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Scoping report: estimating bird sensitivity to Trollvind offshore wind farm

Victoria Marja Sofia Ollus, Manuel Ballesteros, Arnaud Tarroux, Lila Buckingham, Signe Christensen-Dalsgaard, Børge Moe, Tone Kristin Reiertsen, Geir Helge Rødli Systad, Per Fauchald

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Per Fauchald

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CLIENTS/SUBSCRIBER CONTACT PERSON(S)
Arne Myhrvold, Tonje Waterloo Rogstad

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Black-legged kittiwake, photo: Eirik Grønningsæter ©

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CONTACT DETAILS

NINA head office
P.O.Box 5685 Torgarden
NO-7485 Trondheim
Norway
P: +47 73 80 14 00

NINA Oslo
Sognsveien 68
0855 Oslo
Norway
P: +47 73 80 14 00

NINA Tromsø
P.O.Box 6606 Langnes
NO-9296 Tromsø
Norway
P: +47 77 75 04 00

NINA Lillehammer
Vormstuguvegen 40
NO-2624 Lillehammer
Norway
P: +47 73 80 14 00

NINA Bergen:
Thormøhlens gate 55
NO-5006 Bergen.
Norway
P: +47 73 80 14 00

www.nina.no

Abstract

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Equinor is exploring possibilities for constructing a floating offshore wind farm, Trollvind, in the northern North Sea, approximately 65 km off the Norwegian coast. This scoping report investigates which bird species use the area and assesses their sensitivity to wind farms. Indicators of bird sensitivity are compiled based on species' habitat preference models and indices for sensitivity to wind farms. The sensitivity indices used in the present report do not quantify the vulnerability of bird populations to the proposed wind farm. However, they combine the best available data and knowledge and were used to assess the relative sensitivity of birds in the Trollvind area compared to the Norwegian Exclusive Economic Zone (EEZ) at large, as well as to identify the most sensitive species and seasons.

The construction, operation, maintenance, and decommissioning of marine wind farms have the potential to negatively affect birds using the area. The most obvious risks are direct mortality from birds colliding with turbine blades or other parts of the turbines, displacement of birds from the wind farm and neighbouring areas, and habitat alteration. Species-specific traits determine whether collision or displacement is the preponderant risk for a species.

The study area includes the planned wind farm site, and a buffer zone of 10 km. Species distribution was modelled within the EEZ for 58 species of seabirds and other waterbirds in four seasons (spring, summer, autumn, and winter), based on observational and tracking data. These species distribution models were used to model species' habitat preference in the EEZ. Species-specific sensitivity indices were calculated based on factors known to affect individual birds' and populations' general sensitivity (e.g., conservation status and adult survival) and sensitivity specifically to wind farms (e.g., proportion of time spent flying and response to wind farms). Habitat preference models were then combined with species-specific sensitivity indices to yield models of species' sensitivity to offshore wind farms. Values were extracted for our study area, and species sensitivity, seasonal bird sensitivity, and total bird sensitivity were estimated relative to sensitivity in the EEZ.

The results indicate below-medium to medium total sensitivity of birds in the study area. The study area reflects the overall pattern in bird sensitivity seen for the whole EEZ, with sensitivity decreasing with increasing distance to the coast. Highest seasonal sensitivity was found in summer, with the model showing above-medium values in the parts of the study area closest to the Norwegian coast. Lowest sensitivity was found in winter, when below-medium sensitivity was found in the whole study area. Several gull species (*Larus spp.*), terns (*Sterna spp*.), European storm petrel (*Hydrobates pelagicus*), great skua (*Stercorarius skua*), and black-legged kittiwake (*Rissa tridactyla*) are among the species most sensitive to collision in the study area. Among the species in highest risk of displacement, and consequently habitat loss, we find divers (*Gavia spp*.), brant goose (*Branta bernicla*), and common guillemot (*Uria aalge*). The northern fulmar (*Fulmarus glacialis*) and northern gannet (*Morus bassanus*) are also among the most sensitive species in the area, and though they may be displaced by wind farms, their risk of collision predominates.

We conclude that the sensitivity of seabirds and other waterbirds in the Trollvind study area ranges from below-medium to medium compared to the rest of the EEZ. Birds are most sensitive in summer and in the eastern and north-eastern parts of the study area. The number of species using the area is also highest in summer. The most sensitive species in the Trollvind area vary between seasons due to seasonal migration and changes in habitat use. Sensitive species

include both locally breeding species and species that breed elsewhere and use the area for migration or as a non-breeding habitat.

Victoria Marja Sofia Ollus, Norwegian Institute for Nature Research, The Fram Centre, P.O. Box 6606 Langnes, NO-9296 Tromsø, Norway, victoria.ollus@nina.no

Manuel Ballesteros, Norwegian Institute for Nature Research, The Fram Centre, P.O. Box 6606 Langnes, NO-9296 Tromsø, Norway, manuel.ballesteros@nina.no

Arnaud Tarroux, Norwegian Institute for Nature Research, The Fram Centre, P.O. Box 6606 Langnes, NO-9296 Tromsø, Norway, arnaud.tarroux@nina.no

Lila Buckingham, Norwegian Institute for Nature Research, P.O. Box 5685 Torgarden, NO-7485 Trondheim, Norway, lila.buckingham@nina.no

Signe Christensen-Dalsgaard, Norwegian Institute for Nature Research, P.O. Box 5685 Torgarden, NO-7485 Trondheim, Norway, signe.dalsgaard@nina.no

Børge Moe, Norwegian Institute for Nature Research, P.O. Box 5685 Torgarden, NO-7485 Trondheim, Norway, borge.moe@nina.no

Tone Kristin Reiertsen, Norwegian Institute for Nature Research, The Fram Centre, P.O. Box 6606 Langnes, NO-9296 Tromsø, Norway, tone.reiertsen@nina.no

Geir Helge Rødli Systad, Norwegian Institute for Nature Research, Thormøhlens gate 55, 5006 NO-Bergen, Norway, geir.systad@nina.no

Per Fauchald, Norwegian Institute for Nature Research, The Fram Centre, P.O. Box 6606 Langnes, NO-9296 Tromsø, Norway, per.fauchald@nina.no

Sammendrag

Ollus, V. M. S., Ballesteros, M., Tarroux, A., Buckingham, L., Christensen-Dalsgaard, S., Moe, B., Reiertsen, T. K., Systad, G. H. R. & Fauchald, P. 2023. Fugl og sårbarhet for havvindanlegg - en scoping rapport for Trollvind havvindpark. NINA Rapport 2286. Norsk institutt for naturforskning.

Equinor utforsker mulighetene for å bygge en flytende havvindpark, Trollvind, i den nordlige Nordsjøen, omtrent 65 km utenfor norskekysten. Denne scoping-rapporten undersøker hvilke fuglearter som bruker området og vurderer deres sensitivitet for vindparker. Indikatorer for sensitivitet er satt sammen av empiriske modeller av artenes habitatpreferanse og indekser for sensitivitet for vindparker. Sensitivitetsindeksene kvantifiserer ikke fuglebestandenes sårbarhet for den foreslåtte vindparken, men de kombinerer data og kunnskap for å vurdere fuglenes relative sensitivitet i Trollvind-området sammenlignet med resten av norsk økonomisk sone. I tillegg blir indeksene brukt til å identifisere de mest følsomme artene og årstidene.

Bygging, drift, vedlikehold og avvikling av marine vindparker har potensiale til å påvirke fugler som bruker området negativt. De mest åpenbare risikoene er direkte dødelighet som følge av kollisjon med turbinblader eller andre deler av turbinene, fortrengning av fugler fra områdene i og rundt vindparken og endringer i fuglenes leveområde. Hvilken faktor som har størst betydning, kollisjon eller fortrengning, er bestemt av artsspesifikke egenskaper.

Studieområdet omfatter den planlagte vindparken og en buffersone på 10 km. Utbredelse ble predikert i norsk økonomisk sone for 58 arter av sjøfugl og andre vannfugl i fire årstider (vår, sommer, høst og vinter). Modeller for utbredelse var basert på observasjons- og sporingsdata, og ble brukt til å predikere artenes habitatpreferanse i norsk økonomisk sone. Artsspesifikke sensitivitetsindekser ble satt sammen av faktorer som er kjent for å påvirke generell sensitivitet (f.eks. rødlistestatus og voksenoverlevelse), samt spesifikk sensitivitet for vindparker (f.eks. andel tid brukt på flyging og reaksjon på vindparker). Modellert habitatpreferanse ble kombinert med artsspesifikke sensitivitetsindekser for å gi arealbaserte indekser for sensitivitet for havvindparker. Data ble hentet ut fra studieområdet, og total sensitivitet, sensitivitet i ulike årstider, og artsspesifikk sensitivitet ble beregnet relativt til sensitivitet i norsk økonomisk sone.

Resultatene indikerer under middels til middels total sensitivitet for fugler i studieområdet sammenlignet med norsk økonomisk sone. Studieområdet gjenspeiler det overordnede mønsteret i fuglesensitivitet sett for hele norsk økonomisk sone, og avtar med avstanden fra kysten. Høyest sensitivitet ble funnet om sommeren, hvor modellen viser over middels verdier i de delene av studieområdet som ligger nærmest norskekysten. Lavest sensitivitet ble funnet om vinteren med under middels sensitivitet i hele studieområdet. Flere måkearter (*Larus* spp.), terner (*Sterna* spp.), havsvale (*Hydrobates pelagicus*), storjo (*Stercorarius skua*) og krykkje (*Rissa tridactyla*) er blant de artene som er mest sensitive for kollisjon i studieområde. Blant artene med høyest risiko for fortrengning, og følgelig tap av habitat, finner vi dykkere (*Gavia* spp.), ringgås (*Branta bernicla*) og lomvi (*Uria aalge*). Havhest (*Fulmarus glacialis*) og havsule (*Morus bassanus*) er også blant de mest følsomme artene i området, og selv om de også kan bli fortrengt av vindparker, er risikoen for kollisjon dominerende.

Vi konkluderer at sensitiviteten for sjøfugl og andre vannfugl i Trollvind området varierer fra under middels til middels sammenlignet med resten av norsk økonomisk sone. Høyest sensitivitet finner vi om sommeren og i de østlige og nordøstlige delene av studieområdet. Antall arter som bruker området er også høyest om sommeren. De mest sensitive artene i Trollvindområdet varierer mellom årstidene på grunn av migrasjon og endringer i habitatbruk. Sensitive arter omfatter både lokalt hekkende arter og arter som hekker andre steder og som migrerer gjennom området eller bruker det til overvintring.

Victoria Marja Sofia Ollus, Norsk institutt for naturforskning, Framsenteret, Postboks 6606 Langnes, 9296 Tromsø, victoria.ollus@nina.no

Manuel Ballesteros, Norsk institutt for naturforskning, Framsenteret, Postboks 6606 Langnes, 9296 Tromsø, manuel.ballesteros@nina.no

Arnaud Tarroux, Norsk institutt for naturforskning, Framsenteret, Postboks 6606 Langnes, 9296 Tromsø, arnaud.tarroux@nina.no

Lila Buckingham, Norsk institutt for naturforskning, Postboks 5685 Torgarden, 7485 Trondheim, lila.buckingham@nina.no

Signe Christensen-Dalsgaard, Norsk institutt for naturforskning, Postboks 5685 Torgarden, 7485 Trondheim, signe.dalsgaard@nina.no

Børge Moe, Norsk institutt for naturforskning, Postboks 5685 Torgarden, 7485 Trondheim, borge.moe@nina.no

Tone Kristin Reiertsen, Norsk institutt for naturforskning, Framsenteret, Postboks 6606 Langnes, 9296 Tromsø, tone.reiertsen@nina.no

Geir Helge Rødli Systad, Norsk institutt for naturforskning, Thormøhlens gate 55, 5006 Bergen, geir.systad@nina.no

Per Fauchald, Norsk institutt for naturforskning, Framsenteret, Postboks 6606 Langnes, 9296 Tromsø, per.fauchald@nina.no

Contents

Foreword

This scoping report is written on behalf of Equinor, as part of the exploration of possibilities for constructing a floating offshore wind farm in the northern North Sea. We scope which bird species use the area, at what time of year, and assess each species' sensitivity to offshore wind farms throughout the year. We also compile indicators of species-specific and general bird sensitivity.

We thank Artsobservasjoner, European Seabirds At Sea (ESAS), and SEAPOP for providing data on bird observations and population data from Norwegian seabird colonies, as well as SEATRACK for providing tracking data.

The contact persons at Equinor were Arne Myhrvold and Tonje Waterloo Rogstad. We thank you for good cooperation. Eirik Grønningsæter photographed the young black-legged kittiwake (*Rissa tridactyla*) in the cover picture.

Tromsø January 2023

Victoria Ollus, Manuel Ballesteros, Arnaud Tarroux, Lila Buckingham, Signe Christensen-Dalsgaard, Børge Moe, Tone Reiertsen, Geir Systad & Per Fauchald

1 Introduction

1.1 Background

Equinor is exploring possibilities for constructing a floating offshore wind farm in the northern North Sea. The electricity would be delivered to the Statnett-grid in Kollsnes and serve as an additional supply to the electrical grid in the regions around Bergen. In connection with the planning of a wind farm project, an impact assessment must be conducted, describing possible effects on environment and society as well as ways to avoid or minimize negative effects and increase positive effects of the project. The Norwegian Institute for Nature Research (NINA) has been asked to provide information on bird distribution and sensitivity in the Trollvind offshore wind farm area. This work is a scoping report assessing bird area use and sensitivity to offshore wind farms in the Trollvind area. It is based on the latest estimates of the distribution and abundance of seabirds and other waterbirds in the Norwegian Exclusive Economic Zone in different seasons, species-specific sensitivity to offshore wind farms, and the available knowledge on conflicts between birds and marine wind installations.

1.2 Seabird ecology and distribution

True seabirds include northern fulmar (*Fulmarus glacialis*), northern gannet (*Morus bassanus*), great cormorant (*Phalacrocorax carbo*), European shag (*Phalacrocorax aristotelis*), all auks, many gulls and terns, and some sea ducks. A trait shared by all true seabirds is that they find most if not all their food in the marine environment and spend most of their time at sea. This makes them tightly connected with the marine ecosystem and an important part of the marine food web. Other waterbirds, such as divers, grebes, many sea ducks and some gulls, might be reliant on the marine environment for part of the year. The fact that the sea plays such an important role in the lives of these birds implies that they might be affected by the construction and operation of offshore wind farms. The ways birds respond or fail to respond to the presence of a wind farm and associated anthropogenic activities will determine the nature of impacts (Garthe & Hüppop 2004), while the degree to which birds are affected will depend on their distribution in the area influenced by the installations. Hence, the placement of a wind farm in relation to breeding colonies, foraging areas, migration routes and non-breeding areas is of key importance.

In addition to being dependent on the sea for resources, other typical traits of seabirds are their relative longevity, late maturity (typically at the age of 4-10 years), low adult mortality rates, and low reproductive capacity (most seabird species lay only 1-3 eggs per year; Nelson 1980). These traits are an adaptation to highly variable and sometimes unpredictable environmental conditions where variations in prey availability dictate breeding success. This life-history strategy makes seabird populations less sensitive to years of low chick recruitment by ensuring the survival of adults to the next breeding season. However, these traits mean that populations are more vulnerable to factors that increase adult mortality. The recovery of a population that has lost a major part of its mature individuals is therefore slow and uncertain.

Seabirds are highly mobile and therefore their distribution is typically dynamic in both space and time, often reflecting the distribution of their prey species. The distribution of many species undergoes strong seasonal variation. In the breeding season, generally between May and July in the North Atlantic, breeding birds travel between their colony and foraging areas at sea, though the extent of foraging trips varies between species. Outside the breeding season, seabirds are free to move and are found further at sea with a more dispersed distribution.

Seabird species can be divided into ecological groups based on their habitat use and feeding strategies; for example, there are coastal and pelagic seabirds, and such groupings can be further divided into diving and surface-feeding birds (Anker-Nilssen 1994, Christensen-Dalsgaard et al. 2008). Consequently, seabird distribution is largely driven by proximity to the coast and to breeding sites. Thus, the distance at which a wind farm is located with respect to the coast and breeding colonies impacts which species are likely to be present and affected.

The planned location of the Trollvind wind farm is 65 km west of Kollsnes in Øygarden, in the northern North Sea, around 90 km south-east of the offshore wind farm Hywind Tampen. The Trollvind development area is used by many bird species, but the species present and their use of the area vary with season. In summer it is occupied mainly by breeding pelagic seabirds on their foraging trips from colonies on shore and by non-breeding seabirds such as juveniles. In autumn and spring, the area is used by overwintering and migrating birds, while in winter overwintering birds will be occupying the area with likely highly dynamic distribution because of variable prey distribution and availability. In addition to Norwegian populations, seabirds from other populations around the North Sea might be present in the area.

1.2.1 Threatened species

Many of the Norwegian seabird populations are declining, and several species are found on the Norwegian red list of threatened species together with other waterbirds that rely on the marine environment for part of the year (Artsdatabanken 2021, Table 1).

Table 1. Red-listed birds using the Trollvind area (Artsdatabanken 2021).

Critically endangered (CR)	Endangered (EN)	Vulnerable (VU)	Near threatened (NT)
Black-headed gull (*Larus ridibundus*)	Atlantic puffin (*Fratercula arctica*)	Arctic skua (*Stercorarius parasiticus*)	Black guillemot (*Cephus grylle*)
Brünnich's guillemot (*Uria lomvia*)	Black-legged kittiwake (*Rissa tridactyla*)	Common eider (*Somateria mollissima*)	Brant goose (*Branta bernicla*)
Common guillemot (*Uria aalge*)	Common tern (*Sterna hirundo*)	Common gull (*Larus canus*)	Gadwall (*Mareca strepera*)
	Garganey (*Spatula querquedula*)	Common scoter (*Melanitta nigra*)	Great cormorant (*Phalacrocorax carbo*)
	Little grebe (*Tachybaptus ruficollis*)	Glaucous gull (*Larus hyperboreus*)	Long-tailed duck (*Clangula hyemalis*)
	Northern fulmar (*Fulmarus glacialis*)	Herring gull (*Larus argentatus*)	Red-necked phalarope (*Phalaropus lobatus*)
		Horned grebe (*Podiceps auritus*)	
		Northern shoveler (*Spatula clypeata*)	
		Razorbill (*Alca torda*)	
		Steller's eider (*Polysticta stelleri*)	
		Velvet scoter (*Melanitta fusca*)	
		Yellow-billed diver (*Gavia adamsii*)	

1.3 Habitat use and important areas

Seabirds and other waterbirds that associate with the marine environment (henceforth referred to as birds) typically depend on different areas for foraging, nesting, resting, and moulting, and species differ largely in their feeding strategies and space use. The function of an area varies with both species and season, and therefore the vulnerability of different species in a specific area will depend on the time of year (Busch & Garthe 2016, 2018, Peschko et al. 2020). The size and location of a wind farm are hence essential factors in determining the extent of its impacts on birds, which species are affected, and in which seasons.

1.3.1 Foraging areas

In the marine environment, areas of high biological productivity and elevated prey abundance, are generally found in areas where different water masses meet, i.e., at oceanographic fronts, as well as in upwelling areas such as continental slopes, where changes in bathymetry cause nutrient-rich deep water to rise towards the surface. A frontal area is characterized by strong horizontal gradients in temperature, salinity, and density. Here, the mixing of water brings nutrients to the surface, creating good conditions for primary producers. This in turn results in increased secondary and tertiary productivity, so that top predators such as many birds also find increased prey abundance along the front (e.g., Bost et al. 2009). Two main water masses are found in the northeast North Sea, relatively warm Atlantic water, and colder and fresher coastal water from the Norwegian coastal current. Where these two water masses meet, a frontal system is created that follows the entire Norwegian coast.

1.3.2 Nesting areas

In summer, most birds are bound to their nesting sites on the coast, as chicks need to be fed regularly and adequately to maximize their chances of survival. Due to their need to return to feed their chicks regularly, the foraging range of breeding birds is restricted (Orians & Pearson 1979). Simultaneously their own energetic demand is elevated because of the activity level required for the provisioning of young (Markones et al. 2010). The foraging range varies between species with differences in their energetic cost of flight and the age of the chicks, but also with prey availability. When prey availability is poor close to colonies, adult foraging trip length increases (both spatially and temporally), resulting in greater energy expenditure in adults and reduced feeding of chicks. This will in turn lead to lower body weight in chicks, higher chick mortality and lower breeding success (Houston et al. 1996, Davoren & Montevecchi 2003). From the perspective of nesting birds, it is therefore important that high quality foraging areas are found within a relatively short distance from colonies. Pelagic species can fly hundreds (Deakin et al. 2022) and even thousands (Jouventin & Weimerskirch 1990) of kilometres in search of prey, while coastal birds are more vulnerable to poor prey availability close to colonies.

