</td><td>Visual</td><td>60</td></tr>
<tr><td>2</td><td>B</td><td>Sound</td><td>20</td></tr>
<tr><td>3</td><td>B</td><td>Sound</td><td>20</td></tr>
</table>
</td></tr>
<tr><td>Result</td><td>Visual disturbance (60%) > Changes in food availability (20%) = Sound disturbance (20%)</td></tr>
</table>

<table>
<tr><th>Species</th><th>Lesser Black-backed gull</th></tr>
<tr><td>Drivers</td><td>A – Visual
B – Food availability
C – Habitat</td></tr>
<tr><td>Choices in comparison s</td><td>A vs B – A little bit more important
A vs C – A more important
B vs C – B more important</td></tr>
<tr><td>Resulting matrix</td><td><table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>A</td><td>1</td><td>3</td><td>5</td></tr>
<tr><td>B</td><td>0,333333333</td><td>1</td><td>5</td></tr>
<tr><td>C</td><td>0,2</td><td>0,2</td><td>1</td></tr>
<tr><td>Sum of columns</td><td>1,533333333</td><td>4,2</td><td>11</td></tr>
</table></td></tr>
<tr><td>Normalized matrix</td><td><table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>A</td><td>0,66</td><td>0,71</td><td>0,45</td></tr>
<tr><td>B</td><td>0,22</td><td>0,24</td><td>0,45</td></tr>
<tr><td>C</td><td>0,13</td><td>0,05</td><td>0,09</td></tr>
</table></td></tr>
<tr><td>Weights per driver</td><td><table>
<tr><th>Driver</th><th>Weight</th><th>Label</th><th>Weight (%)</th><th>%</th></tr>
<tr><td>A</td><td>0,61</td><td>Visual</td><td>0,61</td><td>60,70</td></tr>
<tr><td>B</td><td>0,30</td><td>Food availability</td><td>0,30</td><td>30,33</td></tr>
<tr><td>C</td><td>0,089</td><td>Habitat</td><td>0,09</td><td>8,97</td></tr>
</table></td></tr>
<tr><td>Ranking</td><td><table>
<tr><th>Rank</th><th>Driver</th><th>Label</th><th>Weight (%)</th></tr>
<tr><td>1</td><td>A</td><td>Visual</td><td>60,70</td></tr>
<tr><td>2</td><td>B</td><td>Food availability</td><td>30,33</td></tr>
<tr><td>3</td><td>C</td><td>Habitat</td><td>8,97</td></tr>
</table></td></tr>
<tr><td>Result</td><td>Visual disturbance (61%) > Changes in food availability (30%) > Changes in habitat structure (9%)</td></tr>
</table>

<table>
<tr><th>Species</th><th>Northern Gannet</th></tr>
<tr><td>Drivers</td><td>A – Visual
B – Food availability
C – Habitat</td></tr>
<tr><td>Choices in comparison s</td><td>A vs B – A more important
A vs C – A more important
B vs C – B little bit more important</td></tr>
<tr><td>Resulting matrix</td><td><table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>A</td><td>1</td><td>5</td><td>5</td></tr>
<tr><td>B</td><td>0,2</td><td>1</td><td>3</td></tr>
<tr><td>C</td><td>0,2</td><td>0,333333333</td><td>1</td></tr>
<tr><td>Sum of columns</td><td>1,4</td><td>6,33</td><td>9</td></tr>
</table></td></tr>
<tr><td>Normalized matrix</td><td><table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>A</td><td>0,71</td><td>0,79</td><td>0,56</td></tr>
<tr><td>B</td><td>0,14</td><td>0,16</td><td>0,33</td></tr>
<tr><td>C</td><td>0,14</td><td>0,05</td><td>0,11</td></tr>
</table></td></tr>
<tr><td>Weights per driver</td><td><table>
<tr><th>Driver</th><th>Weight</th><th>Label</th><th>Gewicht (%)</th><th>%</th></tr>
<tr><td>A</td><td>0,69</td><td>Visual</td><td>0,69</td><td>68,64</td></tr>
<tr><td>B</td><td>0,21</td><td>Food availability</td><td>0,21</td><td>21,14</td></tr>
<tr><td>C</td><td>0,10</td><td>Habitat</td><td>0,10</td><td>10,22</td></tr>
</table></td></tr>
<tr><td>Ranking</td><td><table>
<tr><th>Ranking</th><th>Driver</th><th>Label</th><th>Weight (%)</th></tr>
<tr><td>1</td><td>A</td><td>Visual</td><td>68,64</td></tr>
<tr><td>2</td><td>B</td><td>Food availability</td><td>21,14</td></tr>
<tr><td>3</td><td>C</td><td>Habitat</td><td>10,22</td></tr>
</table></td></tr>
<tr><td>Result</td><td>Visual disturbance (68%) > Changes in food availability (21%) > Changes in habitat structure (10%)</td></tr>
</table>

