



Assessing the vulnerability of marine bird species to offshore wind farms using a sensitivity scoring framework

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Summary

Over the past decade, offshore developments like offshore wind farms (OWFs) have been rapidly expanding in the Greater North Sea, including Dutch waters. This has and will continue to substantially alter the marine landscape. At the same time, new insights into the impacts of OWFs on wildlife have emerged. In the Netherlands, the *Kader Ecologie en Cumulatie* (KEC) programme has been developed to quantify the cumulative ecological effects of OWFs on marine wildlife, including impacts on selected coastal and marine bird species. The current changes in the Dutch waters regarding OWF developments highlight the need for a reproducible framework to assess species sensitivity towards OWF-related pressures, such as collision and displacement risks, and to select and prioritise marine and coastal bird species for a KEC assessment.

In this study, the sensitivity scoring framework by Heße and Melis (2026) was applied to evaluate the vulnerability of seven species to OWF-related collision and displacement effects, with the aim of identifying marine and coastal bird species with medium to high sensitivity towards OWFs. Following the framework, these species were then recommended for consideration in future KEC assessments. The species evaluated here were common scoter (*Melanitta nigra*), common eider (*Somateria mollissima*), great cormorant (*Phalacrocorax carbo*), northern gannet (*Morus bassanus*), northern fulmar (*Fulmarus glacialis*), Atlantic puffin (*Fratercula arctica*), and red-throated diver (*Gavia stellata*), in combination with Manx shearwater (*Puffinus puffinus*), Arctic tern (*Sterna paradisaea*), little auk (*Alle alle*), and yellow-billed loon (*Gavia adamsii*) scored within Heße and Melis (2026).

Using a structured, literature-based approach supplemented by expert judgement where necessary, species-specific scores were derived for collision vulnerability, displacement vulnerability, and overall species vulnerability. The results indicate that all assessed species exhibit at least moderate sensitivity to OWFs, with overall sensitivity scores ranging from 0.47 to 0.83. Five species (common scoter, Arctic tern, yellow-billed loon, northern fulmar, and common eider) were classified as highly sensitive, while the remaining six species showed overall moderate sensitivity to OWFs.

We identified displacement as the dominant risk across the eleven species, with seven species scoring high for displacement sensitivity and the remaining four showing moderate vulnerability. In contrast, collision risk was generally lower: only Arctic tern was classified as highly sensitive, while most other species showed moderate vulnerability to collision. These score patterns underline the importance of considering both risk components, while highlighting the vulnerability towards displacement effects for all species assessed.

Based on these results, all eleven species were recommended for consideration for inclusion in future KEC assessments. However, species with high overall sensitivity should be prioritised, as they are most likely to experience significant impacts from OWF development. The outcomes of the scoring framework were largely in line with our expectations, and any deviations could be explained by the underlying literature informing the scoring, as well as by precautionary assumptions applied where empirical evidence was limited. Scores should therefore be interpreted with the ecological context, available data, and underlying assumptions in mind. While the scoring framework does not incorporate explicit spatial exposure factors, species' spatial overlap with OWFs and number of birds affected is addressed within the KEC assessment. Within this defined scope, the results of this study support the framework as a transparent and reproducible tool for species selection.

The sensitivity scores presented in this study are based on the best available literature, but remaining data gaps and uncertainties highlight the need for regular updates as new empirical evidence becomes available.

Samenvatting

In het afgelopen decennium is de omvang van gerealiseerde en geplande offshore windparken (OWF's) in de Noordzee, inclusief het Nederlandse deel, aanzienlijk toegenomen. Tegelijkertijd zijn gedurende deze periode nieuwe inzichten opgedaan naar de effecten van OWF's op soorten. Het 'Kader Ecologie en Cumulatie' (KEC) biedt instrumentarium voor het kwantificeren van cumulatieve ecologische effecten van OWF's, onder meer voor een selectie van kust- en zeevogelsoorten. De huidige en geplande ontwikkelingen voor windenergie op zee, samen met de ontwikkelde kennis, onderstrepen de noodzaak van een robuust en reproduceerbaar kader waarmee de gevoeligheid van soorten voor OWF-gerelateerde drukfactoren, zoals aanvaringen en vermijding van leefgebied, kan worden bepaald.

In deze studie is het raamwerk van Heße en Melis (2026) toegepast. Met behulp van dit raamwerk is de gevoeligheid van zeven soorten voor aanvaring en vermijding van leefgebied door OWF's geëvalueerd. Het doel van deze analyse was om zee- en kustvogelsoorten met een middelmatige tot hoge gevoeligheid voor OWF's te identificeren. Deze soorten worden vervolgens aanbevolen om te overwegen voor opname in toekomstige KEC-beoordelingen. De onderzochte soorten zijn zwarte zee-eend (*Melanitta nigra*), eidereend (*Somateria mollissima*), aalscholver (*Phalacrocorax carbo*), jan-van-gent (*Morus bassanus*), noordse stormvogel (*Fulmarus glacialis*), papegaaiduiker (*Fratercula arctica*), en roodkeelduiker (*Gavia stellata*), in combinatie met noordse pijlstormvogel (*Puffinus puffinus*), noordse stern (*Sterna paradisaea*), kleine alk (*Alle alle*) en geelsnavelduiker (*Gavia adamsii*), waarvan de laatste vier soorten reeds zijn geëvalueerd in Heße en Melis (2026).

Op basis van een gestructureerde literatuurstudie, aangevuld met expert judgement, zijn soort specifieke scores bepaald voor aanvaringskwetsbaarheid, vermijdingskwetsbaarheid en de algehele gevoeligheid. De resultaten laten zien dat alle onderzochte soorten op zijn minst een matige gevoeligheid voor OWF's vertonen. Totale gevoeligheidsindices varieerden van 0,47 tot 0,83, waarbij vijf soorten (zwarte zee-eend, noordse stern, geelsnavelduiker, noordse stormvogel en eidereend) zijn geclassificeerd met een hoge gevoeligheid terwijl de overige zes soorten een matige gevoeligheid vertonen.

Vermijding kwam naar voren als het meest dominante effect van OWF's met zeven soorten die hiervoor een hoge gevoeligheid scoorden. De overige vier scoorden een matige gevoeligheid voor vermijding. Over het algemeen was de gevoeligheid voor aanvaring lager: alleen de noordse stern werd geclassificeerd met een hoge gevoeligheid, terwijl de meeste soorten een matige gevoeligheid voor aanvaringen vertoonden. Deze uitkomst benadrukt het belang van het meenemen van beide risicocomponenten.