1.3.3 Migration routes

Many birds migrate between nesting areas in summer and overwintering areas in winter, with large differences in migration distance between species and even individuals. Migration journeys range from a couple of tens of kilometres from the coast out to pelagic areas, to migration routes extending from pole to pole in the case of some arctic terns (*Sterna paradisaea*; Egevang et al. 2010). Other birds, such as many European shags (*Phalacrocorax aristotelis*), do not leave their breeding grounds in winter. Most migrating birds undertake their journey flying, but some swim. The male parent of common and Brünnich's guillemots (*Uria aalge* and *U. lomvia*, respectively) and razorbills (*Alca torda*) follow their flightless chick to sea through swim-migration in the post-breeding season and all adults undertake a flightless period during the post-breeding moult.

1.3.4 Non-breeding distribution

While bird distribution in the breeding season is concentrated around nesting sites, the distribution typically becomes much more dispersed in the non-breeding season. Some species are found in productive sites along the coast during this time, while others spend the non-breeding season far out in pelagic areas. The non-breeding distribution of pelagic seabirds is very dynamic, but areas such as oceanographic fronts and continental slopes are often areas of aggregation, due to their high productivity. While some species or populations use the same area during the whole non-breeding season, others have autumn stopover areas that differ from wintering areas. These autumn stopover areas are particularly important during moulting and for chick rearing in species with intermediate chick rearing strategies such as the razorbill.

1.4 Potential conflicts between birds and wind farms

The growing demand for renewable energy is resulting in an increasing number of planned and operational offshore wind farms. The construction, operation, maintenance, and decommission of marine wind farms has the potential to negatively affect populations of birds that use the neighbouring areas for at least part of the year, e.g., while foraging or migrating. The most obvious risks are direct mortality from birds colliding with turbine blades or other parts of the turbines, displacement of birds that would have used the area occupied by the wind farm was it not for the installations, and habitat alteration (Garthe & Hüppop 2004, Drewitt & Langston 2006, Fox et al. 2006, Furness et al. 2013, Dierschke et al. 2016).

1.4.1 Collision mortality

The collision risk between birds and wind turbines depends on factors such as which species use the area, their abundance, their fine-scale habitat use, their mode of travel, and weather conditions (Drewitt & Langston 2006). The risk will likely be most significant in areas that are used by many birds, such as areas associated with colonies, foraging areas, resting sites and along migration routes. Poor weather conditions reduce visibility and hence increase collision risk if the birds are still flying. For example, migrating birds fly despite poor weather conditions, and might be flying at lower elevations, which further increases collision risk (Drewitt & Langston 2006).

Flight altitude and avoidance behaviour are considered key factors determining species-specific collision risk (Cook et al. 2012). Collision mortality is more likely among birds that do not avoid wind farms than among birds showing avoidance behaviour, and species flying frequently at heights corresponding to the height range of rotor blades (~50-200 m a.s.l) are at greatest risk. Large species generally have poorer flight manoeuvrability than smaller ones, putting them at greater risk of collisions (Drewitt & Langston 2006). Some species may be attracted to the Trollvind area by the oil and gas platforms of Troll and Oseberg, which increases collision risk. Birds might be attracted to these platforms because of their light sources, or because they act as surfaces for resting or as artificial reefs that attract prey (Wiese et al. 2001, Drewitt & Langston 2006, Montevecchi 2006). In addition to being attracted to lights, species habitually flying at dawn, dusk, or night might also be at greater risk because of poor visibility.

Floating offshore wind farms include underwater cables, chains and power lines between mooring equipment, the floating turbines, and installations on land. These have the potential to cause injury or death to diving birds through collision or entanglement. The risk of underwater collision and entanglement is particularly poorly known for birds, while there is some more knowledge on risks for fish and marine mammals (Wilson et al. 2006). Diving birds extend limbs for propelling and steering, making wings and legs likely the most vulnerable body parts to injuries from collision. An injury that makes the bird unable to forage will have a lethal effect. Because vision is the primary sense for birds, they might be particularly vulnerable to collisions and entanglement underwater where visibility can be poor (Wilson et al. 2006).

1.4.2 Displacement

Wind farms can usually induce displacement in birds due to three main effects (e.g., Drewitt & Langston 2006):

1. Loss of physical habitat due to installations. The effect of lost physical habitat in terms of foraging area depends on the size of the wind farm but is likely to be minor because the surface area taken up by the turbines is relatively small.

2. Loss of effective habitat. The presence of wind turbines, and visual, noise, or vibration disturbance from them, might cause birds to avoid the wind farm and its surrounding area. Birds that avoid the wind farm or anthropogenic activities associated with construction or operation of the installations, such as vessel or helicopter traffic, experience loss of effective habitat. In contrast to lost physical habitat, the extent of lost effective habitat can be considerable and impactful if it includes important foraging areas. The extent of lost effective habitat depends on the degree of avoidance behaviour, which varies between species and seasons (Welcker & Nehls 2016, Mendel et al. 2019). Also, the distance between turbines and the size of turbines on a given wind farm can have an impact

on the degree to which birds avoid it. It is unclear if birds can habituate and adjust their behaviour to wind farms, but a literature study noted that the decrease in bird abundance in fact increased with time in marine areas affected by wind farms (Stewart et al. 2005). Loss of habitat due to avoidance of human infrastructure is generally substantially larger than habitat loss due to installations.

3. Barrier effects. Barrier effects occur when birds perceive the wind farm as a barrier and alter their migration pathways or local flight paths to avoid flying through, or near, the wind farm footprint. Such increased journey distances may increase energy expenditure, with possible negative effects on body condition and reproductive fitness or survival. The extent of the detour depends on the species, season, time of day and weather conditions, as well as the size of the wind farm and the layout of turbines. Barrier effects during the breeding season may persistently increase the length and energetic cost of foraging trips, which can have negative consequences for body condition and breeding success (Fox et al. 2006). For seabirds that are at or near the limit of their energy budgets, barrier effects could be detrimental and therefore need to be considered (Masden et al. 2010).

Habitat loss that affects important foraging areas may result in reduced body condition and reproductive success. Increased intra- or interspecific competition in the remining habitat might also have negative impacts on the body condition and reproductive success of both displaced birds and birds they interact with (Burton et al. 2006, Durell et al. 2001, 2000). In contrast to direct mortality due to collisions, which may affect population size swiftly, avoidance and barrier effects may take decades before they are revealed in population size estimates. Within our study species, divers and common scoters are considered the most vulnerable to displacement effects (Furness et al. 2013). For example, a study by Welcker & Nehls (2016), conducted at a 4 km² offshore wind farm in the southern North Sea, showed displacement of divers, northern gannets (*Morus bassanus*), little gulls (*Larus minutus*), terns and alcids. Conversely, lesser (*Larus fuscus*) and great black-backed gulls (*Larus marinus*) were attracted to the wind farm and were found in greater numbers within than outside of the wind farm. Common gulls (*Larus canus*) and herring gulls (*Larus argentatus*) were not affected by the farm. The results from Welcker & Nehls (2016) agree well with a literature review by Dierschke et al (2016), which summarizes the responses of seabirds to twenty offshore wind farms found in the Celtic Seas, North Sea and Baltic Sea. However, Dierschke et al. (2016) show that common gulls and herring gulls were attracted to some of the wind farms, while they did not respond to others.

1.4.3 Habitat modification

A wind farm is likely to affect the physical marine environment and ecosystem, with potential consequences for bird habitats. For example, the turbines may act as refuges for prey species (Inger et al. 2009), resulting in attraction effects in some seabird species. These birds might also find reduced competition inside the wind farm. This could increase the foraging success of birds attracted to the wind farm but also increase their risk of collision with wind turbines. However, if for example vibration from operating turbines drives fish away to areas farther from bird colonies, it could have negative consequences for the reproductive success of piscivorous birds in the area.

1.4.4 Migrating birds

Migrating birds can be affected by all three risks described above. A wind farm along a migration route might increase adult mortality from collisions and contribute to loss of resting and feeding habitats along the migration route. A wind farm can further form a barrier for migrating birds causing them to spend extra energy on a detour. The barrier effect of one wind farm on the body condition of migrating birds might seem marginal but combined with the effects of multiple wind farms along a migration route and of other anthropogenic disturbances, it might become substantial (Masden et al. 2009). For birds that perform swim-migration and most notably moulting seabirds, changing the migration route and taking a long detour to avoid the wind installations could have a negative effect on body condition, particularly if the detour goes through areas with poor foraging possibilities. Detours can also possibly force migrating birds to fly or swim in areas where the winds and currents hinder their movements.

1.4.5 Cumulative effects

It is important to recognise that while the effects of an individual wind farm might be minor or even negligible, the effects of several offshore installations (e.g., wind farms or oil platforms) found within a population's distributional range will add up (Drewitt & Langston 2006, Bailey et al. 2014). The size of a wind farm and the number and size of wind turbines will similarly be fundamental factors in determining the degree to which individuals and populations of birds are affected. In addition to offshore installations, other factors such as climate change, pollution, fisheries, and displacement by shipping and other human activities, bring risks to birds (e.g., Schwemmer et al. 2011). Many Norwegian seabird populations are indeed declining as a result of changes in climate and food resources among other factors (Fauchald et al. 2015). The effects of anthropogenic activities accumulate or interact to form cumulative effects, which are difficult to study and not yet well understood (Topping & Petersen 2011, Willsteed et al. 2018). Comprehensive and far-sighted impact assessments therefore need to consider (with reasonable precaution) the effects of offshore wind farms in light of possible cumulative effects from all factors affecting bird populations.

1.4.6 Predicting sensitivity

Because the risks from wind farms vary between seasons, species, and even populations, sensitivity indices have typically been used in predicting effects of wind farms on birds (Garthe & Hüppop 2004, Furness et al. 2013). These consider factors that make the individual and/or population more vulnerable to wind farms, typically population size, conservation status, adult survival rate, breeding status, nocturnal flight activity, proportion of time spent at flight, proportion of time spent at rotor height, behaviour causing collision risk, behaviour causing risk of displacement, and habitat flexibility. A small population size and high conservation status are indicative of sensitive populations for which an increase in mortality rate can be particularly dangerous. Species with a naturally high survival rate are sensitive to increased adult mortality because populations depend on recruitment from individuals breeding for many years. Breeding status affects the sensitivity of birds because breeding birds are spatially constrained, more active (moving between feeding grounds and the colony) and have a high energetic demand. Nocturnal flight activity, proportion of time spent at flight, and proportion of time spent at rotor height are on the other hand directly linked to risk of collision with wind turbines. Behaviour such as avoiding wind turbines, being attracted to them, or not reacting to them, affects the risk of collision and displacement, while habitat flexibility affects an individual's or population's ability to cope with displacement and consequent habitat loss. Gulls and skuas are typically at risk of collision with turbines, as these species do not avoid wind farms and regularly fly at rotor height. Divers and sea ducks on the other hand avoid wind farms and are consequently at risk of displacement effects (Furness et al. 2013).

1.5 Objectives

The aim of this study is to:
1) scope which bird species use the Trollvind area, and
2) identify how sensitive the different species are to offshore wind farms and how they are most likely to be affected (by collision or displacement).

2 Methods

2.1 Description of the study area

Possibilities for constructing an offshore wind farm “Trollvind” are being explored. The wind farm is proposed to be constructed next to the Troll and Oseberg oil platforms, 65 km west of Bergen, within an area covering 1623 km² (Figure 1). Electricity from Trollvind would be transferred to shore, to the electricity grid of the Bergen area, from where it could be distributed to Troll and Oseberg offshore installations or elsewhere in the Bergen area. Our study area includes the area in which the Trollvind wind farm is planned, as well as a 10 km buffer zone around the planned wind farm (Figure 1). The study area therefore covers a total of 3676 km². The avoidance distances of birds to an offshore wind farm of 12 turbines, covering an area of 4 km², have been estimated to range up to 6 km (Welcker & Nehls 2016). Mendel et al. (2019) studied avoidance distances of divers in an area with several marine wind farms, each covering an area of up to 70 km², and showed that the avoidance distance of divers extended up to 20 km. Based on existing knowledge on avoidance distances, a buffer zone of 10 km was considered appropriate for our purpose.

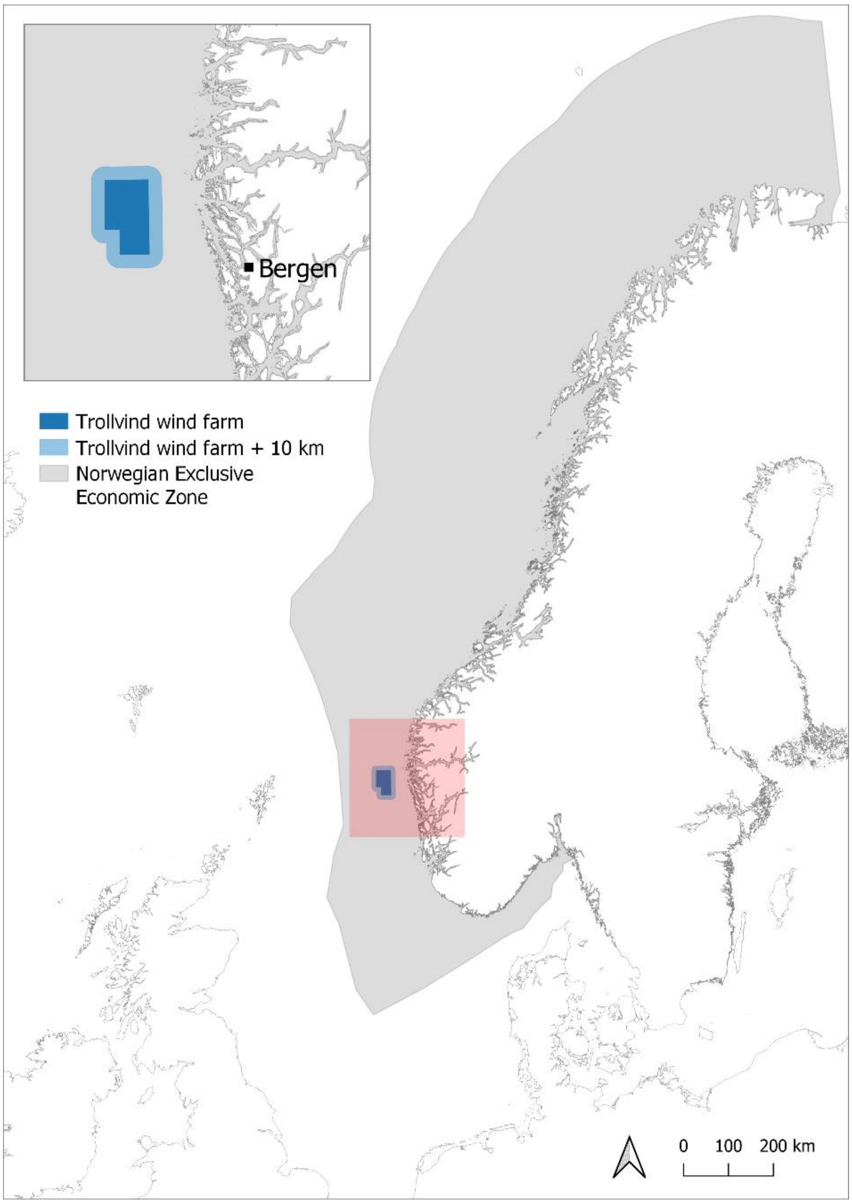

Figure 1. Map showing the area in which Trollvind wind farm is planned to be constructed, as well as the study area, which consists of the Trollvind wind farm area and a buffer zone of 10 km around the wind farm. The

Norwegian Exclusive Economic Zone is also shown. The European coastline was downloaded from EEA (2022). The map was created using QGIS (QGIS Development Team 2022).

2.2 Local seabird populations

In 1987 and 1993 important seabird breeding sites in the Vestland county were protected as seabird reserves (Figure 2). In 1987, 69 sites were protected in the south (Hordaland) while 57 sites were protected in the northern part (Sogn og Fjordane) in 1993. The locally breeding birds are dominated by coastal surface-feeding and diving seabirds. These include gulls (*Larus* spp.); terns (*Sterna* spp.); black guillemot (*Cepphus grylle*), European shag (*Phalacrocorax aristotelis*) and sea ducks (Byrkjeland 2015, Larsen 2021). The seabird reserves typically host a relatively small number of birds (< 500 pairs) where the breeding sites are scattered on small islands and skerries in the archipelago. The seabird fauna is richer in the north, where three larger seabird colonies are found that historically hosted ten thousand (Veststeinen and Einevarden) and several hundred thousand (Runde) pairs of pelagic seabirds (Figure 2). Characteristic pelagic species at these sites are Atlantic puffin (*Fratercula arctica*), common guillemot (*Uria aalge*), black-legged kittiwake (*Rissa tridactyla*) and northern fulmar (*Fulmarus glacialis*).

Monitoring by the park managers shows that seabirds in the Vestland county have declined substantially since the establishment of the seabird reserves (Byrkjeland 2015, Larsen 2021). There is reason to believe that for several species, this decline started before the establishment of the reserves (Byrkjeland 2015, Larsen 2021). For the 123 seabird reserves presented in Figure 2, only 13 sites have shown relatively stable populations since the 1980s (decline in seabird numbers by less than 25%), 50 colonies have shown a substantial decrease in the number of seabirds (i.e., between 25 and 90% decline), while in 60 reserves the seabirds have disappeared completely or declined by more than 90%. Piscivorous species have been most seriously affected, as food scarcity has resulted in series of breeding failure. The main cause for food scarcity and the observed population declines is probably the declines or collapses in the stocks of small pelagic fish such as sandeel (*Ammodytes* spp.), herring (*Clupea harengus*) and sprat *(Sprattus sprattus*). Particularly for the black guillemot and terns, food scarcity has been exacerbated by predation from the American mink (*Neovison vison*) which is an introduced species along the coast. However, the mink population has decreased in recent years (Byrkjeland 2015, Larsen 2021). Increasing temperatures have probably also had negative effects on seabird populations around the North Sea, including the coast of Vestland county (Byrkjeland 2015, Larsen 2021).

Analyses of the monitoring data from the seabird reserves show that the populations of common and Arctic terns (*Sterna hirundo* and *S. paradisaea*, respectively) have declined by more than 95% in the North Sea area (Vestland and Rogaland) (Table 2, Arneberg et al. In prep.), and these species have accordingly disappeared from many places along the coast (Byrkjeland 2015, Larsen 2021). The gull species have declined by between 60 and 95% (Table 2). For other species in Vestland county, Byrkjeland (2015) and Larsen (2021) found that European shag has increased in south but has declined in north, black guillemot has declined, and common eider (*Somateria mollissima*) has also declined recently. Northern fulmar and the once numerous black-legged kittiwake have disappeared from the large seabird colonies in the north. In the same colonies, Atlantic puffin and common guillemot have declined by 68% and 45% respectively (Larsen 2021).

Table 2. Estimated percent decline in population size from 1980 to 2020. Estimates are analyses of data from the monitoring of seabird reserves in Rogaland and Vestland counties. Details of analyses are found in Arneberg et al. (In prep.).