Species	Sandwich Tern
Drivers	A – Visual B – Food availability C – Habitat
Choices in comparisons	A vs B – A more important A vs C – A little bit more important B vs C – Equal (with the note that habitat and food availability are very difficult to consider separately).
Resulting matrix	(see below)
Normalized matrix	(see below)
Weights per driver	(see below)
Ranking	(see below)
Result	Visual disturbance (66%) > Changes in food availability (16%) = Changes in habitat structure (19%)

Resulting matrix

	A	B	C
A	1	5	3
B	0,2	1	1
C	0,33	1	1
Sum of columns	1,57	7	5

Normalized matrix

	A	B	C
A	0,65	0,71	0,6
B	0,13	0,14	0,2
C	0,22	0,14	0,2

Weights per driver

Driver	Weight	Label	Weight (%)	%
A	0,66	Visual	0,66	65,55
B	0,16	Food availability	0,16	15,78
C	0,19	Habitat	0,19	18,67

Ranking

Ranking	Driver	Label	Weight (%)
1	A	Visual	65,55
2	C	Habitat	18,67
3	B	Food availability	15,78

<table>
<tr><th>Species</th><th>Black-legged kittiwake</th></tr>
<tr><td>Drivers</td><td>A – Visual
B – Food availability
C – Habitat</td></tr>
<tr><td>Choices in comparison s</td><td>A vs B – A little bit more important
A vs C – A more important
B vs C – B little bit more important</td></tr>
<tr><td>Resulting matrix</td><td>
<table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>A</td><td>1</td><td>3</td><td>5</td></tr>
<tr><td>B</td><td>0,33</td><td>1</td><td>3</td></tr>
<tr><td>C</td><td>0,2</td><td>0,33</td><td>1</td></tr>
<tr><td>Sum of columns</td><td>1,53</td><td>4,33</td><td>9</td></tr>
</table>
</td></tr>
<tr><td>Normalized matrix</td><td>
<table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>A</td><td>0,65</td><td>0,69</td><td>0,56</td></tr>
<tr><td>B</td><td>0,22</td><td>0,23</td><td>0,33</td></tr>
<tr><td>C</td><td>0,13</td><td>0,08</td><td>0,11</td></tr>
</table>
</td></tr>
<tr><td>Weights per driver</td><td>
<table>
<tr><th>Driver</th><th>Weight</th><th>Label</th><th>Weight (%)</th><th>%</th></tr>
<tr><td>A</td><td>0,63</td><td>Visual</td><td>0,63</td><td>63,33</td></tr>
<tr><td>B</td><td>0,26</td><td>Food availability</td><td>0,26</td><td>26,05</td></tr>
<tr><td>C</td><td>0,11</td><td>Habitat</td><td>0,11</td><td>10,62</td></tr>
</table>
</td></tr>
<tr><td>Ranking</td><td>
<table>
<tr><th>Ranking</th><th>Driver</th><th>Label</th><th>Weight (%)</th></tr>
<tr><td>1</td><td>A</td><td>Visual</td><td>63,33</td></tr>
<tr><td>2</td><td>B</td><td>Food availability</td><td>26,05</td></tr>
<tr><td>3</td><td>C</td><td>Habitat</td><td>10,62</td></tr>
</table>
</td></tr>
<tr><td>Result</td><td>Visual disturbance (63%) > Changes in food availability (26%) > Changes in habitat structure (11%)</td></tr>
</table>