Uit de resultaten volgt de aanbeveling om alle elf soorten te overwegen voor opname in toekomstige KEC-beoordelingen. Soorten met een hoge totale gevoeligheidsindex dienen daarbij prioriteit te krijgen, aangezien zij het meest waarschijnlijk significant worden beïnvloed door de ontwikkeling van OWF's. De uitkomsten van het raamwerk komen grotendeels overeen met de verwachtingen. Enkele afwijkingen hiervan konden worden verklaard door de onderliggende literatuur waarop de scores zijn gebaseerd, of door voorzorg benaderingen die zijn toegepast wanneer empirisch bewijs beperkt was. Scores moeten daarom worden geïnterpreteerd in het licht van zowel de ecologische context, als de beschikbare gegevens en de onderliggende aannames die zijn gedaan. Het raamwerk bevat geen expliciete ruimtelijke verspreiding en ruimtelijke blootstellingsfactoren. Deze ruimtelijke overlap van soorten met OWF's en aantallen getroffen vogels wordt wel meegenomen binnen de KEC-beoordelingen. Binnen de scope van deze studie ondersteunen de resultaten de inzet van het raamwerk als een transparant en reproduceerbaar instrument voor soortselectie op basis van gevoeligheid. Tot slot blijft het regelmatig actualiseren van gevoeligheidsindices essentieel om toekomstige KEC-beoordelingen accuraat en relevant te houden, gezien de voortdurende ontwikkeling van kennis over de effecten van OWF's.

1 Introduction

The Netherlands has set ambitious targets for offshore wind development, aiming to install 21 GW of offshore wind capacity by 2030 and 70 GW by 2050 (Netherlands Enterprise Agency, 2024). The expansion of offshore wind farms (OWFs) in the North Sea poses conservation challenges for wildlife such as marine and coastal bird species that use the sea as foraging grounds, resting area or migration corridor. The main impact pathways of OWFs on marine and coastal bird species stem from mortality due to collisions with turbines and displacement from wind farm areas (Drewitt and Langston, 2006; Garthe and Hüppop, 2004; Masden et al., 2010; Soudijn et al., 2022). Displacement can occur during operation of the turbines as well as a result of increased OWF-related human activity in the area (e.g. (maintenance) vessel traffic) and may lead to a loss of foraging habitat or create barriers to daily and seasonal movements (Mendel et al., 2019; Peschko et al., 2020). Species responses to OWFs are heterogeneous with behaviours ranging from avoidance to attraction (Dierschke et al., 2016; Furness et al., 2013; Garthe and Hüppop, 2004).

The KEC (*Kader Ecologie en Cumulatie*) is a framework developed to assess the ecological and cumulative effects of OWFs on sensitive animal species and their habitats. The KEC quantifies the combined impacts of both existing and planned wind farms on displacement and collision of, among others, coastal and marine bird species. As scientific understanding of OWF impacts continues to develop (Peschko et al., 2020), the KEC framework is subject to regular revision every two years. Given this iterative nature of the KEC, the identification of species sensitive to collision or displacement based on the latest knowledge is important, as this provides the most recent insights on species to be considered in future KEC assessments.

Sensitivity scoring presents an approach to select marine and coastal bird species to consider for assessment for collision and/or displacement effects in future KEC assessments. Scoring frameworks have been primarily developed for wind farm site selection and comparative area assessments and have been used as tool for strategic environmental impact assessments (Garthe and Hüppop, 2004). Such a tool is specifically convenient when knowledge and data are limited because such a framework generally is mathematically defined, assumptions are clearly stated, and the framework can be adjusted according to new knowledge (Certain et al., 2015). Sensitivity scoring helps in identifying species most likely to be at risk, providing a clearer focus for assessments on those species of greatest concern (Furness et al., 2013). This allows for a better understanding and addressing of risks resulting from potential interactions between OWFs and bird species present in the North Sea. Heße and Melis (2026) introduced a sensitivity index framework based on the framework developed by Certain et al. (2015), and applying a systematic literature review. The overall species sensitivity to OWF impacts is determined by species-specific susceptibility to collisions and to displacement. Within this framework, individual vulnerability encompasses the behavioural, morphological, and ecological traits that influence the probability of an individual being affected by a given pressure, such as flight height or habitat flexibility (Heße and Melis, 2026). Species vulnerability reflects the intrinsic severity of any impact on a population, incorporating traits such as conservation status across spatial scales and adult survival rate. This structured, evidence-based framework thereby provides a transparent and reproducible sensitivity scoring for species warranting inclusion in future KEC assessments.

1.1 Aim of the study

Specifically, the aims of this study were

- 1) to derive sensitivity index scores for seven marine and coastal bird species, covering both collision and displacement impact pathways,
- 2) to compare the resulting sensitivity scores, including the sensitivity scores of four additional species reported in Heße and Melis (2026), to each other and discuss and explain the final scores,
- 3) to identify which species, based on their final sensitivity scores, warrant consideration for inclusion in future KEC assessments in relation to offshore wind farms.

2 Methods

In this study, we applied the sensitivity scoring framework as described in Heße and Melis (2026) to seven marine and coastal birds with a focus on the Dutch North Sea. In addition to the seven species scored here, four additional species were included in the discussion of the final scores (Table 1). The sensitivity scores for these four species were adopted directly from Heße and Melis (2026).

To assess species vulnerability to OWFs, a targeted literature search was conducted to compile species-specific ecological and behavioural information relevant to OWF interactions. Primarily Google Scholar, Science Direct, and Scopus were used for the literature search. The literature review focussed on seven species, namely common scoter (*Melanitta nigra*), common eider (*Somateria mollissima*), northern gannet (*Morus bassanus*), great cormorant (*Phalacrocorax carbo*), Atlantic puffin (*Fratercula arctica*), northern fulmar (*Fulmarus glacialis*), and red-throated diver (*Gavia stellata*) (Table 1). Search queries combined species names (scientific and common English and Dutch names) with OWF-related keywords, such as “offshore wind (farm)”, “collision (risk)”, “flight altitude”, “displacement” or “avoidance behaviour”. A list of search terms and keywords used in this literature search is provided in Table 8 (Annex 4). The main focus was on publications from the (Dutch) North Sea and the (North-East) Atlantic region. If no information could be obtained for these regions, a wider search was conducted, also considering proxy species and/or other regions while carefully filtering for publications and values deemed applicable for birds in Dutch waters. Where available, peer-review published and grey literature was used to derive scores for the thirteen factors describing collision and displacement sensitivity and general species vulnerability (Annex 1; Table 4). For factors lacking empirical evidence, scores were based on expert judgement, in consultation with a seabird specialist from Wageningen Marine Research, following the approach outlined by Heße and Melis (2026). Detailed descriptions of the factors and the applied scoring methodology are provided in Heße and Melis (2026).

This scoring framework does not explicitly incorporate a spatial component. Consequently, species distributions at sea are not considered when deriving sensitivity scores. The resulting scores therefore represent intrinsic, species-level vulnerability, rather than exposure-weighted risk within specific OWF development areas. For detailed information how this affects species final sensitivity scores, please refer to the discussion (section 4).

Table 1 Focal marine and coastal bird species included in this sensitivity assessment. The four species below the horizontal line were already scored in Heße and Melis (2026).