Species	**Decline in seabird populations from 1980 to 2020 (±95% CI)**	
Common gull (*Larus canus*)	93.7	(82.1, 97.8)
Lesser black-backed gull (*Larus fuscus*)	85.9	(73.3, 92.5)
Herring gull (*Larus argentatus*)	84.6	(71.3, 91.8)
Great black-backed gull (*Larus marinus*)	59.5	(36.7, 74.1)
Common tern (*Sterna hirundo*)	99.4	(97.6, 99.9)
Arctic tern (*Sterna paradisaea*)	99.5	(97.0, 99.9)
Terns (unspec.) (*Sterna* spp.)	98.8	(93.0, 99.8)

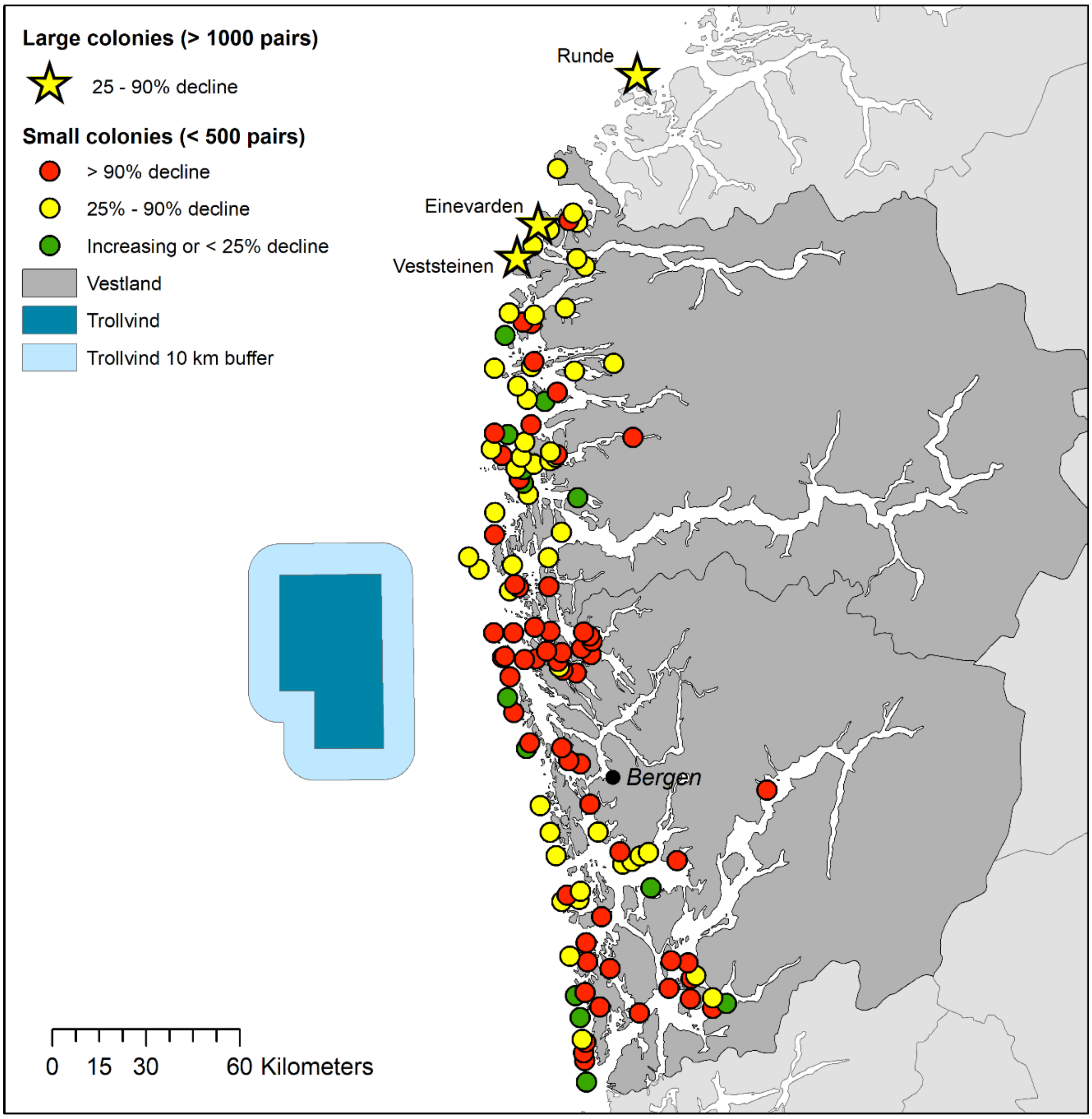

Figure 2. Status of seabird reserves in Vestland county (data from Byrkjeland 2015; Larsen 2021). Colours indicate the development in the number of breeding seabirds since the 1980s. Circles are relatively small breeding sites hosting coastal seabird species. Stars are larger seabird colonies which also host large populations of pelagic seabirds. In addition to the Vestland seabird reserves, the large seabird colony, Runde in Møre og Romsdal is also shown (data from seapop.no). The map was created using ArcGIS (2020).

2.3 Datasets and modelling

Knowledge of bird distribution in space and time is paramount in assessing possible short and long-term impacts of Trollvind offshore wind farm on birds in the different stages of its lifetime. Here we describe the data and methodology used to estimate the importance of the study area as habitat for different bird species in different seasons: autumn (August-October), winter (November-January), spring (February-April) and summer (May-July). The resulting dataset for the Norwegian Exclusive Economic Zone (EEZ) was developed in a parallel project and is described in detail in Fauchald et al. (In prep.) Here, we give a summary of the dataset used and the modelling approach.

2.3.1 Datasets used for the prediction of bird distribution

For six common pelagic seabird species (little auk [*Alle alle*], Atlantic puffin, northern fulmar, black-legged kittiwake, Brünnich's guillemot [*Uria lomvia*] and common guillemot), seasonal distribution models were obtained from the NEAS (Northeast Atlantic Seabird distribution) dataset provided by SEATRACK (Fauchald et al. 2021). This dataset is based on models of tracking data of breeding individuals from multiple seabird colonies in the Northeast Atlantic combined with data from population censuses. In total, for the six species, the dataset covers 87% of the Northeast Atlantic breeding populations. The dataset provides monthly estimates of densities for the North Atlantic. Data were obtained from the Norwegian EEZ and averaged over seasons. For the rest of the species, the seasonal distributions were modelled based on observation data derived from different sources covering the Norwegian EEZ (see section 2.2.2). The datasets used were collected from Artsobservasjoner (www.artsobservasjoner.no), ESAS (European Seabirds at Sea, 2022), and SEAPOP (www.seapop.no/en), and consisted of a combined total of 4.3 million observations of 77 species.

Seabirds at sea observations

Data on seabirds at-sea were obtained from the ESAS (European Seabirds at Sea) database and the SEAPOP dataset for seabirds in the open sea (Fauchald 2011, Fauchald et al. 2011). For both sources, the strip-transect methodology (Tasker et al. 1984) was used for data collection, as it is standard practice for ship-based seabird surveys. Using this method, birds are counted within a sector with a radius of 300 m, defined by a 90° angle between the bowline and an imagined line perpendicular to one side of the ship, while moving at constant speed. The birds counted are identified to the lowest taxonomic level possible, and their behaviour is noted (flying or resting on the sea surface). All bird species, including migratory and terrestrial birds, are included in these datasets. Because species that follow ships, such as gulls and fulmars, would be overestimated in these continuous strip-transect counts, they are counted in snapshot counts conducted every 10 minutes. In a snapshot count, all birds present in the observed sector at a specific moment of time are counted and identified.

Coastal observations

Coastal observations of birds were acquired from Artsobservasjoner (Species Observations System, www.artsobservasjoner.no), and the SEAPOP dataset of coastal observations (www.seapop.no/en/activities/methods/methods-mapping-coast). Artsobservasjoner is a Norwegian database encompassing species observations from various sources, including citizen science observations. Observed species must be registered at the lowest taxonomic level at which identification is certain, and with the most precise coordinates that can be given without compromising certainty. The Norwegian ornithological organisation *BirdLife Norway* has a standard procedure for gathering data to this database, and for the dataset used here, only observations registered by BirdLife Norway were included. The SEAPOP coastal data include seabirds in breeding colonies, summer observations of non-breeding birds, and observations from dedicated moulting counts and winter counts (Systad et al. 2018).

2.3.2 Species Distribution Models

Except for the six species covered by the SEATRACK-NEAS dataset, Species Distribution Models (SDMs) were used to model the seasonal distribution of each bird species. While the seabirds at sea dataset follows a transect-based design that includes observer effort, the coastal datasets, and in particular, the data from Artsobservasjoner are “presence-only” data (Guisan and Thuiller 2005). To combine the two data sources, the at-sea observations in the present study were also included as presence only data.

The datasets have highly variable coverage with many observations reflecting high observation effort in densely populated coastal areas and low coverage in the open sea, especially in the deep-sea areas of the Norwegian Sea (See Fauchald 2011). If not accounted for, spatially variable observation effort could seriously bias model predictions from SDMs (Elith et al. 2009). In the models presented here, we used the Target Group method suggested by Phillips et al. (2009) to account for observation bias. SDMs on presence-only data compare the presence of a species to background or pseudo-absence points, often acquired by a random selection of points in the habitat. To account for observation bias, Phillips et al. (2009) suggested instead to use the presence of other species in the same guild (i.e., other bird species) as background points. This Target Group (TG) method effectively reduces the effect of variable observer effort (e.g., Barber et al. 2022); i.e., it introduces the same bias in the background points as is found in the presence data. However, areas with high diversity of birds will tend to have an over-representation of background points and thus slightly bias the predictions towards areas with low diversity (e.g., Ranc et al. 2016, Vollering et al. 2019).

Species Distribution Models (SDMs) of birds in the Norwegian Exclusive Economic Zone (EEZ) were calculated and used as estimates of bird occurrence within the study area. Using packages *mgcv* (Wood 2011) and *terra* (Hijmans 2022) in R (R Core Team 2022), species distribution was predicted for 10*10 km^2 raster cells from Generalized Additive Models (GAMs), which model the relationship between environmental conditions and the occurrence of a species. GAMs calculate this relationship based on values for environmental variables chosen to describe the conditions in which the species has or has not been encountered. The GAMs were then used to predict the likelihood of encountering a species in an area based on the environmental conditions in that area. The full GAM used was specified as

gam(Presence/Background ~ s(Depth) + s(Slope) + s(SST) + log(TGrad) + s(SSS) + DFCoast + s(DACoast) + factor(Source), family = binomial, data=data) (1)

Presence/Background represents the response variable, *Presence* represents the number of observations of the species modelled and *Background* represents the number of observations of all other species (i.e., pseudo absences represented by the target group). The environmental conditions at observation sites are described by the predictor variables *Depth* (Amante & Eakins 2009), bathymetric slope (*Slope*, calculated as spatial change in *Depth*), sea surface temperature (*SST*, Huang et al. 2020), the SST gradient (*TGrad*, calculated as spatial change in *SST*), sea surface salinity (*SSS*, ICES Data Portal 2022), distance from the nearest coast (*DFCoast*), and distance along the Norwegian coast (from Skagerrak to the Norwegian-Russian border, *DACoast*). To control for the different data sources used, *Source* was included as a control variable.

Because of uneven spatial coverage of observations or lack of presence, the model had to be modified for several species in some or all seasons. Most seriously model overfitting was a problem for rare species with few presences, resulting in unrealistic predictions in areas with low data coverage. For each model, model predictions and diagnostics were assessed, and models were adjusted to reduce overfitting and remove unrealistic predictions. The modifications included setting the maximum number of knots that the GAM was allowed to use for a specific predictor variable (restricting the “wiggliness” of the smooth function) and removing one or several of the explanatory variables from the model.

2.3.3 Habitat suitability

Maps of species-specific habitat suitability were developed for each season from the SDMs by weighing the importance of each raster cell against the other cells. Values for the 10*10 km^2 raster cells in the habitat suitability models were calculated as

$c_{i,j} = n * p_{i,j} / sum_i (p_{i,jmax})$ (2)

where $c_{i,j}$ is habitat suitability for cell i in season j; n is the total number of cells in the habitat; $p_{i,j}$ is the predicted value from the SDM or the NEAS-SEATRACK dataset, and $sum_i (p_{i,jmax})$ is the sum of predicted values in the habitat in the season with the highest sum. Habitat suitability might therefore vary between seasons for a specific species, but values are standardized between species.

2.4 Bird sensitivity assessment

To estimate bird sensitivity to marine wind farms, the habitat suitability models were used together with species-specific sensitivity indices to yield models of each species' seasonal sensitivity to collision and displacement, respectively (Appendix 2). These were further used to calculate total sensitivity of birds to wind farms in each season. Sensitivity indices have been widely used in impact assessments to describe birds' vulnerability to wind farms (e.g., Garthe & Hüppop 2004, Furness et al. 2013).

2.4.1 Calculating species-specific sensitivity to wind farms

Species-specific sensitivity was estimated for each season in the EEZ using a sensitivity index consisting of two parts, one considering general sensitivity and the other considering sensitivity specifically to wind farms.

General sensitivity was estimated considering *seasonal sensitivity in marine habitats* on a three-point scale:

- summer, for birds breeding in association with fresh water: 0.5
- summer, for birds breeding in association with the marine habitat: 1
- outside the breeding season: 1

as well as three factors on a scale from 1 (least sensitive) to 5 (most sensitive):

- Norwegian share of the European population (*a*)
- Status on the Norwegian red list of endangered species (*b*)
- Adult survival (*c*)

Species' general sensitivity was then calculated for each season as

$Sg = \text{Seasonal sensitivity in marine habitats} * (a + b + c)/3$ (3)

Sensitivity to offshore wind farms was calculated separately for risk of collision and risk of displacement. The estimations were made using six factors on a scale from 1 (least sensitive) to 5 (most sensitive):

- Nocturnal flight activity (*d*)
- Time spent at flight (*e*)
- Time spent at rotor height (*f*)
- Avoidance behaviour (risk of collision) (*g*)
- Avoidance behaviour (risk of displacement) (*h*)
- Habitat flexibility (*i*)

Risk of collision was calculated for each species and season as

$Sc = ((d+e)/2+f+g)/3$ (4)

Risk of displacement was calculated for each species and season as

$Sd = (h+i)/2$ (5)

Total sensitivity index values, that consider both general sensitivity as well as sensitivity to collision and displacement, respectively, were then calculated as

$WSIc_{i,j} = c_{i,j,s} * Sg_s * Sc_s$ (6)

and

$WSId_{i,j} = c_{i,j,s} * Sg_s * Sd_s$ (7)

where $WSIc_{i,j}$ and $WSId_{i,j}$ represent total sensitivity for collision and displacement, respectively, in cell i and season j; $c_{i,j,s}$ is habitat suitability in cell i and season j for species s; Sg_s is general sensitivity for species s; Sc_s is sensitivity to collision with turbines for species s; and Sd_s is sensitivity to displacement by wind farms for species s.

In the following, for each species, we selected either the collision index (WSIc) or the displacement index (WSId), whichever giving the highest value.

2.4.2 Accounting for seabird colonies: Functional areas

Areas close to large seabird colonies are expected to be especially vulnerable for human disturbances, including wind farms. It was therefore decided to increase the index values in areas close to large seabird colonies during the seasons when the birds are present in the colonies.

Functional areas were established to account for high concentrations of birds around colonies in the breeding season. A functional area is defined as the area around a colony in which breeding birds collect their food. Birds from different colonies along the Norwegian coast were divided into functional areas following Systad et al. (2018).

For the summer season, the functional value ($F_{i,j=2}$, where j=2 is summer)[1] for each cell i was classified based on the total number of birds (n_i) as follows:
$F_{i,j=2} = 1$ for $n_i = 0$
$F_{i,j=2} = 2$ for $0 < n_i < 1000$
$F_{i,j=2} = 3$ for $1000 \leq n_i < 10\,000$
$F_{i,j=2} = 4$ for $10\,000 \leq n_i < 100\,000$
$F_{i,j=2} = 5$ for $n_i \geq 100\,000$

For the spring season (j=1), functional areas were given half the summer weighing, the functional values were hence calculated as

$F_{i,j=1} = 1/2 * F_{i,j=2}$ (8)

For the autumn season (j=3), functional areas were given a third of the summer weighing, the functional values were hence calculated as

$F_{i,j=3} = 1/3 * F_{i,j=2}$ (9)

For the winter season (j=4), no weighing of functional areas was done, and the functional value is hence 1 for all cells.

$F_{i,j=4} = 1$ (10)

---

[1] Season (j) is given as: j=1 for spring, j=2 for summer, j=3 for autumn and j=4 for winter.

2.4.3 Total and seasonal sensitivity

Accounting for the proximity to seabird colonies the seasonal total sensitivity to offshore wind farms for all bird species was calculated as:

$WSIs_{i,j} = F_{i,j} * sum_s(c_{i,j,s} * Sg_s * Sx_s)$ (11)

where $WSIs_{i,j}$ represents sum of seasonal sensitivity for all species, in cell i and season j; F_i is the functional value for cell i, $c_{i,j,s}$ is habitat suitability in cell i, season j and for species s; Sg_s is general sensitivity for species s; and Sx_s represents either Sc_s (sensitivity to collision for species s) or Sd_s (sensitivity to displacement for species s), whichever is higher.

Total sensitivity was defined as the maximum sensitivity found in a cell during the four seasons. Thus, the total sensitivity to offshore wind farms in a cell was defined as
$WSI_{i,jmax}$ (12)

where $jmax$ is the season with the highest $WSIs$ value in cell i.

2.4.4 Normalisation and standardisation of index values

The WSI index had a highly skewed distribution with many low values and some very large values. To normalise seasonal and total index values, the values were $\log_e$-transformed.

The indexes are dimensionless relative values. To give the values a distinct meaning, they were standardised to the highest value in the Norwegian EEZ. Thus, the presented value in a cell represents the percentage of the highest sensitivity found within the Norwegian EEZ.

Three different variants of the index are shown, each representing a specific degree of detail:

Total WSI (cf. eq. 12): Maximum sensitivity during four seasons. Log_e-transformed values of $WSI_{i,jmax}$, given as the percentage of the maximum value found in the Norwegian EEZ:
$100 \times \log_e(WSI_{i,jmax})/Max(\log_e(WSI_{i,jmax}))$ (13)

Seasonal WSI (cf. eq 11): Sensitivity during each season. Log_e-transformed values of $WSIs_{i,j}$, given as the percentage of the maximum value found in the Norwegian EEZ irrespective of season:
$100 \times \log_e(WSIs_{i,j})/Max(\log_e(WSI_{i,jmax}))$ (14)

Species-specific sensitivity (cf. eqs. 6 and 7): Seasonal sensitivity for a given species. Values of $WSIx_{i,j}$ (either $WSIc_{i,j}$ or $WSId_{i,j}$, whichever giving the highest score). Given as the percentage of the maximum value found in the Norwegian EEZ irrespective of season and species:
$100 \times WSIx_{i,j}/Max(WSIx_{i,jmax})$ (15)

2.4.5 Finding the most sensitive species

To find the species that would be most sensitive to a wind farm in the study area, species-specific *WSIc* or *WSId* values, whichever preponderant, were summed across cells within the study area. This was done separately for each season. The WSI values of cells that fall only partly inside the study area were weighted corresponding to the proportion of the cell falling inside the area. For each season, species were ranked from highest to lowest sensitivity and the ten most sensitive species were selected as species of highest concern.

3 Results

3.1 Total sensitivity

Total sensitivity was mapped by choosing the highest seasonal sensitivity value for each cell (see section 2.3.2). Relative to the whole EEZ, the bird sensitivity to wind farms is intermediate in our study area, with slightly elevated values of total sensitivity in the north-eastern part of the study area (Figure 3). The total sensitivity of birds decreases with increasing distance from coast.

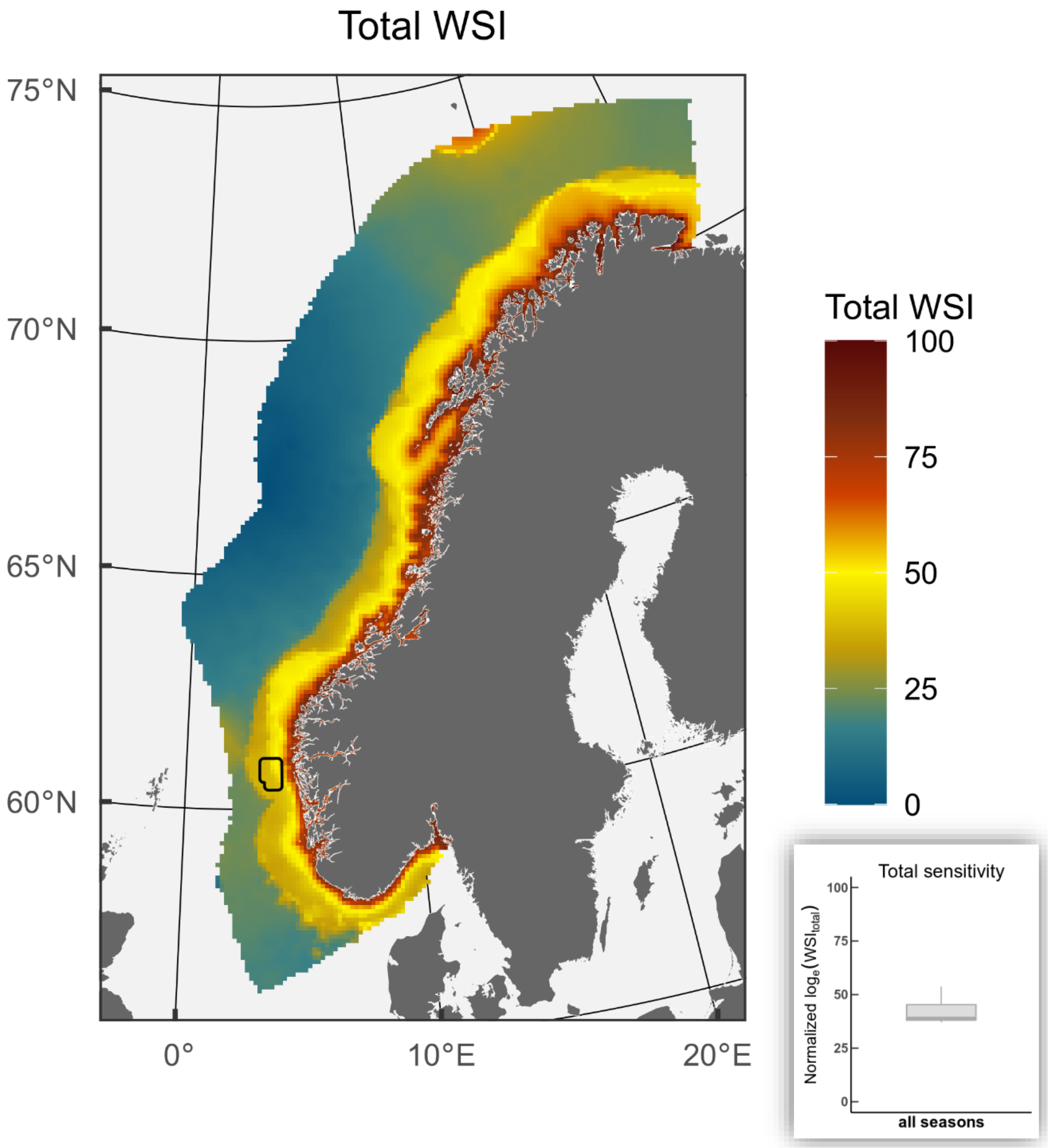

Figure 33. Total sensitivity for the whole Norwegian Exclusive Economic Zone. Each cell represents the highest seasonal normalized and log-transformed WSI value. The boxplot shows variation in normalized log-transformed WSI values within our study area. The horizontal line shows the median value and the box extends from the 25th to the 75th quantile. The map was created using R *(R Core Team* 2022*).*

3.2 Seasonal sensitivity

Seasonal sensitivity of birds was calculated for all species collectively (see section 2.3.2) and is presented in Figure 4. Variation in WSI values within the area and between seasons is presented in Figure 5. Summer was found to be the season with highest sensitivity, with medium to above-medium WSI values within the study area in relation to the whole EEZ. In spring and autumn, WSI values range from below-medium to medium, while winter WSI values are on the lower side in relation to the whole WSI. In all seasons, the highest WSI values lie in the eastern half, and particularly the north-eastern quarter, of the study area.