Species	Common Guillemot
Drivers	A – Visual B – Sound C – Food availability
Choices in comparisons	A vs B – A little bit more important A vs C – A little bit more important B vs C – Equal
Resulting matrix	<table><tr><td></td><td>A</td><td>B</td><td>C</td></tr><tr><td>A</td><td>1</td><td>3</td><td>3</td></tr><tr><td>B</td><td>0,33</td><td>1</td><td>1</td></tr><tr><td>C</td><td>0,33</td><td>1</td><td>1</td></tr><tr><td>Sum</td><td>1,67</td><td>5</td><td>5</td></tr></table>
Normalized matrix	<table><tr><td></td><td>A</td><td>B</td><td>C</td></tr><tr><td>A</td><td>0,6</td><td>0,6</td><td>0,6</td></tr><tr><td>B</td><td>0,2</td><td>0,2</td><td>0,2</td></tr><tr><td>C</td><td>0,2</td><td>0,2</td><td>0,2</td></tr></table>
Weights per driver	<table><tr><td>Driver</td><td>Weights</td><td>Label</td><td>Weights (%)</td><td>%</td></tr><tr><td>A</td><td>0,6</td><td>Visual</td><td>0,6</td><td>60</td></tr><tr><td>B</td><td>0,2</td><td>Sound</td><td>0,2</td><td>20</td></tr><tr><td>C</td><td>0,2</td><td>Food availability</td><td>0,2</td><td>20</td></tr></table>
Ranking	<table><tr><td>Ranking</td><td>Driver</td><td>Label</td><td>Weights (%)</td></tr><tr><td>1</td><td>A</td><td>Visual</td><td>60</td></tr><tr><td>2</td><td>B</td><td>Sound</td><td>20</td></tr><tr><td>3</td><td>B</td><td>Food availability</td><td>20</td></tr></table>
Result	Visual disturbance (60%) > Changes in food availability (20%) = Sound disturbance (20%)

<table>
<tr><th>Species</th><th>Red throated diver</th></tr>
<tr><td>Drivers</td><td>A – Visual
B – Sound
C – Food availability</td></tr>
<tr><td>Choices in comparisons</td><td>A vs B – Equal
A vs C – A more important
B vs C – B little bit more important</td></tr>
<tr><td>Resulting matrix</td><td><table>
<tr><td></td><td>A</td><td>B</td><td>C</td></tr>
<tr><td>A</td><td>1</td><td>1</td><td>5</td></tr>
<tr><td>B</td><td>1</td><td>1</td><td>3</td></tr>
<tr><td>C</td><td>0,2</td><td>0,33</td><td>1</td></tr>
<tr><td>Sum of columns</td><td>2,2</td><td>2,33</td><td>9</td></tr>
</table></td></tr>
<tr><td>Normalized matrix</td><td><table>
<tr><td></td><td>A</td><td>B</td><td>C</td></tr>
<tr><td>A</td><td>0,45</td><td>0,43</td><td>0,56</td></tr>
<tr><td>B</td><td>0,45</td><td>0,43</td><td>0,33</td></tr>
<tr><td>C</td><td>0,09</td><td>0,14</td><td>0,11</td></tr>
</table></td></tr>
<tr><td>Weights per driver</td><td><table>
<tr><td>Driver</td><td>Weights</td><td>Label</td><td>Weights (%)</td><td>%</td></tr>
<tr><td>A</td><td>0,48</td><td>Visual</td><td>0,48</td><td>47,96</td></tr>
<tr><td>B</td><td>0,41</td><td>Sound</td><td>0,41</td><td>40,55</td></tr>
<tr><td>C</td><td>0,11</td><td>Food availability</td><td>0,11</td><td>11,50</td></tr>
</table></td></tr>
<tr><td>Ranking</td><td><table>
<tr><td>Ranking</td><td>Driver</td><td>Label</td><td>Weights (%)</td></tr>
<tr><td>1</td><td>A</td><td>Visual</td><td>47,96</td></tr>
<tr><td>2</td><td>B</td><td>Sound</td><td>40,55</td></tr>
<tr><td>3</td><td>C</td><td>Food availability</td><td>11,50</td></tr>
</table></td></tr>
<tr><td>Result</td><td>Visual disturbance (48%) = Sound disturbance (41%) > Changes in food availability (11%)</td></tr>
</table>