Species	Scientific name	Dutch name
Common scoter	<i>Melanitta nigra</i>	Zwarte zee eend
Common eider	<i>Somateria mollissima</i>	Eider
Great cormorant	<i>Phalacrocorax carbo</i>	Aalscholver
Northern gannet	<i>Morus bassanus</i>	Jan-van-gent
Atlantic puffin	<i>Fratercula arctica</i>	Papagaaiduiker
Northern fulmar	<i>Fulmarus glacialis</i>	Noordse stormvogel
Red-throated diver	<i>Gavia stellata</i>	Roodkeelduiker
Yellow-billed loon	<i>Gavia adamsii</i>	Geelsnavelduiker
Arctic tern	<i>Sterna paradisaea</i>	Noordse stern
Little auk	<i>Alle alle</i>	Kleine alk
Manx shearwater	<i>Puffinus puffinus</i>	Noordse pijlstormvogel

3 Results

Final sensitivity scores for collision vulnerability (c_i), displacement vulnerability (d_i), and overall species sensitivity (s_i) are presented in Table 2. Overall sensitivity scores ranged from 0.47 (little auk and great cormorant) to 0.83 (common scoter). Five species were classified as having high overall sensitivity towards OWFs (score >0.66): common scoter, Arctic tern, yellow-billed loon, northern fulmar, and common eider. The remaining six species (Atlantic puffin, northern gannet, red-throated diver, Manx shearwater, great cormorant, and little auk) received moderate overall sensitivity scores (0.47–0.66).

Table 2 Sensitivity scores based on collision vulnerability c_i , displacement vulnerability d_i , and overall species sensitivity s_i per species. The average c_i , d_i , s_i scores serving as final sensitivity scores are presented for all species. All values presented are rounded to two decimals. Based on the overall sensitivity score, the species above the horizontal line classified as species of high overall sensitivity (>0.66) and are shown in bold, while the species below the line have a moderate overall vulnerability (>0.33–0.66) and are shown as regular text. Tables detailing the ranking for collision risk, displacement risk, and species vulnerability are provided in Annex 3 (Table 5, Table 6, Table 7).

Species	c_i	d_i	s_i	Overall sensitivity score
Common scoter	0.57	0.92	1.00	0.83
Arctic tern	0.76	0.66	1.00	0.81
Yellow-billed loon	0.42	1.00	0.83	0.75
Northern fulmar	0.40	1.00	0.84	0.75
Common eider	0.25	0.82	1.00	0.69
Atlantic puffin	0.23	0.90	0.84	0.66
Red-throated diver	0.40	1.00	0.56	0.66
Northern gannet	0.52	0.85	0.58	0.65
Manx shearwater	0.38	0.52	0.83	0.58
Great cormorant	0.42	0.48	0.51	0.47
Little auk	0.27	0.60	0.54	0.47

Across species, displacement vulnerability scores were generally higher than collision vulnerability scores. Displacement scores (d_i) ranged from 0.48 (great cormorant; moderate vulnerability) to 1.00 (yellow-billed loon, northern fulmar, and red-throated diver; high vulnerability; Table 2, and Annex 3, Table 6). Collision scores (c_i) ranged from 0.23 (Atlantic puffin; low vulnerability) to 0.76 (Arctic tern; high vulnerability; Table 2, and Annex 3, Table 5). Species vulnerability scores, which reflect population-level sensitivity, were high for several species, including common scoter, Arctic tern, and common eider. They received the highest possible score of 1.00 (Table 2, and Annex 3, Table 6). Northern gannet served as a reference species, as it has been included in the most recent two KEC assessments (KEC 4.0 and 5.0) for both collision and displacement risk. For collision risk, it scored with a moderate vulnerability ($c_i = 0.52$), ranking third highest among all eleven species (Annex 3, Table 5). For displacement risk it received a high risk score ($d_i = 0.85$), ranking sixth overall (Annex 3, Table 6). General northern gannet sensitivity was scored with a moderate vulnerability ($s_i = 0.58$), ranking it in eighth place (Annex 3, Table 7).

3.1 Species recommendations

Based on the overall sensitivity scores, all eleven marine and coastal bird species covered in this study and by Heße and Melis (2026) are recommended to be considered for inclusion in future KEC assessments, with a prioritisation of species with high risk scores. However, the reasons for the recommendation vary between species (Table 3). For most species, moderate to high displacement risks qualify them for an inclusion in the KEC displacement assessment. Yellow-billed loon, northern fulmar, and red-throated diver all achieved the maximum displacement score (d_i) of 1.00, reflecting strong avoidance responses and high habitat dependency. Common scoter, Atlantic puffin, northern gannet, and common eider also scored high on displacement ($d_i = 0.92, 0.90, 0.85,$ and $0.82,$ respectively). Common eider, Atlantic puffin, and little auk are recommended for inclusion in the displacement assessment only, given their low collision vulnerability scores ($c_i = 0.25, 0.23,$ and $0.27,$ respectively).

In total, eight species are recommended for assessment of both collision and displacement risk: common scoter, Arctic tern, yellow-billed loon, northern fulmar, red-throated diver, northern gannet, Manx shearwater, and great cormorant. For Manx shearwater, a relatively high species vulnerability score ($s_i = 0.83$) contributes meaningfully to the recommendation despite medium collision and displacement scores ($c_i = 0.38, d_i = 0.52,$ respectively). Great cormorant was also flagged for both risk components, though its recommendation is primarily driven by moderate scores across all three components (c_i, d_i, s_i) rather than a clearly dominant score for either collision, or displacement.

Table 3 Overview of recommendations for the inclusion of bird species in future KEC assessments, together with their primary risk components. Recommendations are derived from collision and displacement risk scores. Components classified as high risk are highlighted in bold, whereas medium-risk components are shown in regular text; low-risk components are not presented. Detailed final scores per species and risk component are shown in Table 2. Species above the horizontal line received a high overall sensitivity score, species below a medium overall sensitivity score.

Species	KEC inclusion recommendation	Key risk component
Common scoter	Yes	Displacement , Collision
Arctic tern	Yes	Displacement, Collision
Yellow-billed loon	Yes	Displacement , Collision
Northern fulmar	Yes	Displacement , Collision
Common eider	Yes	Displacement
Atlantic puffin	Yes	Displacement
Red-throated diver	Yes	Displacement , Collision
Northern gannet	Yes	Displacement , Collision
Manx shearwater	Yes	Displacement, Collision
Great cormorant	Yes	Displacement, Collision
Little auk	Yes	Displacement

4 Discussion

4.1 Scores

Five species had high overall sensitivity scores (>0.66), while the remaining six species were identified with moderate sensitivity scores (>0.33 – 0.66). The species with the highest overall sensitivity to offshore wind farms were common scoter, Arctic tern, yellow-billed loon, northern fulmar, and common eider. Based on the final sensitivity scores, all eleven species assessed scored medium to high vulnerability to OWFs. Following the recommendations of Heße and Melis (2026), these sensitivity scores are high enough to warrant further consideration for inclusion in future KEC assessments.

However, a more detailed examination of the underlying scores helps to better interpret these overall sensitivity values with ecological context in mind and to identify limitations of the method applied. The following sections therefore describe the key factors driving collision risk, displacement risk, and general species vulnerability scores. This provides context for interpreting the final overall sensitivity of each species in relation to the three risk and vulnerability components. Overall, the final scores of eight species performed as expected. The final scores of common scoter, common eider, and northern gannet deviated from our expectations. Therefore, these three species are discussed separately from the other species in sections 4.1.5.1 and 4.1.5.2.