Because our study area lies relatively close to the coast, locally breeding birds, such as many gulls (*Larus* spp.) and terns (*Sterna* spp.), as well as some pelagic birds breeding farther away, such as the black-legged kittiwake (*Rissa tridactyla*) and northern fulmar (*Fulmarus glacialis*), may use the study area as foraging habitat or for commuting between foraging areas and colonies in the breeding season. The breeding seasons of different species of birds extend between late spring to early autumn. In spring and autumn, migrating birds potentially cross the study area, but some late breeding species might migrate through the area in early summer. The wintertime bird community consists mainly of overwintering individuals.

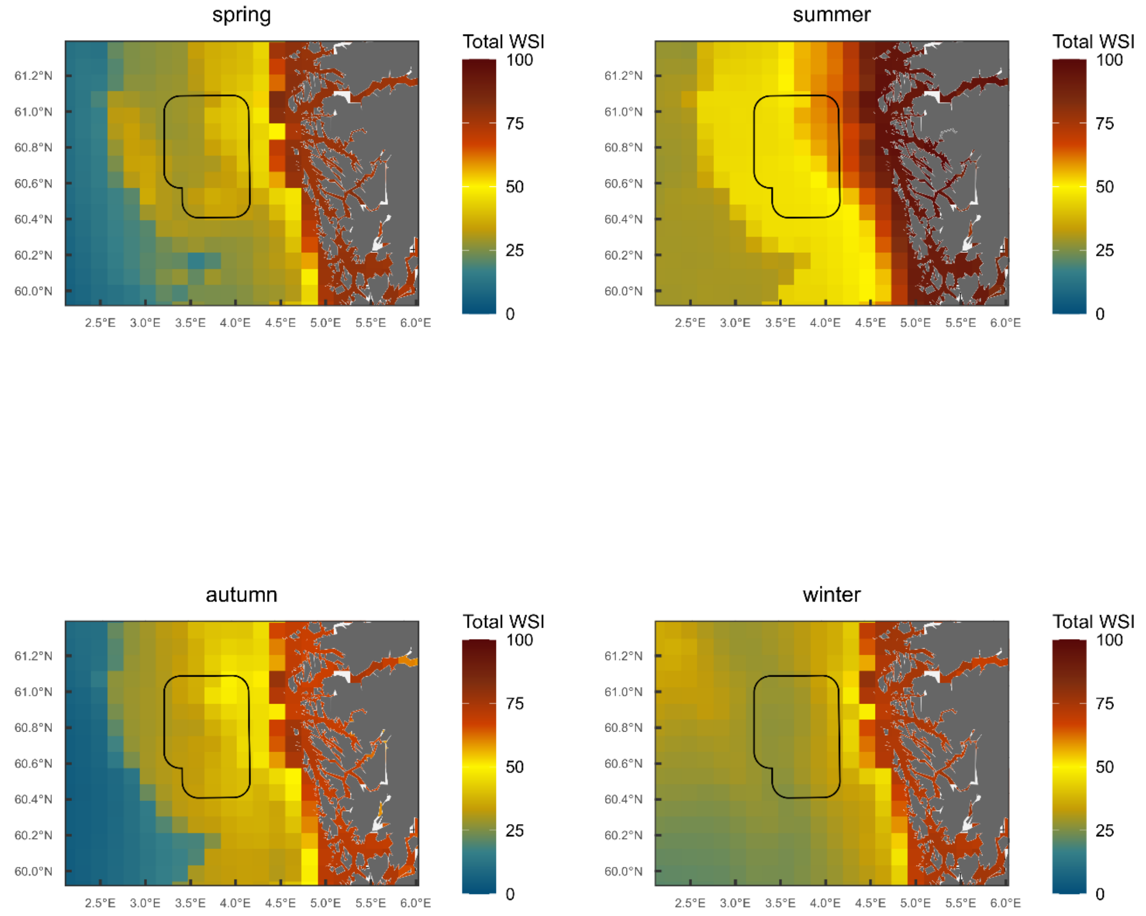

Figure 44. Seasonal normalized log-transformed WSI values within and around our study area. Seasonal WSI values were calculated for all species collectively and hence measure total seasonal sensitivity among birds. The map was created using R (R Core Team 2022).

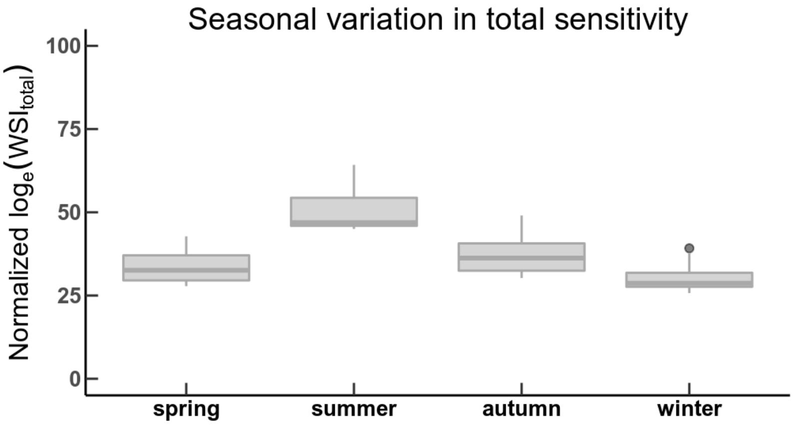

Figure 5. Variation within our study area in seasonal normalized log-transformed WSI values. The horizontal lines show the median values while the boxes extend from the 25th to the 75th quantile.

3.3 Species-specific sensitivity

Species-specific sensitivity to offshore wind farms was modelled for the EEZ based on habitat preference models and species-specific sensitivity indices (see section 2.3.1). The species for which data were insufficient for predicting distribution in any season, as well as species with no significant predicted presence in the study area, are listed in Appendix 1. For fifty-eight (58) species there were enough data for establishing distribution models in at least one season. Of these, forty-nine (49) use our study area in at least one season. These species were considered in our sensitivity analyses and are listed together with sensitivity indices in Appendix 2. WSI values found within our study area for each of these species and seasons are presented in Appendix 3. All species with predicted distribution within our study area are presented per season and ranked in order of sensitivity within the study area in Appendix 4.

For each season, the ten species with the highest sensitivity within the study area were chosen as species of highest concern (Appendix 4). This resulted in the identification of twenty-three (23) species, described in the following sections based on species information in Artsdatabanken (www.artsdatabanken.no). In addition to these 23 species, other species such as the Atlantic puffin (sensitive to displacement) and the great cormorant (*Phalacrocrax carbo*, sensitive to collision), are present in the study area throughout the year and show high sensitivity to wind installations (Appendix 3).

3.3.1 Razorbill (*Alca torda*)

The razorbill is a pelagic bird in the auk family. It breeds in colonies along the Norwegian coast from Rogaland to Finnmark, but the largest colonies are found in the north. In wintertime it is found along the whole coast of Norway, in the North Sea and in Skagerrak. The razorbill feeds primarily on schooling fish that are caught by pursuit diving, but also crustaceans and polychaetas. It is listed as vulnerable on the Norwegian red list due to a declining population and is sensitive to displacement by wind farms due to avoidance behaviour. The razorbill is among the ten most sensitive species in the study area in spring, summer, and autumn, but present in the area and sensitive also in winter (Figure 6). It is not present in particularly large numbers but has a high sensitivity index value due to a high natural adult survival rate, and because it is a red listed species with a large share of the European population residing in Norway.

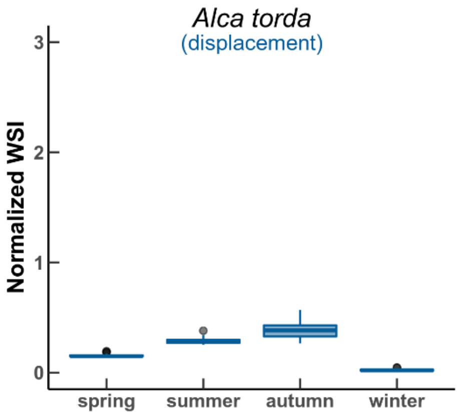

Figure 6. Variation within our study area in normalized WSI values for the razorbill. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

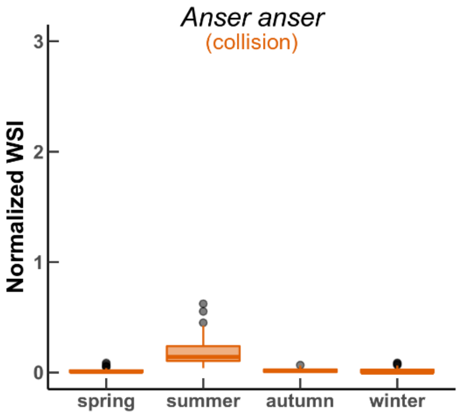

Figure 7. Variation within our study area in normalized WSI values for the greylag goose. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.2 Greylag goose (*Anser anser*)

The greylag goose breeds along the whole coast of Norway, mainly in marine environments, and feeds on plant material such as grass and roots. The winter range of individuals breeding in Norway has recently shifted from southern Spain to now include also northern Spain and the Netherlands. The Norwegian greylag goose population is increasing and has been assessed as being of least concern on the Norwegian red list. The greylag goose spends a lot of time flying, also at night, and typically flies at rotor height. This, together with lack of avoidance of wind farms, puts it at risk of collision with turbines, and it is among the ten most sensitive species in summer (Figure 7).

3.3.3 Common pochard (*Aythya ferina*)

The common pochard is a goose species with no established breeding population in Norway, though breeding individuals have been found in within the country. Its conservation status has therefore not been assessed on the Norwegian red list. The breeding range of the common pochard lies south and east of Norway, where it prefers to nest close to lakes with rich vegetation. It has a broad diet and feeds on plants, invertebrates, amphibians, and small fish. The overwintering grounds of the common pochard lie in southern and western Europe, Africa, and south Asia. It is a mong ten most sensitive species in our study area in spring (Figure 8), because it shows high preference for the area at this time of the year. Due to avoidance of wind farms and low habitat flexibility, it is mainly sensitive to displacement. However, nocturnal flight activity might put it in risk of collision.

3.3.4 Brant goose (*Branta bernicla*)

The brant goose has a circumpolar distribution and in Norway it breeds only on Svalbard, making it our most northerly goose species. It is also among the smallest geese breeding in Norway. The brant goose feeds on plants and breeds in loose colonies or as individual couples on small islets or on the tundra, often in association with freshwater. The individuals that breed on Svalbard overwinter in Denmark, the Netherlands and Britain, and because their migration route follows the coast of mainland Norway, they are found in Norwegian waters during the autumn and spring migrations. The Svalbard population has been assessed as near threatened. Though the population is slowly increasing after being heavily reduced during the last 100 years, the breeding success has been low. The brant goose is sensitive to displacement by wind farms, and according to our models, it would be sensitive in the study area during the autumn migration (Figure 9). However, as we lack a model of its spring distribution, but know its migration route in spring corresponds to the one in autumn, a conservative approach would be to assume similar sensitivity in the study area during the spring migration. A high Norwegian share of the European population, a high natural adult survival rate and strong avoidance behaviour, combined with relatively high presence in the study area in autumn, makes the brant goose stand out as one of the most sensitive species.

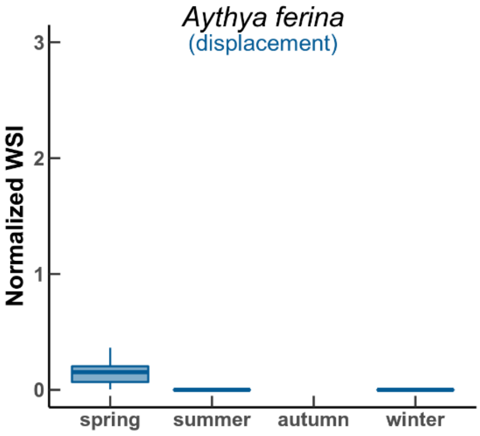

Figure 8. Variation within our study area in normalized WSI values for the common pochard. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

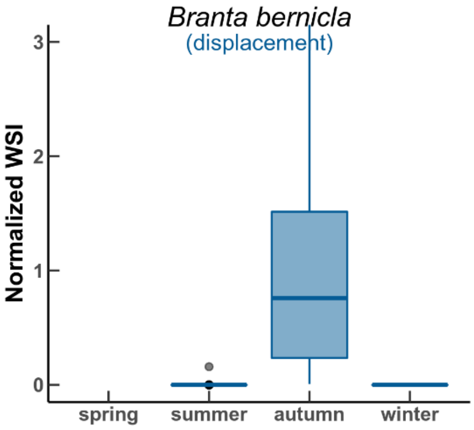

Figure 9. Variation within our study area in normalized WSI values for the brant goose. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.5 Black guillemot (*Cepphus grylle*)

The black guillemot belongs to the auk family and feeds on fish. It breeds along the whole coast of Norway in the outer archipelago and stays along the coast during winter. The Norwegian population is in decline and the conservation status of the species has been assessed as near threatened. A high natural survival rate among adults and low habitat flexibility make the black guillemot sensitive to displacement by wind farms. It is among the ten most sensitive species in our study area in summer (Figure 10), which is when it shows highest preference for the study area.

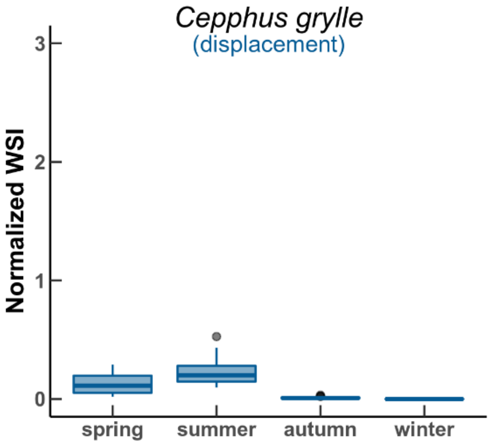

Figure 10. Variation within our study area in normalized WSI values for the black guillemot. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

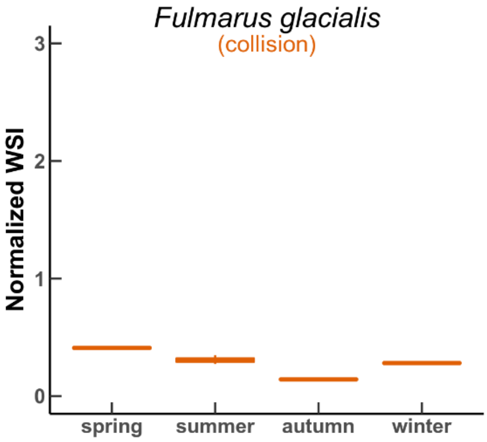

Figure 11. Variation within our study area in normalized WSI values for the northern fulmar. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.6 Northern fulmar (*Fulmarus glacialis*)

The northern fulmar is a pelagic seabird that spends most of its time far out at sea. It feeds on fish, crustaceans, and molluscs, as well as opportunistically on offal from the fishery. Breeding northern fulmars are found in loose colonies on bird cliffs, often together with other species, along the coast of Norway from Rogaland to Finnmark. The northern fulmar is active at night and may be sensitive to both collision and displacement (Deakin et al. 2022). The population is declining and listed as endangered on the Norwegian red list. It is among the ten most sensitive species in our study area in all seasons but autumn. It is present in the area throughout the year however, and sensitive in all seasons (Figure 11). In addition to being red listed and a nocturnally active species, a large share of the European population of the northern fulmar resides in Norway (Svalbard and Bjørnøya) and its natural adult survival rate is high. These factors together with a strong preference for the study area as habitat, put the northern fulmar among the most sensitive species in the area.

3.3.7 Great northern diver (*Gavia immer*)

The great northern diver is a piscivorous bird and a visitor in our study area. It does not breed in Norway and its colonies are found in North America, Greenland, and Iceland, but its winter distribution stretches along the Norwegian coast. The birds overwintering in Norwegian waters constitute less than one percent of the global population however, making the species unsuited for a status assessment on the Norwegian red list. Internationally, the species has been listed as vulnerable due to a small and declining population. The great northern diver is, as all divers, sensitive to displacement by wind farms due to strong avoidance behaviour. In addition, a high adult survival rate contributes to giving the species a high sensitivity index. It is found in our study area throughout the year, but shows highest sensitivity in winter due to highest presence at this time of the year (Figure 12).

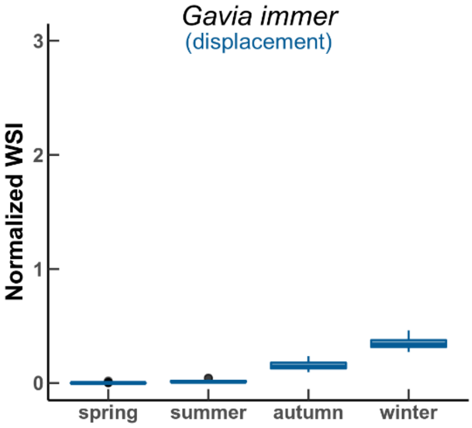

Figure 12. Variation within our study area in normalized WSI values for the great northern diver. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

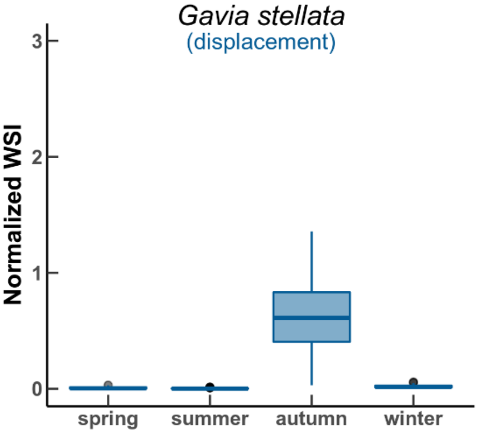

Figure 13. Variation within our study area in normalized WSI values for the red-throated diver. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.8 Red-throated diver (*Gavia stellata*)

The red-throated diver is the smallest of the divers (*Gavia* spp.), and a piscivorous species that hunts by pursuit diving. It breeds close to freshwater over most of Norway but heads out to the coast as soon as the chicks can fly. Most of the individuals that breed in Norway overwinter in the North Sea and along the Norwegian coast. The red-throated diver is very sensitive to anthropogenic disturbance and shows strong avoidance behaviour. It is therefore in little risk of collision with wind turbines but is particularly vulnerable to displacement and habitat loss. It has been assessed as a species of least concern on the Norwegian red list because the population size remains stable. Because of particularly strong avoidance behaviour, the red-throated diver is sensitive in the area throughout the year, but its high preference for the area in autumn makes it most sensitive in this season (Figure 13). A project that tracks red-throated divers tagged in their wintering area in the southern North Sea (DiverLog, www.divertracking.com), shows that many red-throated divers migrate to and from arctic breeding grounds along the Norwegian coast, close to our study area (https://www.divertracking.com/en/tracking-map/). In addition to being sensitive to wind farms, red-throated divers are very sensitive to ship traffic, which is likely to increase between the mainland and the Trollvind area in all life-cycle phases of the wind farm.