<table>
<tr><th>Species</th><th>Great Black-backed Gull</th></tr>
<tr><td>Drivers</td><td>A – Visual
B – Food availability
C – Habitat</td></tr>
<tr><td>Choices in comparisons</td><td>A vs B – B little bit more important
A vs C – C more important
B vs C – B little bit more important</td></tr>
<tr><td>Resulting matrix</td><td>
<table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>A</td><td>1</td><td>0,2</td><td>0,2</td></tr>
<tr><td>B</td><td>5</td><td>1</td><td>3</td></tr>
<tr><td>C</td><td>5</td><td>0,33</td><td>1</td></tr>
<tr><td>Sum of columns</td><td>11</td><td>1,53</td><td>4,2</td></tr>
</table>
</td></tr>
<tr><td>Normalized matrix</td><td>
<table>
<tr><th></th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>A</td><td>0,09</td><td>0,13</td><td>0,05</td></tr>
<tr><td>B</td><td>0,45</td><td>0,65</td><td>0,71</td></tr>
<tr><td>C</td><td>0,45</td><td>0,22</td><td>0,24</td></tr>
</table>
</td></tr>
<tr><td>Weights per driver</td><td>
<table>
<tr><th>Driver</th><th>Weights</th><th>Label</th><th>Weights (%)</th><th>%</th></tr>
<tr><td>A</td><td>0,09</td><td>Visual</td><td>0,09</td><td>8,97</td></tr>
<tr><td>B</td><td>0,61</td><td>Food availability</td><td>0,61</td><td>60,70</td></tr>
<tr><td>C</td><td>0,30</td><td>Habitat</td><td>0,30</td><td>30,33</td></tr>
</table>
</td></tr>
<tr><td>Ranking</td><td>
<table>
<tr><th>Ranking</th><th>Driver</th><th>Label</th><th>Weights (%)</th></tr>
<tr><td>1</td><td>B</td><td>Food availability</td><td>60,70</td></tr>
<tr><td>2</td><td>C</td><td>Habitat</td><td>30,33</td></tr>
<tr><td>3</td><td>A</td><td>Visual</td><td>8,97</td></tr>
</table>
</td></tr>
<tr><td>Result</td><td>Changes in food availability (61%) > Changes in habitat structure (30%) > Visual disturbance (9%)</td></tr>
</table>

6.3 Conceptual framework

For this project, a clearly defined scope was established. To support and structure the discussions during the workshop, a conceptual framework was introduced (Figure 1). While this framework proved useful as a guiding tool throughout the sessions, it also elicited substantial criticism from the experts. In particular, participants noted that, in its current form, the framework lacks sufficient refinement to be applied rigorously. Further development and clarification would therefore be required before such a framework could be used more broadly or interpreted as analytically robust.

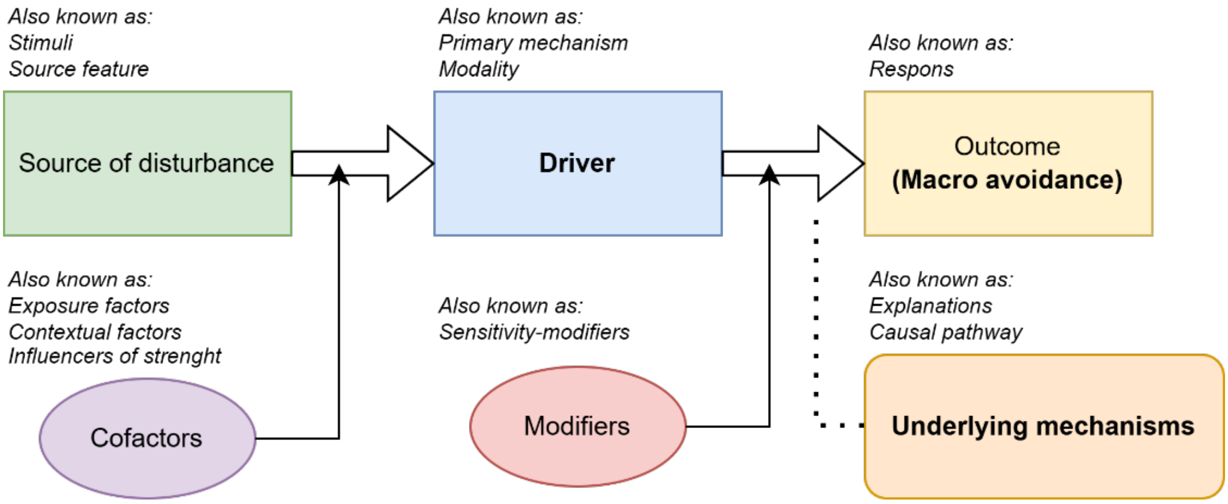

Figure 2 Framework to define terminology in pathways related to macro-avoidance behaviour.