4.1.1 Final overall sensitivity to OWFs

Among the five species with high overall sensitivity towards offshore wind farms (common scoter, northern fulmar, yellow-billed loon, common eider, Arctic tern), the final scores were largely driven by high general species vulnerability (s_i). For all of these species except Arctic tern, high displacement risk scores further contributed to the final sensitivity index. Arctic tern was the only species among the five high-risk species that exhibited a high collision risk.

4.1.2 Collision risk

Arctic tern showed the highest collision risk score of all assessed species ($c_i = 0.76$) and was the only species classified as having a high collision risk. This was primarily driven by its high percentage of time spent flying (81–100%; Garthe and Hüppop, 2004) and its high offshore migration percentage (e.g., Fijn et al., 2013). At the other end of the spectrum, little auk, common eider, and Atlantic puffin had the lowest collision risk scores. These species were classified as having low collision risk, mainly due to the influence of the primary factors F_{n1} and F_{n2} ('Percent time spent flying', 'Flight altitude within rotor swept zone'). They spend a relatively low proportion of time flying during non-breeding season and at wintering grounds and typically fly at altitudes outside the rotor swept zone (RSZ; Garthe and Hüppop, 2004; Larsen and Guillemette, 2007), defined here with 19–305m (Heße and Melis, 2026). For little auk, values were inferred from razorbill and common guillemot data presented in Garthe and Hüppop (2004), given the lack of data and their ecological similarity as auk species.

The remaining species, including northern fulmar, common scoter, northern gannet, red-throated diver, yellow-billed loon and great cormorant, received intermediate collision risk scores ranging between 0.38 and 0.57. For northern fulmar, intermediate collision risk is partially driven by its nocturnal offshore movements. Several studies showed that northern fulmars are active at night, especially when following ships (Danielsen, 2011; Darby et al., 2023; Garthe & Hüppop, 1993). Northern gannet received an intermediate collision vulnerability score due to the species' ability to reach flight altitudes within the RSZ during commuting and foraging flights. Cook et al. (2023) projected that 29% of commuting flights and 32% of foraging/search flights occur within the 20–150 m RSZ. Moreover, Skov et al. (2026) reported an average commuting flight altitude of 68.9 m (± 23.3 m), also suggesting partial overlap with rotor blades. Similarly, red-throated diver and great cormorant were scored intermediate based on observed flight altitudes. Red-throated divers generally have a flight

altitude up to 30 m but migration flights occurred at even higher altitudes (Krijgsveld et al., 2011), potentially resulting in overlap with the RSZ. It should be noted that the scoring framework does not distinguish between different behavioural contexts, such as migration, foraging, or local commuting flights. Because migration flights occur less frequently than local movements, their influence on the overall score should be interpreted with caution. Nevertheless, collision risk may be elevated when OWFs intersect with species-specific migratory corridors, justifying a precautionary interpretation and application of these scores. For great cormorant, although most flights occurred at low to intermediate altitudes, below 5 m and rarely exceed 75 m, ship-based surveys and telemetry data indicate that approximately 8–9% of flight occurs at rotor height (20–150 m) See section 4.1.5 for more detailed explanation on the collision scores of northern gannet, common scoter, and common eider.

4.1.3 Displacement risk

Yellow-billed loon, red-throated diver, and northern fulmar had the highest displacement risk scores (d_i), each receiving the highest score possible ($d_i = 1.00$). These high scores were primarily driven by the high displacement probabilities assigned to each species. For yellow-billed loon, displacement risk values were inferred from red-throated diver due to the limited availability of species-specific data.

Red-throated divers are known to be highly susceptible to disturbance from ships (Schwemmer et al., 2011), and substantial reductions in abundance have been reported in OWF areas, generally exceeding 90% within the wind farm footprint and surrounding areas (Garthe et al., 2023; Heinänen et al., 2020; Mendel et al., 2019; Nehls et al., 2018). In addition, significant reductions in red-throated diver densities have been observed over distances often exceeding 10 km, with effect distances of up to 16.5 km reported in German waters (Garthe et al., 2023; Heinänen et al., 2020; Mendel et al., 2019; Nehls et al., 2018). For northern fulmar, maximum reductions in abundance of approximately 91% were reported within the offshore wind farm area plus a 1 km buffer between mid-March and mid-May (Peschko et al., 2025), while changes in fulmar densities before and after OWF construction showed 95% confidence intervals between -80% and -99% (Lamb et al., 2024). For both diver species, suggested low habitat flexibility further contributed to their high displacement vulnerability scores (Garthe & Hüppop, 2004; U.S. Fish & Wildlife Service, 2014).

Atlantic puffin, northern gannet, common scoter, and common eider also received high displacement risk scores. For Atlantic puffin, available literature on displacement is scarce. The only available value was a displacement probability of 0.6 suggested for use in OWF assessments in the United Kingdom (NatureScot, 2023). This value was adjusted by expert judgement from a moderate score to a high avoidance/displacement score, taking into consideration that other auk species, namely common guillemot and razorbill, are relatively susceptible to displacement due to OWFs (Peschko et al., 2024, 2025). As a precautionary approach, maximum percentage abundance changes within offshore wind farms and effect distances reported for razorbill (-67%) and common guillemot (-97%) (Peschko et al., 2024, 2025) were used as proxy values for the Atlantic puffin. See section 4.1.5 for more detailed explanation on the displacement scores of northern gannet, common scoter, and common eider.

Arctic tern, little auk, Manx shearwater, and great cormorant were all classified with a medium displacement risk, with scores ranging from 0.48 to 0.66. Arctic tern scored at the upper boundary between moderate and high risk (0.66), mainly driven by its moderate habitat flexibility (Garthe and Hüppop, 2004). The other three species were categorised with moderate to high habitat flexibility and generally show weak to no avoidance of offshore wind farms and/or limited disturbance responses to ship and helicopter traffic (Deakin et al., 2022; Dierschke et al., 2016; Furness et al., 2013; Garthe & Hüppop, 2004).

Great cormorant presents a more complex case, as reported displacement probabilities vary considerably. While on the one hand, the species has been observed to show attraction to OWFs, using structures as additional roosting sites (Dierschke et al., 2016; Lindeboom et al., 2011), it has also been scored relatively high for sensitivity to disturbance from ship and helicopter traffic (Furness et al., 2013). This stressor may be partly captured by the displacement probability factor used here (see Heße and Melis, 2026 for a detailed description of this factor). Lamb et al. (2024) reported changes in abundance before and after OWF construction for great cormorant and European shag (*Phalacrocorax aristotelis*) combined, with the 95% confidence intervals ranging from a 75% reduction to a 129% increase. The displacement factor F_n7 does not

explicitly account for attraction to OWFs, but instead considers a 0 to 10% reduction in abundance as an indicator of displacement (Heße and Melis, 2026). Great cormorant therefore received the lowest score among the eleven species for this factor. Combined with its moderate habitat flexibility (Garthe and Hüppop, 2004), this resulted in an overall moderate displacement risk for great cormorant. Despite the low displacement probability score, the overall moderate displacement risk assigned to great cormorant is primarily driven by its moderate habitat flexibility, based on values derived from Garthe and Hüppop (2004). Given that this parameter is likely precautionary in nature and relies on relatively dated information, the resulting overall displacement score may represent a conservative estimate of displacement risk for great cormorant. Updated empirical data on habitat use and flexibility would therefore be valuable to refine this component and reduce uncertainty in future assessments.