3.3.9 European storm petrel (*Hydrobates pelagicus*)

The European storm petrel is a small pelagic sea bird that feeds on small fish, squid, and plankton, foraging while flying close to the sea surface. It breeds on a few islands along the Norwegian coast from Møre and Romsdal to Finnmark, but most of the population breeds along the coasts of Great Britain, Ireland, and the Faroe Islands. The European storm petrel overwinters in the south-eastern Atlantic. There is limited information about this species' sensitivity to wind farms; it is thought to have low collision risk, but as it is active at night and is attracted to nocturnal lights, it may be attracted to wind turbines, increasing its risk of collision (Deakin et al. 2022). There is a lack of information about changes in the size of the population, and because there is no evidence of a declining population, the European storm petrel is assessed as a species of least concern on the Norwegian red list. However, due to strong preference for the area, the European storm petrel shows high sensitivity in the study area in summer and autumn and is in autumn among the ten most sensitive species (Figure 14).

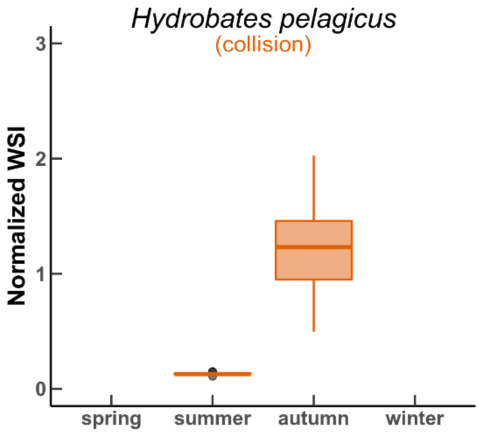

Figure 14. Variation within our study area in normalized WSI values for the European storm petrel. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

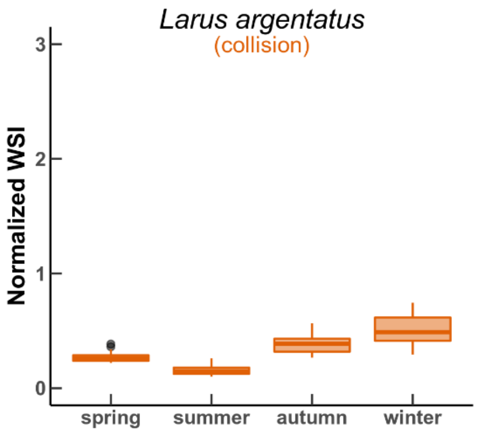

Figure 15. Variation within our study area in normalized WSI values for the herring gull. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.10 Herring gull (*Larus argentatus*)

The herring gull breeds in colonies on islets along the whole coast of Norway, often together with great and lesser black-backed gulls. Birds that breed in southern Norway often stay within Norwegian waters or move to other coasts of the North Sea in winter, while birds that breed in northern Norway migrate longer distances. The herring gull preys primarily on fish, crustaceans, molluscs, small mammals, and birds, but has adapted to feeding opportunistically on fisheries offal and on dumpsters. It is listed as vulnerable on the Norwegian red list, due to a decreasing population size. The herring gull does not avoid wind turbines and may even show attraction effects by using offshore wind farms as roosting sites. In addition, it typically flies at rotor height and is somewhat active at night, putting it at risk of collision with the turbines. A high survival rate among adults increases its sensitivity index further. Because it shows relatively high preference for the area, it is sensitive in our study area throughout the year and is among the ten most sensitive species in spring, autumn, and winter (Figure 15).

3.3.11 Common gull (*Larus canus*)

The common gull is not an exclusively marine bird, but breeds over the whole country from the marine environments along the coast to freshwater habitats inland and in towns far from water. Most of the individuals that breed in Norway spend their winters in the North Sea, but many stay in Norway, particularly those that breed in northern and eastern parts of the country. Vestland county is a particularly popular place to reside among the birds that stay within Norway. The common gull has a varied diet, consisting of invertebrates such as insects, earthworms, and crustaceans, but also fish and human waste. It is listed as vulnerable on the Norwegian red list, due to a decreasing population size. The species runs a high risk of collision with wind turbines because it typically flies at rotor height, does not avoid turbines and is somewhat active at night. It may even show attraction to offshore wind farms by using them as roosting sites. The common gull is sensitive in our study area throughout the year and reaches the top ten sensitive species in summer (Figure 16), as it shows high preference for the area in this season.

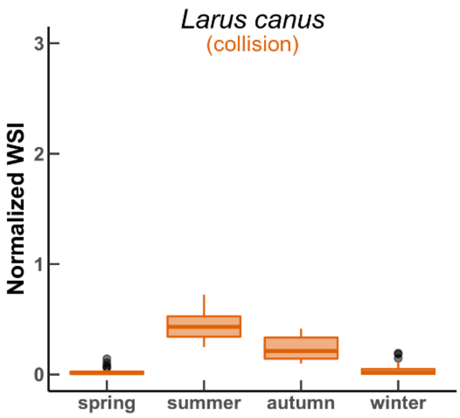

Figure 16. Variation within our study area in normalized WSI values for the common gull. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

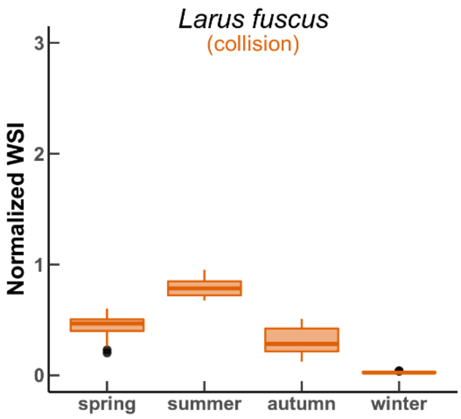

Figure 17. Variation within our study area in normalized WSI values for the lesser black-backed gull. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.12 Lesser black-backed gull (*Larus fuscus*)

The lesser black-backed gull feeds on fish caught at the sea surface. It breeds in colonies on islands along the whole coast of Norway, but most numerously on the coasts of Skagerrak and the North Sea. It habitually flies at rotor height, does not show much avoidance behaviour, and might even use offshore wind farms as roosting sites, putting it at risk of collision. A high adult survival rate increases its sensitivity further. There has not been any overall trend in the population size of the lesser black-backed gull during the last few decades, and the species is assessed on the Norwegian red list as being of least concern. The lesser black-backed gull is sensitive to wind farms throughout the year and among the ten most sensitive species in spring, summer, and autumn (Figure 17). This is explained, together with high a sensitivity index, by a high preference for the study area, particularly in summer, but also in in spring and autumn.

3.3.13 Great black-backed gull (*Larus marinus*)

The great black-backed gull is a particularly marine species. It breeds in the archipelago along the whole coast of Norway, often in colonies together with other gull species. The great black-backed gull feeds not only on fish but also on carrion and small mammals and birds. It overwinters along the coasts of the North Sea and Great Britain. On the Norwegian red list, the great black-backed gull has been assessed as being of least concern, but because Finnish and Swedish populations have been greatly reduced, the Norwegian population needs to be closely monitored. The great black-backed gull typically flies at rotor height and does not avoid wind turbines, putting it at risk of collision. It may show attraction effects by using offshore wind farms as roosting sites. As its adult survival rate and the Norwegian share of the European population are in addition high, it gets a high sensitivity index. The great black-backed gull shows very high preference for our study area in spring, and relatively high preference in the rest of the seasons. This, together with high sensitivity, puts it among the ten most sensitive species around the year (Figure 18).

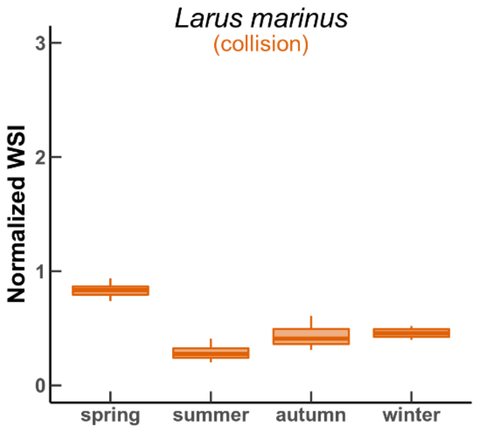

Figure 18. Variation within our study area in normalized WSI values for the great black-backed gull. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

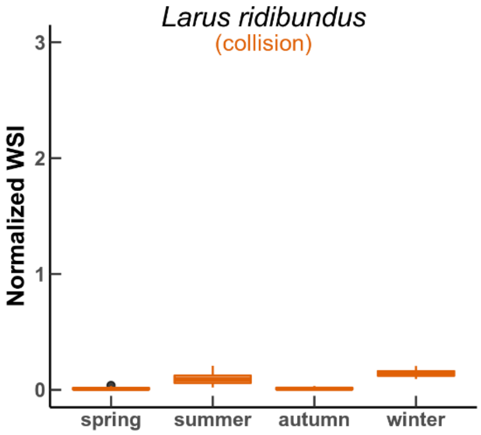

Figure 19. Variation within our study area in normalized WSI values for the black-headed gull. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.14 Black-headed gull (*Larus ridibundus*)

The black-headed gull breeds over all of Norway. It prefers wetlands and freshwater habitats but is also found breeding on islets in the archipelago. The black-headed gull feeds primarily on invertebrates such as earthworms, insects, and crustaceans, but also some fish. Most individuals that breed in Norway overwinter on the British Isles and along the coast of Western Europe, from Denmark all the way to the Iberian Peninsula. The black-headed gull is listed as critically endangered on the Norwegian red list, due to a strong reduction in population size. The species runs a high risk of collision with wind turbines because it typically flies at rotor height, does not avoid wind turbines, and may even use offshore wind farms as roosting sites. It is sensitive around the year in our study area, and, because it shows relatively high preference for the area in winter, among the ten most sensitive species in winter (Figure 19).

3.3.15 Common scoter (*Melanitta nigra*)

The common scoter breeds scattered and in low numbers over large parts of Norway, generally in proximity to mountain lakes. In northern Norway, it has occasionally been observed breeding on the coast. Some overwinter along the coast of Norway, while others migrate further south to Danish waters. The common scoter feeds mostly on molluscs, but also other aquatic invertebrates and small fish. The Norwegian population has been assessed as vulnerable due to its small and decreasing size. The common scoter shows strong avoidance of wind turbines and is therefore at risk of being displaced by wind farms. Its sensitivity is increased by low habitat flexibility. The common scoter is sensitive within our study area throughout the year but particularly in winter (Figure 20), as it shows high preference for the area in this season.

3.3.16 Northern gannet (*Morus bassanus*)

The northern gannet breeds in a few colonies along the Norwegian coast from Sogn og Fjordane to Finnmark, on low islets as well as on steep bird cliffs. It preys on fish such as mackerel, herring, and capelin by plunge-diving. Individuals that breed in Norway overwinter in the pelagic outside western Europe and western Africa. Due to a generally increasing population in Europe and Norway, the northern gannet is listed on the Norwegian red list as being of least concern. It typically flies at rotor height, making it vulnerable to collision with wind turbines, but also shows strong displacement effects (Peschko et al. 2021). A high survival rate among adults increases its sensitivity. The northern gannet is among the ten most sensitive species in all seasons (Figure 21), which is explained by a very strong preference for the area.

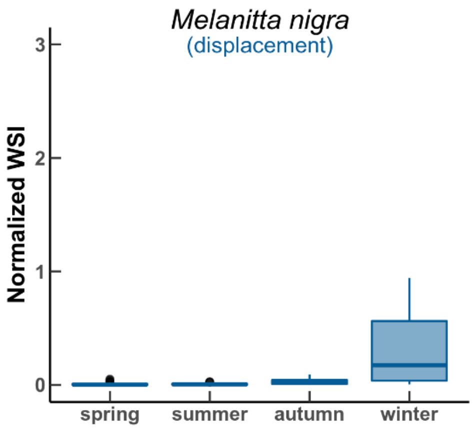

Figure 20. Variation within our study area in normalized WSI values for the common scoter. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

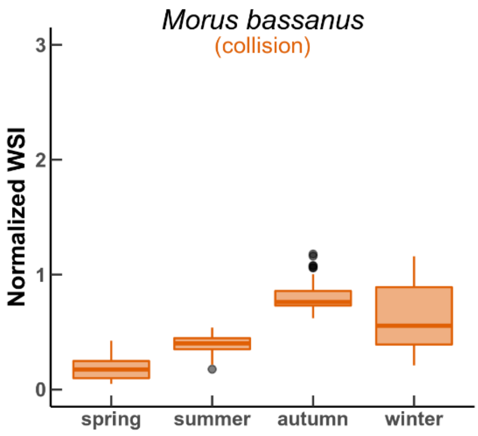

Figure 21. Variation within our study area in normalized WSI values for the northern gannet. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.17 European shag (*Phalacrocorax aristotelis*)

The European shag is a piscivorous bird that breeds in colonies along the whole coast of Norway but is most numerous in mid-Norway. The individuals that breed in Norway also spend their winters along the Norwegian coast. The Norwegian population constitutes a large share of the European population and has been assessed as being of least concern due to being stable. Because the European shag does not avoid wind turbines and may use them as a roosting site, it is at risk of collision. In our study area, it is sensitive all year round and among the ten most sensitive species in spring (Figure 22), which is when it has a high preference for the area. The occurrence of European shags is higher close to the coast and consequently its sensitivity increases to the east of the study area.

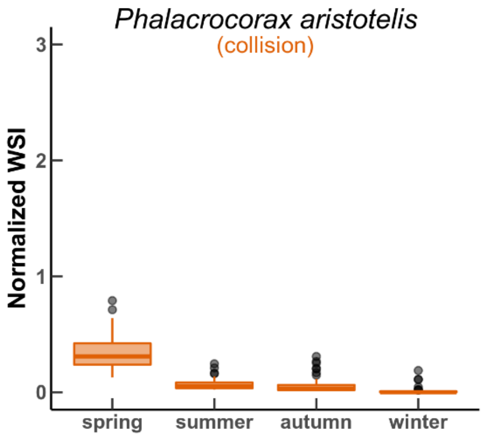

Figure 22. Variation within our study area in normalized WSI values for the European shag. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

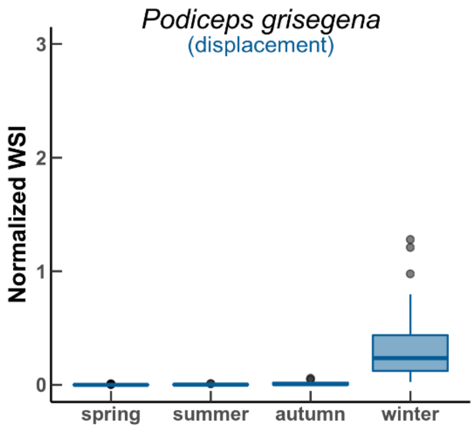

Figure 23. Variation within our study area in normalized WSI values for the red-necked grebe. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.18 Red-necked grebe (*Podiceps grisegena*)

The red-necked grebe breeds in association with freshwater, but only occasionally in Norway. Established breeding populations of red-necked grebes are found in countries south and east of Norway. The species is found overwintering in the Baltic and North Seas, however, and hence also along the Norwegian coast. It feeds on fish, crustaceans, and insects. The conservation status of the red-necked grebe has not been assessed on the Norwegian red list, as there is no established breeding population in Norway. The species avoids wind turbines and is consequently at risk of displacement by wind farms. It is among the ten most sensitive species in our study area during winter when overwintering individuals are present in the area (Figure 23).

3.3.19 Black-legged kittiwake (*Rissa tridactyla*)

The black-legged kittiwake is a pelagic seabird that breeds in colonies along the Norwegian coast from Rogaland to Finnmark. Breeding takes primarily place on bird cliffs, but increasingly also on buildings in towns. The black-legged kittiwake is a surface feeder and preys on small fish and crustaceans. It overwinters in the pelagic in the whole north Atlantic but can occasionally be seen along the Norwegian coast in wintertime. Due to a strong reduction in the Norwegian population, the black-legged kittiwake is regarded as endangered in Norway. In Europe and internationally it is regarded as vulnerable. The black-legged kittiwake is an active flyer, also at night. It flies at rotor height part of the time and does not show much avoidance of wind turbines, making it vulnerable to collision. It may even be attracted to offshore wind farms as breeding sites. The black-legged kittiwake's sensitivity to collision, in combination with being red listed and having a large share of the European population residing in Norway, gives it a high sensitivity index. In our study area, it is among the ten most sensitive species in spring, summer, and winter, which is when it uses the area most actively, but it is sensitive also in autumn (Figure 24).

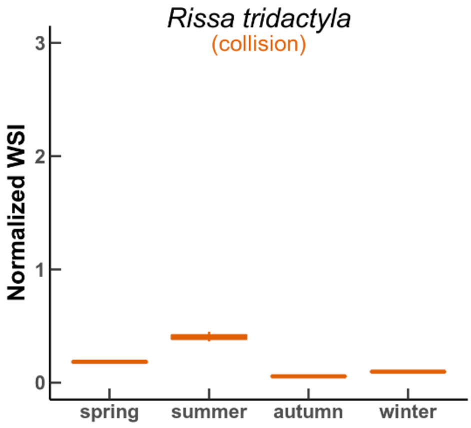

Figure 24. Variation within our study area in normalized WSI values for the black-legged kittiwake. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

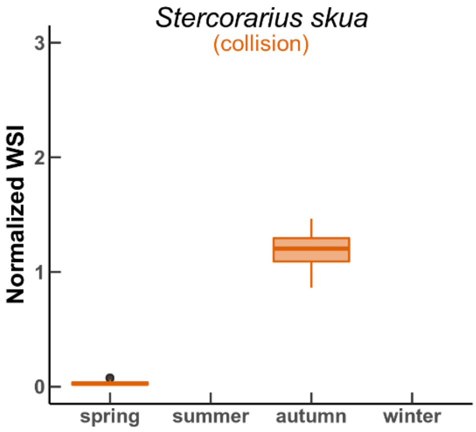

Figure 25. Variation within our study area in normalized WSI values for the great skua. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.20 Great skua (*Stercorarius skua*)

The great skua breeds scattered and in low numbers along the Norwegian coast from Møre og Romsdal all the way to the north. Adults overwinter along the coast of southern Europe, while juveniles have a more pelagic distribution in winter. The great skua has a broad diet consisting of fish, birds, carrion, and offal from the fishery. It is often seen close to bird cliffs and colonies of terns and gulls. The British population of great skuas is increasing and supports the Norwegian population through migration. The great skua is consequently assessed as being of least concern on the Norwegian red list. However, the species spends a large part of its time in flight and does not avoid wind turbines, putting it at risk of collision. It is among the ten most sensitive species in our study area in autumn, as it has a high preference for the area in this season, but it is sensitive also in spring (Figure 25).

3.3.21 Common tern (*Sterna hirundo*)

The common tern breeds along the whole coast of Norway but most of the population resides in the south. It can be seen in association with both freshwater environments inland and the marine environment and feeds primarily on fish. It overwinters along the western and southern coasts of Africa. The common tern is assessed as endangered on the Norwegian red list because the population is declining. It is a species at high risk of collision with wind turbines because it spends a lot of time flying and does not avoid the turbines, and its sensitivity index is further increased by high adult survival, its red list status, and the fact that Norway hosts a large share of the European population. Within our study area, the common tern is among the ten most sensitive species in summer due to a relatively high preference for the area at this time of the year, but it is sensitive also in autumn (Figure 26).

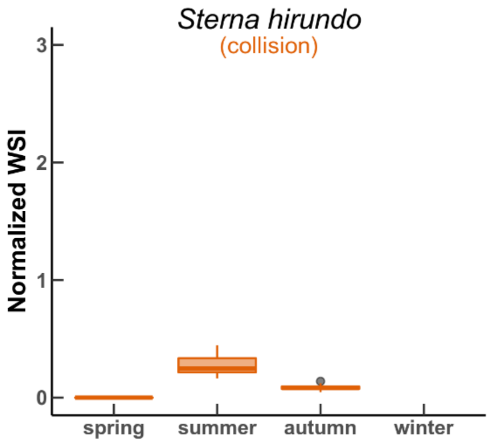

Figure 26. Variation within our study area in normalized WSI values for the common tern. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

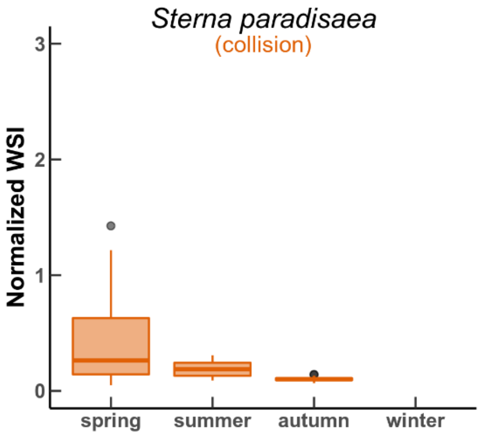

Figure 27. Variation within our study area in normalized WSI values for the arctic tern. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

3.3.22 Arctic tern (*Sterna paradiasea*)

The arctic tern breeds along the whole coast of Norway, preferably in large colonies. While it is common from Hordaland to Finnmark, it is less numerous south and east from Hordaland. The arctic tern is also found breeding inland, often in mountainous environments. It feeds primarily on fish, crustaceans, and insects. The arctic tern undertakes the longest animal migration known, some individuals travel each year as far as between breeding grounds in the Arctic and overwintering grounds in the Antarctic. The Norwegian population of arctic terns is assessed as being of least concern. However, it is a species that spends a lot of time flying and does not avoid wind turbines, putting it at risk of collision. It shows high preference for our study area particularly in spring, but also in summer. The arctic tern is highly sensitive within our study area in spring, summer, and autumn, and among the ten most sensitive species in spring (Figure 27).