4.1.4 Vulnerability

Yellow-billed loon, northern fulmar, Arctic tern, common eider, Manx shearwater, common scoter, and Atlantic puffin had the highest vulnerability scores (s_i), ranging from 0.83–1.00. These scores were primarily influenced by conservation status, fecundity, and adult survival rate.

Regarding conservation status, common scoter, common eider, and Arctic tern showed high vulnerability due to their 'unfavourable (bad)' conservation status in the Netherlands (*Staat van Instandhouding, SvI*; Sovon, 2022). Atlantic puffin, northern fulmar, and Manx shearwater were classified with an 'unfavourable (inadequate)' SvI, while no SvI was available for yellow-billed loon (Sovon, 2022). Instead, the European Red List status was used for yellow-billed loon, which is listed as 'Vulnerable' (BirdLife International, 2021).

The yellow-billed loon has, to date, been classified as an irregular winter visitor in Dutch waters. Consequently, no national conservation status (SvI) has been assigned in the Netherlands. However, a recent ship-based survey conducted in April–May 2025 indicates that the Dogger Bank serves as an important spring staging area for yellow-billed loons, potentially supporting up to 10% of the European-wintering population (approximately 130 individuals; Dierschke et al., 2026). The Dogger Bank is shared between the Exclusive Economic Zones (EEZs) of four countries, including the Netherlands. Although the precise wintering areas of yellow-billed loons staging at the Dogger Bank remain unknown (Dierschke et al., 2026), individuals using this area in spring may also be exposed to pressures in the Dutch EEZ during winter, and potential effects of OWFs cannot be ruled out. This warrants yellow-billed loon for consideration in Dutch assessments.

Low fecundity further contributed to the high vulnerability in Arctic tern, yellow-billed loon, northern fulmar, and Atlantic puffin (British Trust for Ornithology, n.d.-a, n.d.-d, n.d.-b, n.d.-c; U.S. Fish & Wildlife Service, 2014), all of which received the maximum score for this factor. In addition, adult survival rates are relatively high across all species considered here, with rates >0.85 (Anker-Nilssen et al., 2020; Fayet et al., 2025; Landsem et al., 2023; Lane et al., 2024; U.S. Fish and Wildlife Service, 2014), which further increased their vulnerability score.

4.1.5 Species-specific risk profiles

While the previous sections describe general patterns in collision vulnerability, displacement vulnerability, and general species sensitivity, a more detailed, species-specific interpretation helps to contextualise the final sensitivity scores for the three species for which the final scores were different than expected. In particular, the northern gannet was considered as a reference species due to its established role in KEC assessments for both collision and displacement effects (IJntema et al., 2025; Potiek et al., 2022; Soudijn et al., 2022, 2024). It was therefore used as reference species to evaluate the performance and consistency of the applied sensitivity scoring framework (see section 4.1.5.2). Common scoter and common eider are discussed in more detail as their final overall sensitivity scores require additional ecological interpretation and explanation, and the species also differ in their spatial distribution at sea and seasonal risk exposure compared to the other nine species assessed here (see section 4.1.5.1).

4.1.5.1 Common scoter and common eider

Common scoter has a high overall sensitivity score of 0.83, which is higher than expected given that the species has a pre-dominantly coastal distribution (Camphuysen and van Lieshout, 2024) and consequently is unlikely to have a high spatial overlap with Dutch OWFs. However, this high-risk score can be partially explained by its behaviour during migration, particularly by its nocturnal (offshore) movements. Common scoters migrate between their breeding and wintering ground (BirdLife International, 2018). During these migration periods, tracking data of 23 individuals suggests nocturnal flight activity (Camphuysen and Lieshout, 2025). This was further supported by expert judgement. Common scoters are further likely to spend moderate amounts of their flights at rotor swept zone height (expert judgement). In combination with nocturnal flight activity in other periods than only during migration (expert judgement), this resulted in higher scores for nocturnal flight activity and time spent at rotor swept zone height, which should be considered as precautionary. These scores consequently increased the overall collision risk score ($c_i = 0.57$) for common scoter.

The high displacement risk score for common scoter ($d_i = 0.92$) is primarily driven by the species' susceptibility to disturbance from ship traffic (Fließbach et al., 2019; Furness et al., 2013) and by displacement data indicating maximum abundance reductions of approximately 86%, derived from Horns Rev OWFs in Denmark (Scott-Hayward et al., 2025). These wind farms are located in relatively shallow waters, for example Horns Rev 1 at depths of 6 to 14 m (Vattenfall, n.d.), which may serve as suitable habitats for scoters based on the water depth (Skov et al., 2011). In contrast, Dutch OWFs are generally located in deeper areas further offshore (*Roadmap Offshore Wind Energy*, 2025), where displacement effects in the day-to-day life of common scoters are likely to be less relevant. However, spatial overlap between bird distributions and offshore wind farm footprints are not explicitly accounted for in this framework. However, common scoters may still encounter Dutch OWFs during their migration and could be displaced from their migration routes due to the presence of turbines or associated ship traffic. The extent to which common scoters use Dutch offshore wind farm areas remains unclear.

Common eider also received a high overall sensitivity score (0.82), driven primarily by high displacement risk and high species vulnerability. The species is generally found in coastal and shallow areas (Bustnes & Lønne, 1997), undertakes mainly coastal and diurnal local migration (Minot, 1980), and spends relatively little time flying (Garthe & Hüppop, 2004; Larsen & Guillemette, 2007). In combination, this resulted in a low collision risk score ($c_i = 0.25$). The high vulnerability score ($s_i = 1.00$) is driven by its 'unfavourable (bad)' Dutch conservation status, both as breeding and non-breeding bird (Sovon, 2022), and by its high adult survival rate (Coulson, 2010). The high displacement risk ($d_i = 0.82$) identified for common eider is largely explained by low habitat flexibility (Garthe and Hüppop, 2004). Similar to common scoter, the spatial distribution of the species at sea is not explicitly incorporated into the sensitivity scoring.

While both common eider and common scoter are unlikely to encounter Dutch offshore wind farms during their day-to-day activities, encounters during migration are possible, particularly for common scoter. Therefore, the risk scores for these species should be interpreted as precautionary and the species seen as primarily vulnerable when migrating. In this context, collision risk is particularly relevant for common scoter. Displacement effects in deep offshore areas in Dutch OWFs are likely to be limited for both species, as they predominantly occupy coastal habitats for most of the year.

4.1.5.2 Northern gannet

Northern gannet has been included in previous KEC assessments for both displacement and collision effects (IJntema et al., 2025; Potiek et al., 2022; Soudijn et al., 2022, 2024). Results from the most recent assessment round, KEC 5.0, indicated effects of OWFs on both processes (IJntema et al., 2025; Soudijn et al., 2024). Therefore, northern gannet was expected to rank within a medium to high-risk overall sensitivity to OWFs and therefore to be recommended for inclusion in the KEC list in this study. Based on the results presented here, seven species ranked higher than northern gannet in terms of overall sensitivity to OWFs. However, as northern gannet scored with a medium overall sensitivity to OWFs (0.65), a moderate collision vulnerability ($c_i = 0.52$) and a high displacement vulnerability ($d_i = 0.85$), it is recommended for inclusion on the KEC list as expected.

The fact that northern gannet is not classified within the high-risk overall sensitivity category can largely be explained by the vulnerability component of the scoring framework as well as by the collision risk score. The Dutch conservation status (SvI) currently relies on pre-highly pathogenic avian influenza (pre-HPAI) data from 2021 (Sovon, 2022) and therefore does not yet reflect the substantial population declines reported for northern gannet colonies in recent years (Lane et al., 2024; Matthiopoulos et al., 2025; Tremlett et al., 2024). As many of the northern gannets occurring in Dutch waters originate from colonies in the United Kingdom, these population-level impacts are likely to be directly relevant to the individuals assessed here. An increase in species vulnerability is therefore expected once an updated SvI becomes available. In a separate small-scale exercise, we explored the effect of alternative SvI classifications for northern gannet. Assuming a moderately 'unfavourable (inadequate)' SvI instead of the 'favourable' status from 2021 would increase the general vulnerability score (s_i) from currently 0.58 to 0.84 and raise the species' overall sensitivity score to from 0.68 to 0.74. Assuming the worst-case, an 'unfavourable (bad)' conservation status would increase the vulnerability score (s_i) to the maximum possible score of 1.00 and the species' final sensitivity score to 0.79. This indicates that the final sensitivity score of 0.65 presented here is likely an underestimation of the current species sensitivity towards OWFs and should be treated with caution. The calculations and resulting scores of this exercise are not presented in this report, but can be reproduced adapting the scores presented in Annex 1, Table 4 and the equation described in Heße and Melis (2026).

The medium collision risk score of northern gannets ($c_i = 0.52$) can be attributed to their relatively low flight activity during periods of highest abundance in Dutch waters (35.2% of daylight hours in winter in the North Sea; Garthe et al., 2012) and their limited nocturnal flight activity (Cook et al., 2023). In contrast, IJntema et al. (2025) use a fraction of time spent flying of 0.82 for their collision risk modelling, which stems from tracking data in the breeding season at Bass Rock. However, we applied the value of Garthe et al. (2012) for scoring as it is based on geolocation logger data of northern gannets wintering in the North Sea and which was therefore deemed more representative for northern gannets present in the Dutch waters than the values used in IJntema et al. (2025). The high displacement risk score for northern gannet ($d_i = 0.85$), was primarily driven by reported maximum abundance reductions of 81% for northern gannets in OWF areas in German waters between September and the end of October (Peschko et al., 2025).

Although northern gannet received a moderate collision risk score, its inclusion in collision assessments remains justified. The most recent KEC assessments identified effects of offshore wind farms on northern gannet (IJntema et al., 2025; Soudijn et al., 2024). The results from both collision risk and displacement modelling indicate that acceptable levels of impact (ALI) could be exceeded in some OWF scenarios (IJntema et al., 2025; Soudijn et al., 2024). Given that current sensitivity scores s_i are likely underestimated due to the use of pre-HPAI conservation status data, the additional population-level pressure from HPAI may further reduce species resilience and thereby increase the likelihood that thresholds like the ALI are exceeded. This supports the interpretation that a medium collision risk score does not preclude ecological relevance. Instead, it highlights that species with moderate risk scores may still experience measurable impacts and should therefore be retained in KEC assessments.

Taken together, these results indicate that the sensitivity scoring framework performs as expected. The classification of northern gannet as having moderate overall sensitivity is consistent with existing KEC assessment results, while the underlying scores can be clearly explained by the available data and assumptions applied.

4.2 Limitations

For several factors, limited or no empirical information was available, for example for F_{n5} 'Micro-avoidance'. In addition, the relative contributions of OWF-related air and vessel traffic and turbine-induced disturbance on bird abundance and displacement rates currently cannot be disentangled (Heße and Melis, 2026). As a result, observed reductions in abundance within OWFs cannot be clearly linked to specific disturbance mechanisms, highlighting the need for further research to better describe and quantify species-specific responses to OWF-related disturbances. Such research would improve the estimation of the displacement probability factor F_{n7} within this framework.

Data-limited species such as yellow-billed loon pose additional challenges to the sensitivity scoring framework. In these cases, expert knowledge was used to fill knowledge gaps, following recommendations of HeBe and Melis (2026). In addition, some factor scores were also based on values reported by Garthe and Hüppop (2004), as no more recent or alternative information was available. Many recent studies continue to rely on the values by Garthe and Hüppop (2004), indicating persistent data gaps and highlighting opportunities for further research.

Overall, the scoring framework reflects both the availability and quality of the underlying literature. It is therefore important to ensure that the most recent data are used wherever possible, and that expert judgement is applied to account for emerging evidence or expected changes that may not yet be formally published or assessed. These limitations should be taken into consideration when interpreting the final scores.

Expert judgement to address knowledge gaps in this assessment was based on a single expert rather than a formal expert elicitation process. Expert elicitation has been identified as a preferred approach for addressing data-limited species or factors, as highlighted during a workshop organised and presented by HeBe and Melis (2026), although it was also recognised as time-intensive. While expert elicitation generally remains desirable to address knowledge gaps, it requires several distinct steps from recruiting participants to the final aggregation of the results of the elicitation process itself (Hemming et al., 2018). The implementation of an expert elicitation may therefore pose a challenge in future scoring rounds. Where feasible, the involvement of multiple experts is recommended, particularly for data-limited species and factors. In the present assessment, uncertainties were addressed using a precautionary approach, and reliance on a single expert is considered justified in this context.

The scoring framework assesses overall collision and displacement risks for marine and coastal bird species and combines these with species vulnerability in Dutch waters. However, it does not explicitly account for the location or spatial extent of current and planned offshore wind farms or other OWF details. An exception is the rotor swept zone height, which was derived from Dutch offshore wind farm scenarios up to 2031 (HeBe and Melis; 2026). Other characteristics, such as turbine dimensions, turbine spacing, wind farm footprint, and water depth, are not included.

This framework focuses on general species sensitivity towards OWFs and does not incorporate spatial species distributions or other spatial components, nor does it distinguish between species behaviour during migration and behaviour at sea. As such, it identifies species that are potentially vulnerable to collision and displacement without directly accounting for their spatial overlap with OWFs. Nevertheless, the sensitivity scoring framework by HeBe and Melis (2026) includes proxies for exposure, such as the proportion of migration time spent offshore (factor $F_{r,6}$), which reflects the likelihood of a species encountering an OWF and being potentially affected. Additionally, it implicitly accounts for the duration of a species being present within the study area by using the national conservation status or factor $F_{r,12}$ ('Annual occurrence in the study area') where this status is unavailable. A direct comparison between final scores should therefore always be done with the ecological context and the data applied for scoring in mind. Consequently, direct comparisons between species primarily at risk during migration and those exposed throughout the year also require careful consideration.