3.3.23 Common guillemot (*Uria aalge*)

The common guillemot breeds in colonies on bird cliffs along the Norwegian coast from Rogaland to Finnmark. It preys on fish that are caught through pursuit-diving. The species can be observed along the whole coast of Norway in winter but is most numerous in the south because many British birds overwinter in the Skagerrak area. The common guillemot is listed as critically endangered on the Norwegian red list, due to a dramatic reduction in population size during the last decades. This, together with having a high survival rate among adults, gives the common guillemot a high sensitivity index. It is vulnerable to displacement by wind farms and consequently habitat loss. Because of its high sensitivity and preference for the area, it is among the ten most sensitive species within our study area in all seasons (Figure 28).

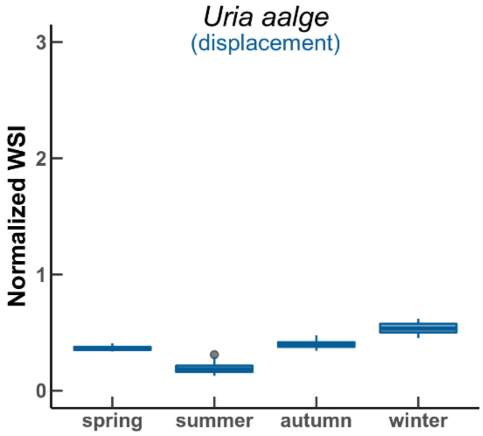

Figure 28. Variation within our study area in normalized WSI values for the common guillemot. The horizontal lines show the median value while the boxes extend from the 25th to the 75th quantile.

4 Discussion

To find out how important the Trollvind study area is for different species of seabirds and other waterbirds in relation to the rest of the EEZ, we used species distribution models to establish models of species-specific habitat preference. The species distribution and habitat preference models are based on tracking of seabirds (SEATRACK dataset) and observations of birds (SEAPOP and Artsobservasjoner datasets) and are independent of population size. While species distribution models predict the chance of finding a species in a specific geographic area, the habitat preference models describe the importance of an area for a specific species and season relative to other areas in the EEZ. The habitat preference models were used together with species-specific sensitivity indices to estimate how sensitive different species are to offshore wind farms. Species sensitivity models were created for the whole EEZ, from which values were extracted for our study area. To calculate seasonal and total sensitivity, species-specific sensitivity values were summed and then standardized in relation to maximum values in EEZ. The seasonal sensitivity models describe differences in sensitivity between seasons and the spatial variation in the sensitivity of birds in each season. The total sensitivity model represents maximum seasonal sensitivity values and hence the highest sensitivity found during the year. All these composite indicators (species-specific, seasonal, and total WSI) are dimensionless and relative to maximum predicted sensitivity in the EEZ. It is important to note that in the present work we do not quantify the effects of the proposed wind farm on specific bird populations but assess the relative sensitivity of birds in the area based on best available data and knowledge.

Total bird sensitivity is highest along the coast and decreases gradually with increasing distance from shore. Sensitivity is also generally higher in the more productive continental seas than in deep sea areas, i.e., the North Sea and Barents Sea show higher WSI values than the Norwegian Sea. The general pattern, where higher sensitivity is found closer to the coast, is reflected in our study area, which shows values of medium sensitivity in the north-eastern quarter and values of below-medium sensitivity in the rest of the area. In the breeding season, all breeding birds are tied to breeding grounds on land, and many species, such as shags, cormorants, and many ducks, find coastal areas the most attractive also outside the breeding season. Although several species spend winters offshore, other species migrate from freshwater environments to coastal areas for the winter, such as many geese and divers, giving coastal areas high WSI values throughout the year.

Our models of seasonal sensitivity show that bird sensitivity within the study area, like in the rest of the EEZ, is highest in the breeding season. Summer WSI values range from medium sensitivity in west and south to above-medium in east and northeast. WSI values in spring and autumn range from below-medium to medium, while they remain below-medium in winter. In all seasons, highest sensitivity was found in the eastern and particularly north-eastern part of the study area. Birds are more sensitive in the breeding season because their feeding range is restricted, making them dependent on food resources found relatively close to the colony. Also, because the activity level of breeding birds is high, and they may fly between the colony and feeding grounds several times a day (or night), they run a higher risk of colliding with wind turbines along the route.

Overwintering birds are found in the study area outside the breeding season. Without spatial constraints from chicks needing to be fed, birds are more flexible in their area use in winter and possibly less affected by displacement. In spring and autumn, migrating and moulting birds are likely to be encountered in the study area. Moulting birds are flightless and not at risk of collision with turbines, except from with submerged structures in the case of diving birds. They are more sensitive to displacement, however, due to stronger avoidance behaviour during the moult. Migrating birds typically fly despite decreased visibility from darkness or weather conditions, putting them at higher risk of collision. The migration routes of many species, such as the red-throated diver (*Gavia stellata*) and the barnacle goose (*Branta leucopsis*), follow the Norwegian coast and lie in proximity to our study area. However, because there is little tracking data form these migrations, we are unable to give a description of e.g., how far from the shore the flyway of a species extends, and further investigation is required to be able to say something about the degree to which the migration routes intersect with our study area. Wind farms that coincide with migratory flyways or local flight paths are likely to impede movement or increase mortality risk for the species affected in the seasons in which migration takes place or flight paths are used.

The study area is used by several species of birds; of the fifty-eight species considered in our study, forty-nine use the area in at least one season. The WSI values found within the study area for each species depend on the importance of the area as habitat for the species in relation to other parts of the EEZ, season (breeding or non-breeding season), and the species' sensitivity index. Therefore, all the species listed as sensitive in our study area show a high or relatively high preference for our study area in the seasons in which they are sensitive. The northern gannet (*Morus bassanus*), great (*Larus marinus*) and lesser black-backed (*L. fuscus*) gulls, European storm petrel (*Hydrobates pelagicus*), great skua (*Stercorarius skua*), and arctic tern (*Sterna paradisaea*) are among species showing particularly high preference for the area.

Divers, gulls, and terns are well represented among the most sensitive birds in our study area. Very strong avoidance behaviour and low habitat flexibility are main factors making divers sensitive to displacement by wind farms. A high natural survival rate among adults makes the populations of divers sensitive to adult mortality, a possible indirect outcome of displacement and habitat loss. Gulls and terns are on the other hand sensitive to collision with wind turbines because they do not avoid wind farms, and gulls may even be attracted to them. Terns spend a great proportion of their time flying, which increases collision risk, while gulls typically fly in rotor height, increasing their risk of flying through the rotor swept area. Also gulls and terns generally have low adult mortality, making their populations sensitive to increased mortality from collisions. The populations of gulls and terns in Vestland county have undergone a substantial reduction during the last decades (Table 2, Arneberg et al. In prep), with poor prey availability likely being the main cause. Additional stressors causing increased adult mortality could hamper the restauration of these populations.

In addition to divers, we find razorbill (*Alca torda*), common scoter (*Melanitta nigra*), brant goose (*Branta bernicla*), red-necked grebe (*Podiceps grisegena*), and common guillemot (*Uria aalge*) among the species most sensitive to displacement in our study area. Strong avoidance behaviour and low habitat flexibility make the brant goose, common scoter, and red-necked grebe sensitive, while the most important factors making the common guillemot and razorbill sensitive are very low natural mortality rate among adults and high conservation status (the common guillemot is critically endangered, and the razorbill is vulnerable). European storm petrel (*Hydrobates pelagicus*), black-legged kittiwake (*Rissa tridactyla*), great skua (*Stercorarius skua*), and European shag (*Phalacrocorax aristotelis*) join gulls and terns in the species most sensitive to collision in our study area. They do not avoid wind turbines and have low adult mortality rates. The sensitivity of the European storm petrel is also increased by its nocturnal flight activity, which increases collision risk due to low visibility, while the collision risk of the great skua is increased by a large proportion of time spent in flight. Northern fulmar (*Fulmarus glacialis*) and northern gannet (*Morus bassanus*) are sensitive to collision but may also be displaced by wind farms. Nocturnal flight activity increases the northern fulmar's collision risk, while the northern gannet typically flies at rotor height. In addition, both species' populations are sensitive to collision mortality due to very low adult mortality rates.

Birds typically move over large areas making distribution models smooth over fine spatial scales. The distribution and consequently sensitivity of species within and around our study area are therefore uniform for most species, and the spatial variation in species-specific sensitivity values within our study area is low for a given season. On the contrary, seasonal variation in species-specific distribution and sensitivity within the study area is large for several species, because of species' migration habits and differences in area use during the breeding and non-breeding seasons.

5 Conclusions

Where birds and wind farms coincide spatially and temporally, conflicts are predicted to arise, at least with species that are sensitive to wind farms. The responses of birds to offshore wind farms range from avoidance, effectively leading to habitat loss, to attraction, causing risk of collision with wind turbines. Also lack of detection of turbines can lead to collision, particularly at night and during poor weather conditions. In this report, we use a sensitivity index based on best available data and knowledge, to assess the relative sensitivity of 58 bird species to wind farms in the Trollvind area. It is important to note that the index does not quantify the vulnerability of the bird populations but is a relative measure that can be used to compare sensitivity among areas, seasons, and species.

For the Norwegian EEZ, bird sensitivity was found to be highest along the coast and decreased offshore. Furthermore, in offshore areas, continental seas (e.g., Barents Sea and North Sea) show higher bird sensitivity than deep-sea areas in the Norwegian Sea. Compared to the Norwegian EEZ, total bird sensitivity in the Trollvind area ranges from below-medium to medium. Birds are most sensitive in summer and in the eastern and north-eastern parts of the study area. The number of species using the area is also highest in summer.

The ranking of the most sensitive species in the Trollvind area changes between seasons due to seasonal migration and changes in habitat use. Sensitive species include both locally breeding species and species that breed elsewhere and use the area for migration or as a non-breeding habitat. In general, the Trollvind area is too far offshore to have a negative impact on sea ducks and waders. Sensitive species that also breed locally include coastal surface-feeding gulls and terns. These are lesser black-backed gull, common gull, herring gull, great black-backed gull, and Arctic tern, which have all seen significant reductions in local populations during the last decades. Sensitive species that use the area as habitat but do not breed locally, include pelagic diving and surface-feeding seabird species. These are northern gannet, common guillemot, black-legged kittiwake, northern fulmar, European storm petrel, and razorbill. Great skua and brant goose migrate through the area and are especially sensitive in autumn. Finally, divers that breed elsewhere but use the area as winter area were found to be sensitive. These were great northern diver, red-throated diver, and red-necked grebe.

6 Limitations and knowledge gaps

The SDMs used to calculate habitat preference, and ultimately used in sensitivity estimation in the study area, include some uncertainty arising from the uneven spatial and temporal coverage of observation effort. Observation effort in the combined dataset we have used is biased towards coastal and continental shelf areas, while coverage further offshore in the Norwegian Sea is poor. This observation bias was accounted for by using the Target Group method (Phillips et al. 2009), where the presence of the species of interest is modelled using observations of other bird species as background points (pseudo-absence points of the species of interest). This introduces the bias found in the presence data into the background data. Highly biased sampling effort creates several challenges related to the modelling. For example, large samples along the coast often resulted in overfitting and unrealistic predictions in offshore areas with few observations. To overcome this problem, model predictions were inspected manually, and unrealistic models were replaced by simplified models.

Due to limited data, we were not able to model the distribution of all species that potentially use the study area. Additionally, for some of the species for which distribution models were obtained, we were not able to predict distribution for all seasons, owing either to seasonally low abundance in Norway or to the lack of observation effort in a specific season. This limitation likely does not affect our results significantly, as species of which there are few observations are typically rare. Some of these rare species could however be sensitive to wind farms, not least due to a small population size, or be on the Norwegian red list of threatened species.

Though the data used for species distribution modelling in this study include observations of migrating birds, migrations were not specifically considered here. We know that the study area lies in proximity to migratory flyways of species that migrate along the Norwegian coast, such as the red-throated diver. The degree to which the study area is used by migrating birds needs to be assessed in future work using fine-scale tracking data during the important spring and autumn migration periods.

The knowledge available on the size and vulnerability of most bird populations is limited, particularly knowledge on their sensitivity to wind farms. These factors directly affect species sensitivity indices, and changes in them may have large effects on our predictions of bird sensitivity.

6.1 Knowledge needs

More knowledge of species-specific behavioural patterns, population effects, and migration routes, as well as knowledge of cumulative effects, are needed for in-depth impact assessments.

The ability of our SDMs to predict species distribution in the study area and the rest of the EEZ should be re-checked to validate all our models and assure their quality.

Most data used here for modelling species distribution were collected outside the study area. To reduce uncertainty and decrease the scale at which species distribution can be predicted, we suggest data collection within the study area. Through repeated and structured observational transects inside the study area, fine-scale data on actual species distributions could be obtained.

The direct effects that an offshore wind farm will have on birds through displacement or collision mortality are difficult to predict and follow-up studies would be needed during all life-cycle stages of a potential wind farm. These include bird surveys inside and outside the wind farm for monitoring changes in birds' use of the area, as well as documentation of collision incidences using for example (thermal) video imaging. The long-term effects on bird populations of indirect effects are even more difficult to predict, and will need detailed, long-term studies, that monitor birds in a before-after-control-treatment design. Given the large temporal and spatial variation in environmental conditions it is crucial that studies are initiated several years in advance of the wind-farm construction.

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Appendices

Appendix 1

Table A1. Species lacking distribution models in all seasons due to insufficient data.

Species with no distribution model	
Latin name	**English name**
Anser erythropus	Lesser white-fronted goose
Anser fabalis	Taiga bean goose
Anser serrirostris	Tundra bean goose
Branta ruficollis	Red-breasted goose
Cygnus columbianus	Tundra swan
Gavia pacifica	Pacific loon
Hydrobates leucorhous	Leach's storm petrel
Larus minutus	Little gull
Larus sabini	Sabine's gull
Marcea penelope	Eurasian wigeon
Melanitta perspicillata	Surf scoter
Mergellus albellus	Smew
Pagophila eburnea	Ivory gull
Phalaropus fulicarius	Red phalarope
Podiceps cristatus	Great crested grebe
Puffinus griseus	Sooty shearwater
Puffinus puffinus	Manx shearwater
Rhodostethia rosea	Ross's gull
Thalasseus sandvicensis	Sandwich tern

Table A2. Species with no significant predicted presence within the study area. Species lacking distribution model in 1-3 season(s) are indicated in yellow.

Species with no significant presence in the study area	
Latin name	**English name**
Anser albifrons	Greater white-fronted goose
Branta canadensis	Canada goose
Cygnus olor	Mute swan
Mareca strepera	Gadwall
Polysticta stelleri	Steller's eider
Spatula clypeata	Northern shoveler
Spatula querquedula	Garganey
Tachybaptus ruficollis	Little grebe
Tadorna tadorna	Common shelduck

Appendix 2

Table A3 (1 of 2). Species list with variables used for the calculation of sensitivity indices (see section 2.3.1; Garthe & Hüppop 2004, King et al. 2009, Furness et al. 2013, Robinson Willmott et al. 2013, Bradbury et al. 2014, Dierschke et al. 2016, Kelsey et al. 2018). Species lacking distribution models in 1-3 seasons due to insufficient data are indicated in yellow.

Species name			Seasonal sensitivity s		National share of the European population	Norwegian Red List status	Adult survival	Nocturnal flight activity	Amount of time spent flying	Amount of time spent at rotor height	Avoidance (risk of collision)	Avoidance (risk of displacement)	Habitat flexibility
Latin	**English**	**Norwegian**	Breeding season	Non-breeding season	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
Alca torda	Razorbill	Alke	1	1	4	4	5	1	1	1	3	3	3
Alle alle	Little auk	Alkekonge	1	1	4	1	4	1	3	1	4	2	2
Anas platyrhynchos	Mallard	Stokkand	0.5	1	2	1	1	1	3	5	1	5	4
Anser anser	Greylag goose	Grågås	1	1	3	1	3	5	5	5	4	2	4
Anser brachyrhynchus	Pink-footed goose	Kortnebbgås	1	1	5	1	3	5	5	5	4	2	4
Aythya ferina	Common pochard	Taffeland	0.5	1	1	1	1	5	2	1	3	3	4
Aythya fuligula	Tufted duck	Toppand	0.5	1	2	1	1	5	2	1	3	3	4
Aythya marila	Greater scaup	Bergand	0.5	1	1	4	1	5	2	1	3	3	4
Branta bernicla	Brant goose	Ringgås	1	1	5	2	4	1	1	5	1	5	4
Branta leucopsis	Barnacle goose	Hvitkinngås	1	1	3	1	4	1	1	5	1	5	4
Bucephala clangula	Common goldeneye	Kvinand	0.5	1	2	1	2	3	2	3	2	4	4
Cepphus grylle	Black guillemot	Teist	1	1	5	2	4	1	1	1	3	3	4
Clangula hyemalis	Long-tailed duck	Havelle	0.5	1	2	2	1	4	3	3	3	3	4
Cygnus cygnus	Whooper swan	Sangsvane	0.5	1	2	1	3	5	5	5	4	2	4
Fratercula arctica	Atlantic puffin	Lunde	1	1	5	4	5	1	1	1	4	2	3
Fulmarus glacialis	Northern fulmar	Havhest	1	1	5	4	5	4	2	1	3	3	1
Gavia adamsii	Yellow-billed diver	Gulnebblom	1	1	5	3	4	1	2	3	1	5	4
Gavia arctica	Black-throated diver	Storlom	0.5	1	2	1	4	1	3	3	1	5	4
Gavia immer	Great northern diver	Islom	1	1	4	1	4	1	2	3	1	5	3
Gavia stellata	Red-throated diver	Smålom	0.5	1	3	1	3	1	2	3	1	5	4
Hydrobates pelagicus	European storm petrel	Havsvale	1	1	2	1	4	4	3	1	5	1	1
Larus argentatus	Herring gull	Gråmåke	1	1	4	3	5	3	2	5	5	1	1
Larus canus	Common gull	Fiskemåke	1	1	4	3	3	3	2	5	5	1	2
Larus fuscus	Lesser black-backed gull	Sildemåke	1	1	3	1	5	3	2	5	5	1	1
Larus glaucoides	Iceland gull	Grønlandsmåke	1	1	1	1	5	3	3	5	4	2	2
Larus hyperboreus	Glaucous gull	Polarmåke	1	1	3	3	5	3	2	5	4	2	1
Larus marinus	Great black-backed gull	Svartbak	1	1	5	2	5	3	2	5	5	1	2
Larus ridibundus	Black-headed gull	Hettemåke	1	1	1	5	3	2	1	5	5	1	3
Melanitta fusca	Velvet scoter	Sjøorre	0.5	1	2	3	3	3	2	1	1	5	3
Melanitta nigra	Common scoter	Svartand	0.5	1	1	3	2	3	2	1	1	5	4
Mergus merganser	Common merganser	Laksand	0.5	1	3	1	1	1	1	3	2	4	4
Mergus serrator	Red-breasted merganser	Siland	1	1	4	1	2	2	1	3	2	4	4
Morus bassanus	Northern gannet	Havsule	1	1	1	1	5	2	3	5	3	3	1
Phalacrocorax aristotelis	European shag	Toppskarv	1	1	5	1	3	1	2	3	5	1	3
Phalacrocorax carbo	Great cormorant	Storskarv	1	1	3	2	3	1	2	3	5	1	3
Phalaropus lobatus	Red-necked phalarope	Svømmesnipe	0.5	1	2	3	1	2	3	3	4	2	2
Podiceps auritus	Horned grebe	Horndykker	0.5	1	1	3	1	2	2	1	1	5	4
Podiceps grisegena	Red-necked grebe	Gråstrupedykker	1	1	1	1	4	1	1	3	1	5	3
Rissa tridactyla	Black-legged kittiwake	Krykkje	1	1	4	4	3	3	3	3	5	1	3
Somateria mollissima	Common eider	Ærfugl	1	1	4	3	4	3	2	1	3	3	4
Somateria spectabilis	King eider	Praktærfugl	1	1	2	2	5	5	5	5	1	5	4
Stercorarius longicaudus	Long-tailed skua	Fjelljo	0.5	1	4	3	4	1	5	3	5	1	2
Stercorarius parasiticus	Arctic skua	Tyvjo	1	1	4	3	4	1	5	3	5	1	2
Stercorarius pomarinus	Pomarine skua	Polarjo	1	1	1	1	4	1	3	3	5	1	2
Stercorarius skua	Great skua	Storjo	1	1	3	1	4	1	4	3	5	1	2
Sterna hirundo	Common tern	Makrellterne	1	1	4	4	4	1	5	3	5	1	3
Sterna paradisaea	Arctic tern	Rødnebbterne	1	1	3	1	4	1	5	3	5	1	3
Uria lomvia	Thick-billed guillemot	Polarlomvi	1	1	5	5	5	1	1	1	1	5	3
Uria aalge	Common guillemot	Lomvi	1	1	4	5	5	2	1	1	3	3	3

Table A3 (2 of 2). Species list with sensitivity indices (see section 2.3.1; Garthe & Hüppop 2004, King et al. 2009, Furness et al. 2013, Robinson Willmott et al. 2013, Bradbury et al. 2014, Dierschke et al. 2016, Kelsey et al. 2018). The type of sensitivity that is the most preponderant, collision or displacement, is indicated in blue. Species lacking distribution models in 1-3 seasons due to insufficient data are indicated in yellow.

Species name			**General sensitivity** $Sg = s*(a+b+c)/3$		**Sensitivity to collision** $Sc = ((d+e)/2+f+g)/3$	**Sensitivity to displacement** $Sd = ((h+i)/2)$	**Total sensitivity to collision** $(Sg*Sc)$		**Total sensitivty to displacement** $(Sg*Sd)$	
Latin	**English**	**Norwegian**	Breeding season	Non-breeding season			Breeding season	Non-breeding season	Breeding season	Non-breeding season
Alca torda	Razorbill	Alke	4.33	4.33	1.67	3.00	7.22	7.22	13.00	13.00
Alle alle	Little auk	Alkekonge	3.00	3.00	2.33	2.00	7.00	7.00	6.00	6.00
Anas platyrhynchos	Mallard	Stokkand	0.67	1.33	2.67	4.50	1.78	3.56	3.00	6.00
Anser anser	Greylag goose	Grågås	2.33	2.33	4.67	3.00	10.89	10.89	7.00	7.00
Anser brachyrhynchus	Pink-footed goose	Kortnebbgås	3.00	3.00	4.67	3.00	14.00	14.00	9.00	9.00
Aythya ferina	Common pochard	Taffeland	0.50	1.00	2.50	3.50	1.25	2.50	1.75	3.50
Aythya fuligula	Tufted duck	Toppand	0.67	1.33	2.50	3.50	1.67	3.33	2.33	4.67
Aythya marila	Greater scaup	Bergand	1.00	2.00	2.50	3.50	2.50	5.00	3.50	7.00
Branta bernicla	Brant goose	Ringgås	3.67	3.67	2.33	4.50	8.56	8.56	16.50	16.50
Branta leucopsis	Barnacle goose	Hvitkinngås	2.67	2.67	2.33	4.50	6.22	6.22	12.00	12.00
Bucephala clangula	Common goldeneye	Kvinand	0.83	1.67	2.50	4.00	2.08	4.17	3.33	6.67
Cepphus grylle	Black guillemot	Teist	3.67	3.67	1.67	3.50	6.11	6.11	12.83	12.83
Clangula hyemalis	Long-tailed duck	Havelle	0.83	1.67	3.17	3.50	2.64	5.28	2.92	5.83
Cygnus cygnus	Whooper swan	Sangsvane	1.00	2.00	4.67	3.00	4.67	9.33	3.00	6.00
Fratercula arctica	Atlantic puffin	Lunde	4.67	4.67	2.00	2.50	9.33	9.33	11.67	11.67
Fulmarus glacialis	Northern fulmar	Havhest	4.67	4.67	2.33	2.00	10.89	10.89	9.33	9.33
Gavia adamsii	Yellow-billed diver	Gulnebblom	4.00	4.00	1.83	4.50	7.33	7.33	18.00	18.00
Gavia arctica	Black-throated diver	Storlom	1.17	2.33	2.00	4.50	2.33	4.67	5.25	10.50
Gavia immer	Great northern diver	Islom	3.00	3.00	1.83	4.00	5.50	5.50	12.00	12.00
Gavia stellata	Red-throated diver	Smålom	1.17	2.33	1.83	4.50	2.14	4.28	5.25	10.50
Hydrobates pelagicus	European storm petrel	Havsvale	2.33	2.33	3.17	1.00	7.39	7.39	2.33	2.33
Larus argentatus	Herring gull	Gråmåke	4.00	4.00	4.17	1.00	16.67	16.67	4.00	4.00
Larus canus	Common gull	Fiskemåke	3.33	3.33	4.17	1.50	13.89	13.89	5.00	5.00
Larus fuscus	Lesser black-backed gull	Sildemåke	3.00	3.00	4.17	1.00	12.50	12.50	3.00	3.00
Larus glaucoides	Iceland gull	Grønlandsmåke	2.33	2.33	4.00	2.00	9.33	9.33	4.67	4.67
Larus hyperboreus	Glaucous gull	Polarmåke	3.67	3.67	3.83	1.50	14.06	14.06	5.50	5.50
Larus marinus	Great black-backed gull	Svartbak	4.00	4.00	4.17	1.50	16.67	16.67	6.00	6.00
Larus ridibundus	Black-headed gull	Hettemåke	3.00	3.00	3.83	2.00	11.50	11.50	6.00	6.00
Melanitta fusca	Velvet scoter	Sjøorre	1.33	2.67	1.50	4.00	2.00	4.00	5.33	10.67
Melanitta nigra	Common scoter	Svartand	1.00	2.00	1.50	4.50	1.50	3.00	4.50	9.00
Mergus merganser	Common merganser	Laksand	0.83	1.67	2.00	4.00	1.67	3.33	3.33	6.67
Mergus serrator	Red-breasted merganser	Siland	2.33	2.33	2.17	4.00	5.06	5.06	9.33	9.33
Morus bassanus	Northern gannet	Havsule	2.33	2.33	3.50	2.00	8.17	8.17	4.67	4.67
Phalacrocorax aristotelis	European shag	Toppskarv	3.00	3.00	3.17	2.00	9.50	9.50	6.00	6.00
Phalacrocorax carbo	Great cormorant	Storskarv	2.67	2.67	3.17	2.00	8.44	8.44	5.33	5.33
Phalaropus lobatus	Red-necked phalarope	Svømmesnipe	1.00	1.00	3.17	2.00	3.17	3.17	2.00	2.00
Podiceps auritus	Horned grebe	Horndykker	0.83	1.67	1.33	4.50	1.11	2.22	3.75	7.50
Podiceps grisegena	Red-necked grebe	Gråstrupedykker	2.00	2.00	1.67	4.00	3.33	3.33	8.00	8.00
Rissa tridactyla	Black-legged kittiwake	Krykkje	3.67	3.67	3.67	2.00	13.44	13.44	7.33	7.33
Somateria mollissima	Common eider	Ærfugl	3.67	3.67	2.17	3.50	7.94	7.94	12.83	12.83
Somateria spectabilis	King eider	Praktærfugl	3.00	3.00	3.67	4.50	11.00	11.00	13.50	13.50
Stercorarius longicaudus	Long-tailed skua	Fjelljo	1.83	3.67	3.67	1.50	6.72	13.44	2.75	5.50
Stercorarius parasiticus	Arctic skua	Tyvjo	3.67	3.67	3.67	1.50	13.44	13.44	5.50	5.50
Stercorarius pomarinus	Pomarine skua	Polarjo	2.00	2.00	3.33	1.50	6.67	6.67	3.00	3.00
Stercorarius skua	Great skua	Storjo	2.67	2.67	3.50	1.50	9.33	9.33	4.00	4.00
Sterna hirundo	Common tern	Makrellterne	4.00	4.00	3.67	2.00	14.67	14.67	8.00	8.00
Sterna paradisaea	Arctic tern	Rødnebbterne	2.67	2.67	3.67	2.00	9.78	9.78	5.33	5.33
Uria lomvia	Thick-billed guillemot	Polarlomvi	5.00	5.00	1.00	4.00	5.00	5.00	20.00	20.00
Uria aalge	Common guillemot	Lomvi	4.67	4.67	1.83	3.00	8.56	8.56	14.00	14.00

Calculation of variable scores for table A3

Norwegian share of the European population (a)

Score	
1	<1%
2	1-4%
3	5-9%
4	10-19%
5	>= 20%

Status on the Norwegian red list of endangered species (*b*)

Score	
1	No classification/ LC
2	NT, Near Threatened
3	VU, Vulnerable
4	EN, Endangered
5	CR, Critically Endangered

Adult survival (*c*)

Score	
1	< 0.75
2	0.75 – 0.80
3	0.81 – 0.85
4	0.86 – 0.90
5	> 0.90

Nocturnal flight activity (*d*)

Five categories, with score 1 (limited flight activity at night) to score 5 (much flight activity at night).

Time spent at flight (*e*)

Score	
1	0-20% of time at sea spend flying
2	21-40% of time at sea spend flying
3	41-60% of time at sea spend flying
4	61-80% of time at sea spend flying
5	81-100% of time at sea spend flying

Time spent at rotor height (*f*)

Score	
5	> 20 %
3	5-20 %
1	< 5 %

Avoidance behaviour (risk of collision) (*g*)

Score	
1	> 40 % avoidance
2	30 – 40 % avoidance
3	18 – 29 % avoidance
4	6 – 17 % avoidance
5	0 – 5 % avoidance

Avoidance behaviour (risk of displacement) (*h*)

Score	
1	0 – 5 % avoidance
2	6 – 17 % avoidance
3	18 – 29 % avoidance
4	30 – 40 % avoidance
5	> 40 % avoidance

Habitat flexibility (*i*)

Five categories, with score 1 (tend to forage over large marine areas with little known association with particular marine features) to score 5 (tend to feed on very specific habitat features).

Appendix 3

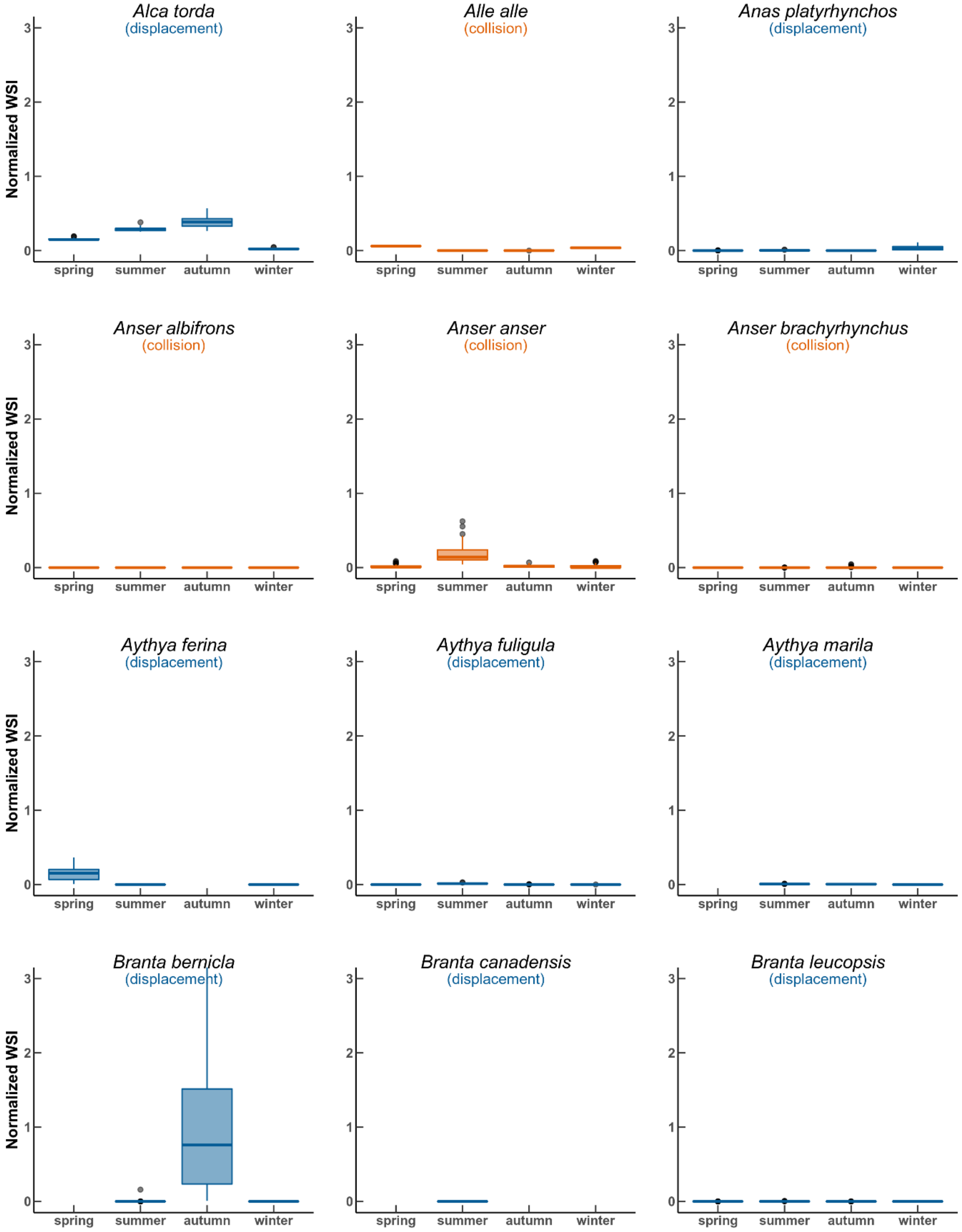

Figure A1 (1 of 5). Boxplots of the seasonal variation in normalized WSI values for each species considered in our study area. The horizontal lines show median values while boxes extend from the 25th to the 75th quantiles. The type of sensitivity that is the most preponderant (displacement or collision) is indicated. For some species x seasons combination the study area was not used by the species, hence some missing values.

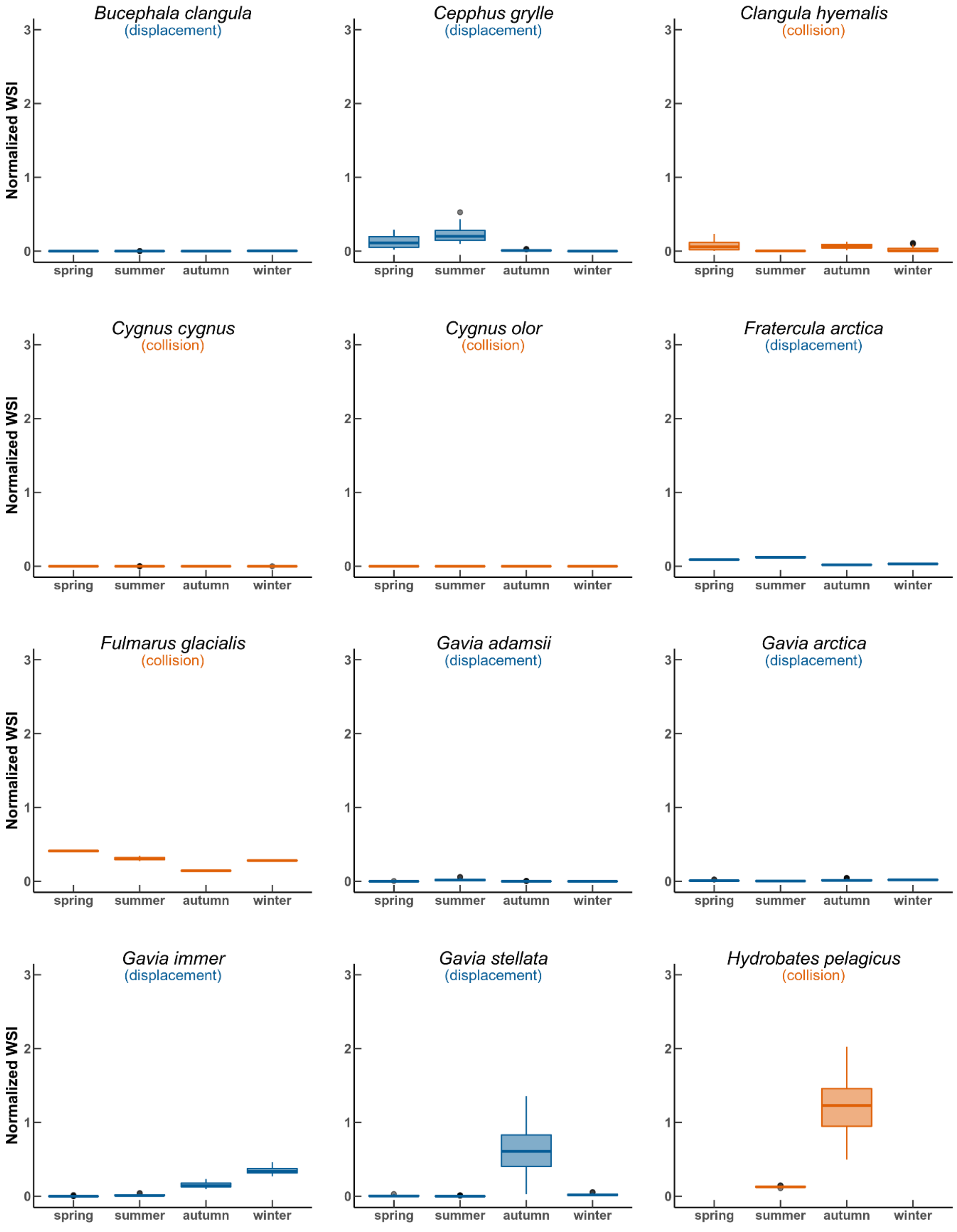

Figure A1 (2 of 5). Boxplots of the seasonal variation in normalized WSI values for each species considered in our study area. The horizontal lines show median values while boxes extend from the 25th to the 75th quantiles. The type of sensitivity that is the most preponderant (displacement or collision) is indicated. For some species x seasons combination the study area was not used by the species, hence some missing values.

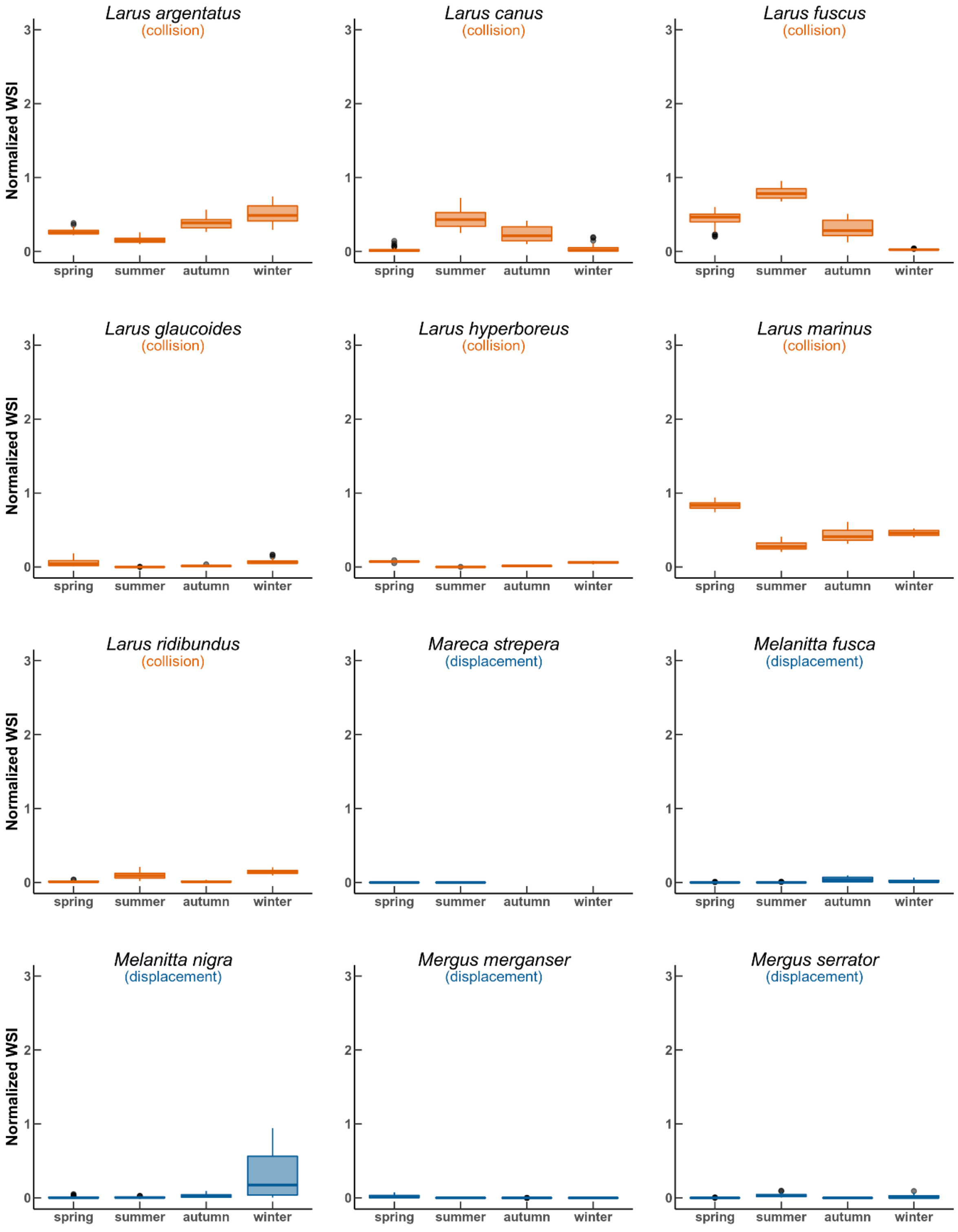

Figure A1 (3 of 5). Boxplots of the seasonal variation in normalized WSI values for each species considered in our study area. The horizontal lines show median values while boxes extend from the 25th to the 75th quantiles. The type of sensitivity that is the most preponderant (displacement or collision) is indicated. For some species x seasons combination the study area was not used by the species, hence some missing values.