While species' at-sea distributions and their spatial overlap with OWFs are not explicitly included in this scoring approach, they are considered within the KEC assessment framework. This assessment uses bimonthly bird distribution maps which are overlaid with spatial OWF scenarios to estimate the number of birds that suffer from either displacement from OWF areas or collisions with wind turbines. The outcome of this spatial analysis is then used in population modelling to assess the impact on population abundance (IJntema et al., 2025; Soudijn et al., 2024). While including an explicit spatial overlap analysis could be considered as an intermediate step following sensitivity scoring, this would lead to considerable overlap with the analysis performed within the KEC assessment. The KEC provides a quantitative evaluation of spatial exposure and population-level impacts. Further, with the implication of an intermediate step between sensitivity scoring and KEC assessments, additional thresholds would have to be identified for the level of spatial overlap that would justify an inclusion in the KEC. This would make the process of species selection and the following assessment in the KEC more complex and less transparent. Finally, the level of spatial overlap would depend on specific wind farm scenarios tested, while the sensitivity scoring framework is intended to provide a general indication of species vulnerability.

Data availability remains a key limitation for the scoring framework, and also for any KEC assessments potentially following the sensitivity scoring, as described in Heße and Melis (2026). For inclusion in KEC assessments, reliable species distribution maps are required, typically based on aerial survey data (Van Donk et al., 2024). Even when a species is identified as having moderate or high sensitivity towards OWFs, insufficient data may prevent the generation of robust distribution maps and in turn the inclusion in a KEC assessment. In such cases, additional survey efforts may be required before population-level effects of offshore wind farms can be assessed within the KEC framework.

5 Recommendations and conclusion

The factor scores presented in this study are based on the best available literature to date, but data gaps and limitations were identified. As new empirical evidence becomes available, scores for collision risk, displacement risk, and general species vulnerability may change. Regular updates of the underlying knowledge base are therefore recommended to ensure that decisions on species inclusion in KEC assessments are informed by the most recent state of knowledge.

Overall, the sensitivity scoring framework performed as expected and provides a general indication of species sensitivity to OWFs. Species-specific spatio-temporal distribution are not explicitly incorporated in the framework and can be considered in subsequent assessment steps. The resulting scores are consistent with the input data and underlying assumptions, for example the inclusion of species' vulnerability during migration in species such as common scoter. Comparisons between final species sensitivity scores should therefore consider the broader ecological context, such as species' seasonal occurrence in the study area and species-specific behaviour at sea or during migration. Furthermore, the values used as input for the scoring are following the precautionary principle, and resulting differences between species should therefore be interpreted with appropriate caution. Overall, the framework fulfils its purpose providing a general indication of species sensitivity to OWFs and behaves as expected to the variation of input values. Additional analyses of variation in temporal and spatial exposure and consequent population-level effects are addressed within the KEC assessment framework and therefore not included in the species scoring framework.

All of the eleven species assessed were recommended to consider for inclusion in KEC assessments based on their moderate to high overall sensitivity to offshore windfarms. Only the Arctic tern received a high collision risk score, while eight additional other species scored with moderate collision risk, and three species had a low collision risk. Seven species were identified as high risk for displacement. The remaining four species received a moderate risk for displacement. While medium to high scoring species should be considered for inclusion in KEC assessments, the high-risk species were recommended to be prioritised.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system, certified since February 27, 2001 by DNV. ISO 9001 is an international standard for quality management, focused on the continuous improvement of processes and ensuring customer satisfaction.

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Justification

Report: C040/26

Project Number: 4315100271

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved: ir. S.C.V. Geelhoed
Researcher

Signature:

Signed by:

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Date: 23 April 2026

Approved: C.J. Wiebinga, PhD
Business Manager Projects

Signature:

Signed by:

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Date: 23 April 2026

Annex 1 Individual sensitivity scores per species

Table 4 Overview of factor scores (F_{n1-13}) and their sources for the seven species assessed in this study. Individual factors were originally scored on a scale from 1 to 5 (shown here) and subsequently scaled to values between 0.2 and 1 following the approach described in Certain et al. (2015). Detailed factor descriptions are provided in Heße and Melis (2026). Where no information was available for a given species, values are indicated with a question mark. Scores adjusted or derived through expert judgement are shown in bold, with the literature-based score presented before the slash. A complete list of sources used to derive the scores is provided in Annex 2. Scores used for the four additional species (Table 1) included in this assessment were reported in Heße and Melis (2026) and are not included here. The 'Annual occurrence' factor (F_{n12}) was only included in the scoring calculations if no F_{n10} was available as the Dutch conservation status already accounts for species' annual occurrence in Dutch waters (see Heße and Melis, 2026).

Factor	Description	Common scoter	Common eider	Great cormorant	Northern gannet	Atlantic puffin	Northern fulmar	Red-throated diver	Sources
F_{n1}	Percent time spent flying	2	2 / 1	2	2-5 / 2	1	2	1-2 / 1	23, 27, 28, 29, 33, 50, 68, 69
F_{n2}	Flight altitude within RSZ	1 / 3	1	3	3-5 / 3	1	1	3	15, 16, 27, 28, 34, 37, 41, 46, 58, 68
F_{n3}	Flight manoeuvrability	3	5	3	3	3	3	5	28, 51
F_{n4}	Nocturnal flight activity	3 / 5	3	1	1	1	3-5 / 5	1	13, 14, 16, 21, 26, 27, 28, 35, 37, 46
F_{n5}	Micro-avoidance of turbines	? / 3	? / 5	? / 5	? / 5	? / 5	? / 5	? / 5	55
F_{n6}	Offshore migration percentage	? / 5	2	1	3-5 / 5	? / 5	5	? / 4	11, 13, 14, 19, 36
F_{n7}	Displacement probability	4	3	1	4	3 / 4	5	5	20, 24, 27, 28, 30, 31, 38, 41, 45, 47, 48, 52, 53, 56, 57
F_{n8}	Habitat flexibility	4	4	3	1	3	1	4	28
F_{n9}	European Red List status	1	5	1	1	5	3	1	3, 4, 5, 6, 7, 8
F_{n10}	Dutch conservation status (<i>Staat van Instandhouding</i>)	5	5	1	1	3	3	1	66
F_{n11}	Adult survival rate	4	4	4	5	5	5	4	2, 17, 23, 25, 39, 40, 42, 54
F_{n12}	Annual occurrence in study region	5	5	5	5	3 / 4	5 / 4	4	59, 60, 61, 62, 63, 64, 65
F_{n13}	Fecundity	1	3 / 1	3	5	5	5	5	1, 10, 12, 39, 44

Annex 2 References for factor scores

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Annex 3 Species sensitivity score rankings

Table 5 Ranking of final collision risk scores (c_i) per species. Displacement vulnerability (d_i), species vulnerability (s_i), and the final score representing species overall sensitivity towards offshore wind farms are shown for reference. Collision values classified as high risk (>0.66) are shown in bold, medium risk ($>0.33-0.66$) in regular text, and low risk (≤ 0.33) in italics. Collision risk categories are divided by horizontal lines. All values presented are rounded to two decimals. Species are ordered from highest to lowest collision risk score. For rankings of displacement and species vulnerability, see Table 6 and Table 7, respectively. Ranking by overall sensitivity score is provided in Table 2.

Species	Scientific name	Dutch name	c_i	d_i	s_i	Overall sensitivity score
Arctic tern	<i>Sterna paradisaea</i>	Noordse stern	0.76	0.66	1.00	0.81
Common scoter	<i>Melanitta nigra</i>	Zwarte zee eend	0.57	0.92	1.00	0.83
Northern gannet	<i>Morus bassanus</i>	Jan-van-gent	0.52	0.85	0.58	0.65
Great cormorant	<i>Phalacrocorax carbo</i>	Aalscholver	0.42	0.48	0.51	0.47
Yellow-billed loon	<i>Gavia adamsii</i>	Geelsnavelduiker	0.42	1.00	0.83	0.75
Red-throated diver	<i>Gavia stellata</i>	Roodkeelduiker	0.40	1.00	0.56	0.66
Northern fulmar	<i>Fulmarus glacialis</i>	Noordse stormvogel	0.40	1.00	0.84	0.75
Manx shearwater	<i>Puffinus puffinus</i>	Noordse pijlstoormvogel	0.38	0.52	0.84	0.58
Little auk	<i>Alle alle</i>	Kleine alk	<i>0.27</i>	0.60	0.54	0.47
Common eider	<i>Somateria mollissima</i>	Eider	<i>0.25</i>	0.82	1.00	0.69
Atlantic puffin	<i>Fratercula arctica</i>	Papagaaiduiker	<i>0.23</i>	0.90	0.84	0.66

Table 6 Ranking of final displacement risk scores (d_i) per species. Collision vulnerability (c_i), species vulnerability (s_i), and the final score representing species overall sensitivity towards offshore wind farms are shown for reference. Displacement values classified as high risk (>0.66) are shown in bold, medium risk ($>0.33-0.66$) in regular text, and low risk (≤ 0.33) in italics. Displacement risk categories are divided by horizontal lines. All values presented are rounded to two decimals. Species are ordered from highest to lowest collision risk score. For rankings of displacement and species vulnerability, see Table 5 and Table 7, respectively. Ranking by overall sensitivity score is provided in Table 2.

Species	Scientific name	Dutch name	c_i	d_i	s_i	Overall sensitivity score
Yellow-billed loon	<i>Gavia adamsii</i>	Geelsnavelduiker	0.42	1.00	0.83	0.75
Red-throated diver	<i>Gavia stellata</i>	Roodkeelduiker	0.40	1.00	0.56	0.66
Northern fulmar	<i>Fulmarus glacialis</i>	Noordse stormvogel	0.40	1.00	0.84	0.75
Common scoter	<i>Melanitta nigra</i>	Zwarte zee eend	0.57	0.92	1.00	0.83
Atlantic puffin	<i>Fratercula arctica</i>	Papagaaiduiker	<i>0.23</i>	0.90	0.84	0.66
Northern gannet	<i>Morus bassanus</i>	Jan-van-gent	0.52	0.85	0.58	0.65
Common eider	<i>Somateria mollissima</i>	Eider	<i>0.25</i>	0.82	1.00	0.69
Arctic tern	<i>Sterna paradisaea</i>	Noordse stern	0.76	0.66	1.00	0.81
Little auk	<i>Alle alle</i>	Kleine alk	<i>0.27</i>	0.60	0.54	0.47
Manx shearwater	<i>Puffinus puffinus</i>	Noordse pijlstoormvogel	0.38	0.52	0.84	0.58
Great cormorant	<i>Phalacrocorax carbo</i>	Aalscholver	0.42	0.48	0.51	0.47

Table 7 Final species vulnerability scores (s_i) per species. Collision vulnerability (c_i), displacement vulnerability (d_i), and the final score representing species overall sensitivity towards offshore wind farms are shown for reference. Values classified as high risk (>0.66) are shown in bold, medium risk ($>0.33-0.66$) in regular text, and low risk (≤ 0.33) in italics. Vulnerability categories are divided by horizontal lines. All values presented are rounded to two decimals. Species are ordered from highest to lowest collision risk score. For rankings of displacement and species vulnerability, see Table 5 and Table 6, respectively. Ranking by overall sensitivity score is provided in Table 2.

Species	Scientific name	Dutch name	c_i	d_i	s_i	Overall sensitivity score
Common scoter	<i>Melanitta nigra</i>	Zwarte zee eend	0.57	0.92	1.00	0.83
Common eider	<i>Somateria mollissima</i>	Eider	0.25	0.82	1.00	0.69
Arctic tern	<i>Sterna paradisaea</i>	Noordse stern	0.76	0.66	1.00	0.81
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Yellow-billed loon	<i>Gavia adamsii</i>	Geelsnavelduiker	0.42	1.00	0.83	0.75
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Red-throated diver	<i>Gavia stellata</i>	Roodkeelduiker	0.40	1.00	0.56	0.66
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Great cormorant	<i>Phalacrocorax carbo</i>	Aalscholver	0.42	0.48	0.51	0.47

Annex 4 Literature review search terms

Table 8 Overview of the search terms and keywords used for the factors (F_n1–13) in the literature search conducted in this study. The search terms presented here are listed per factor group (collision, displacement, vulnerability), and not necessarily per factor.

Factors	Search terms/Keywords
<p>F_n1–F_n6 (Collision)</p>	<p>Offshore wind (farm), wind farm</p> <p>Migration, migratory behaviour, offshore migration</p> <p>Flight altitude, flight height (in rotor swept zone)</p> <p>GPS tag, GPS tagging, GPS logger</p> <p>Collision, collision risk</p> <p>Micro-avoidance (of turbines)</p> <p>Time in flight, time spent flying, activity proportion</p> <p>Wingload, (flight) manoeuvrability</p> <p>Nocturnal (flight) activity</p>
<p>F_n7–F_n8 (Displacement)</p>	<p>Displacement, disturbance, avoidance (behaviour), density reduction</p> <p>Effect radius/distance</p> <p>Shipping (effect), influence ship, influence shipping</p> <p>Sensitivity, vulnerability</p> <p>Habitat requirements, (habitat) flexibility, (habitat) specialisation</p>
<p>F_n9–F_n13 (Vulnerability)</p>	<p>Survival (rate), adult survival (rate)</p> <p>Breeding biology, breeding success</p> <p>Fecundity, egg production</p> <p>Hatching (success), fledging (success)</p> <p>European Red List, Staat van Instandhouding, Dutch conservation status</p> <p>(Spatial) distribution, annual occurrence, (spring/autumn/fall) migration, breeding season, non-breeding season</p>

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