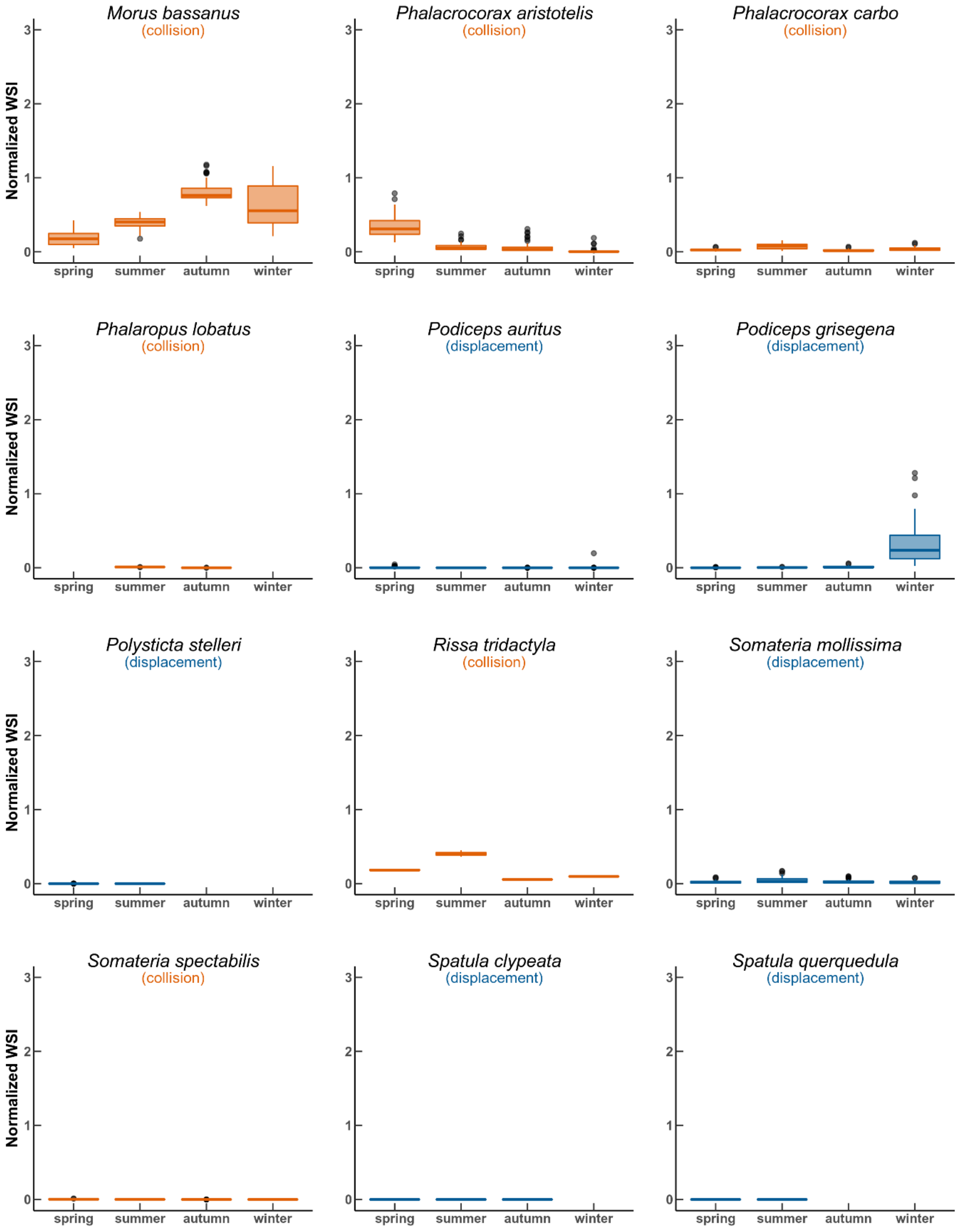

Figure A1 (4 of 5). Boxplots of the seasonal variation in normalized WSI values for each species considered in our study area. The horizontal lines show median values while boxes extend from the 25th to the 75th quantiles. The type of sensitivity that is the most preponderant (displacement or collision) is indicated. For some species x seasons combination the study area was not used by the species, hence some missing values.

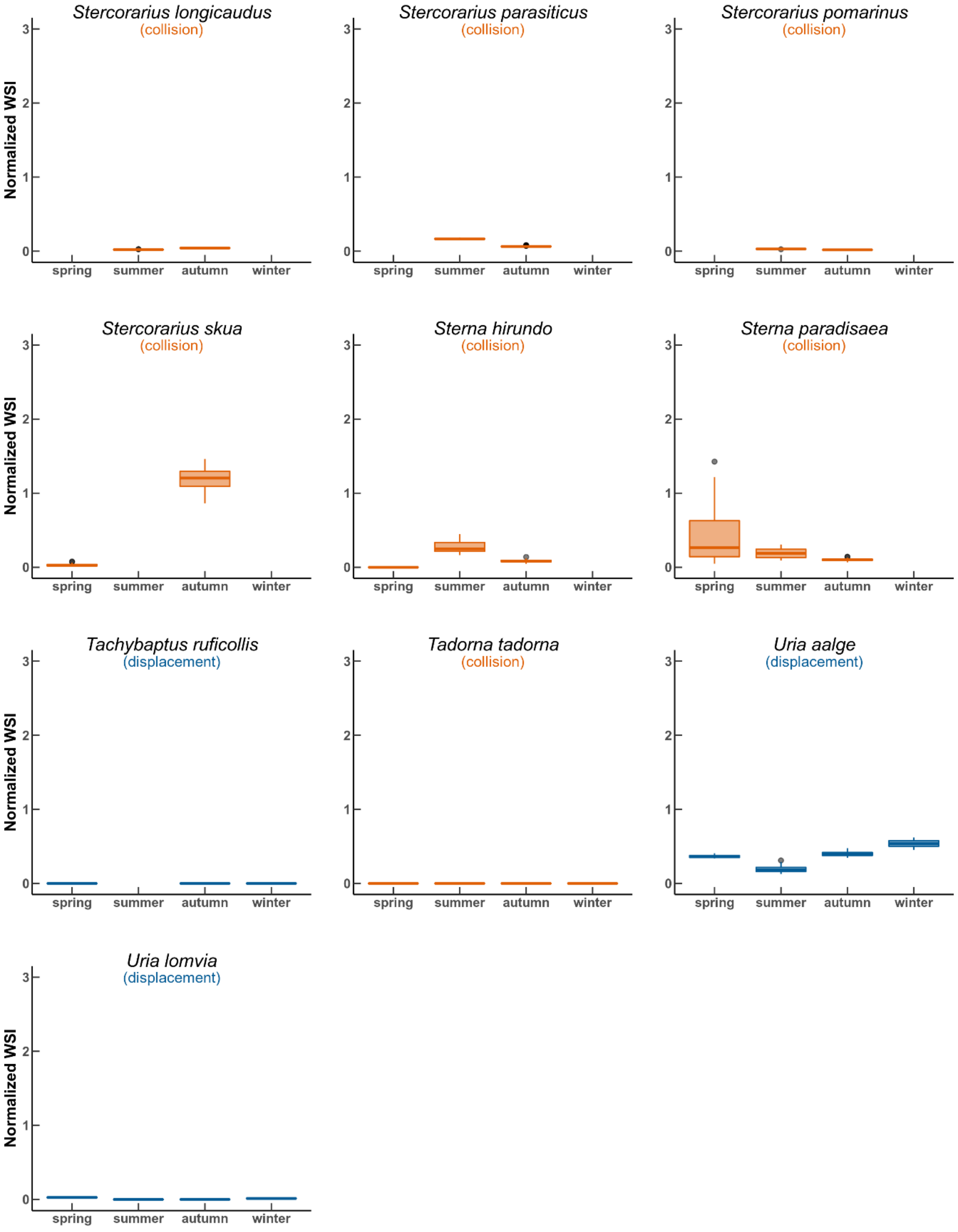

Figure A1 (5 of 5). Boxplots of the seasonal variation in normalized WSI values for each species considered in our study area. The horizontal lines show median values while boxes extend from the 25th to the 75th quantiles. The type of sensitivity that is the most preponderant (displacement or collision) is indicated. For some species x seasons combination the study area was not used by the species, hence some missing values.

Appendix 4

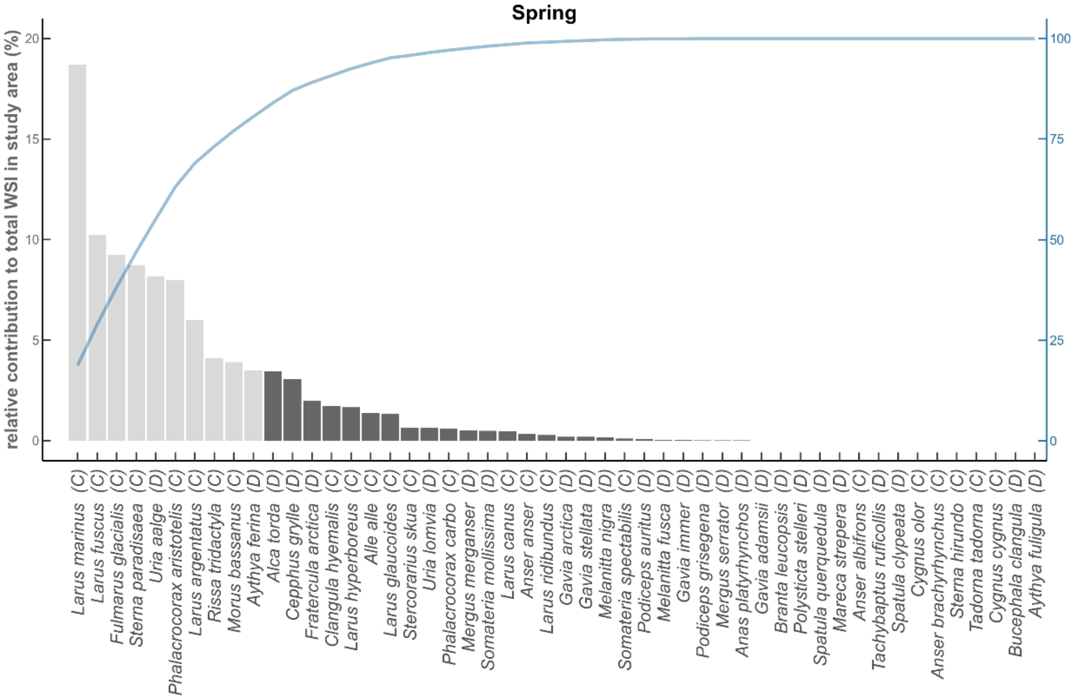

Figure A2 (1 of 4). Species that use the study area, given for spring and ranked from highest to lowest sensitivity within the area. Column height corresponds to the percentage of seasonal sensitivity explained by the species. The ten species with the highest sensitivity within the study area are indicated in light grey. The type of sensitivity that is the most preponderant, (D) displacement or (C) collision, is indicated. The blue line shows the cumulative percentage of species' contribution to seasonal sensitivity.

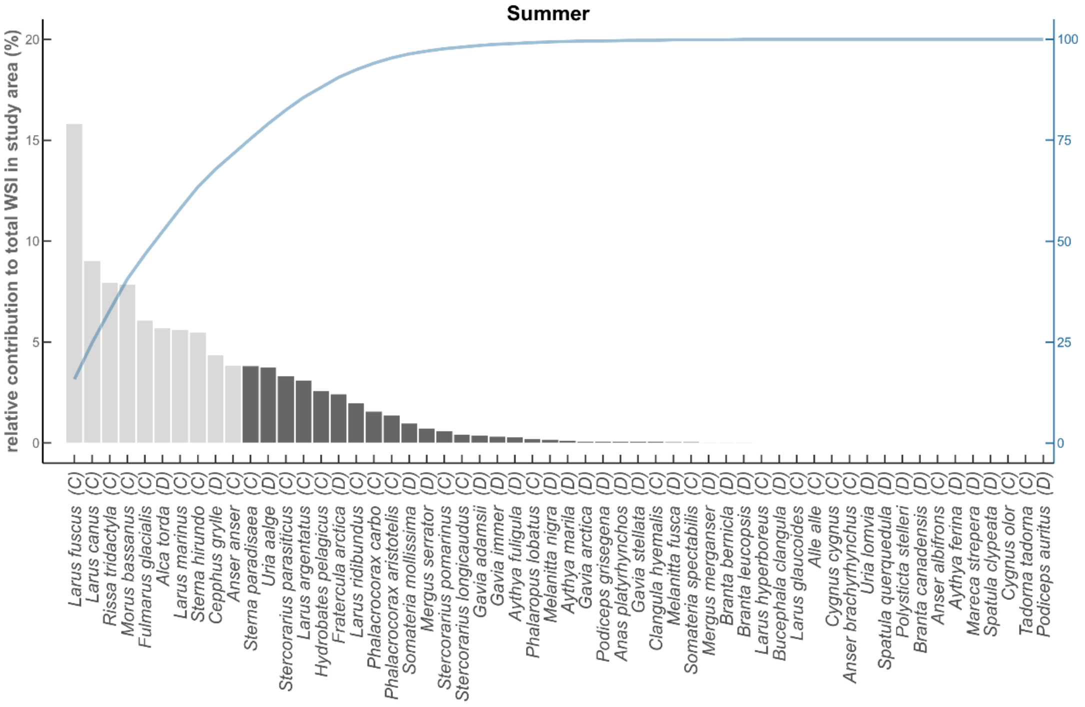

Figure A2 (2 of 4). Species that use the study area, given for summer and ranked from highest to lowest sensitivity within the area. Column height corresponds to the percentage of seasonal sensitivity explained by the species. The ten species with the highest sensitivity within the study area are indicated in light grey. The type of *sensitivity that is the most preponderant, (D) displacement or (C) collision, is indicated. The blue line shows the cumulative percentage of species' contribution to seasonal sensitivity.*

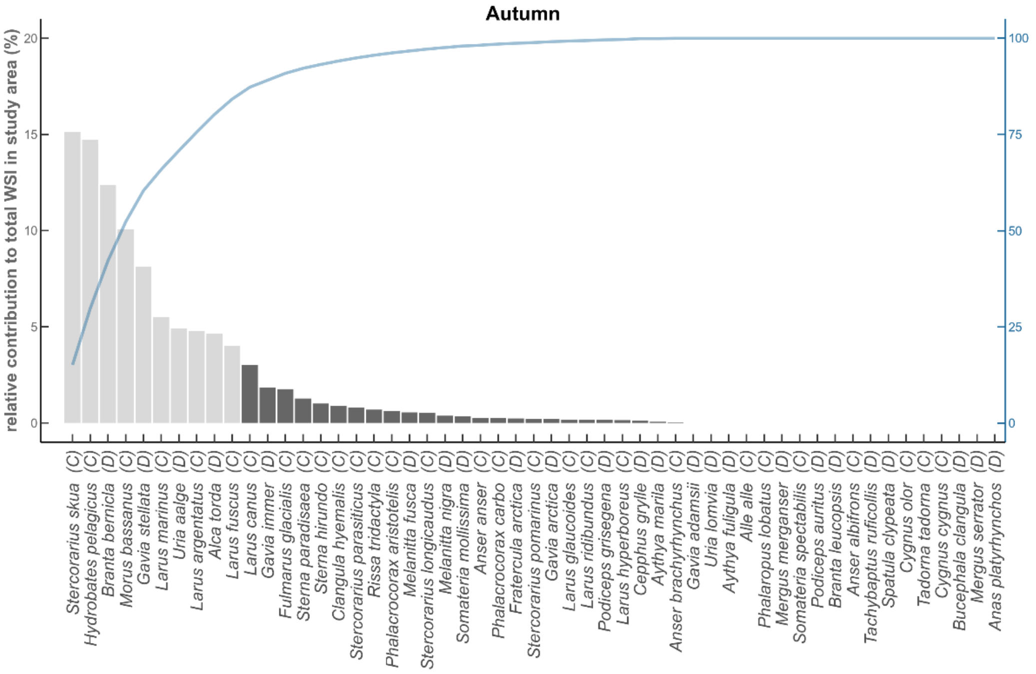

Figure A2 (3 of 4). Species that use the study area, given for autumn and ranked from highest to lowest sensitivity within the area. Column height corresponds to the percentage of seasonal sensitivity explained by the species. The ten species with the highest sensitivity within the study area are indicated in light grey. The type of sensitivity that is the most preponderant, (D) displacement or (C) collision, is indicated. The blue line shows the cumulative percentage of species' contribution to seasonal sensitivity.

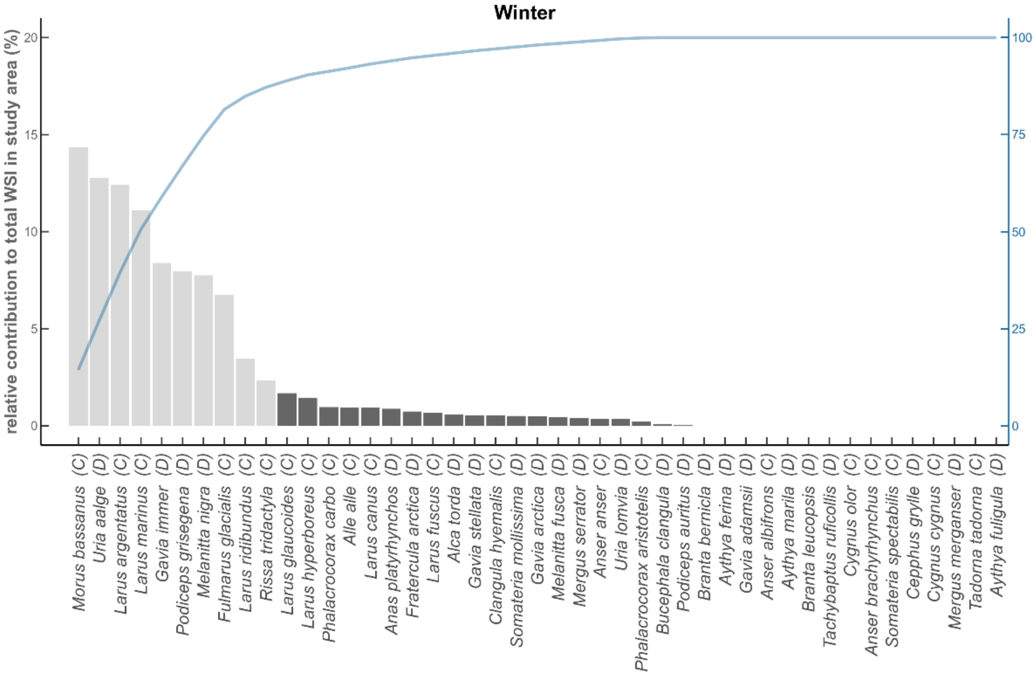

Figure A2 (4 of 4). Species that use the study area, given for winter and ranked from highest to lowest sensitivity within the area. Column height corresponds to the percentage of seasonal sensitivity explained by the species. The ten species with the highest sensitivity within the study area are indicated in light grey. The type of sensitivity *that is the most preponderant, (D) displacement or (C) collision, is indicated. The blue line shows the cumulative percentage of species' contribution to seasonal sensitivity.*

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NINA Report

The Norwegian Institute for Nature Research, NINA,
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Norwegian Institute for Nature Research
NINA head office
Postal address: P.O. Box 5685 Torgarden,
NO-7485 Trondheim, NORWAY
Visiting address: Høgskoleringen 9, 7034 Trondheim
Phone: +47 73 80 14 00
E-mail: firmapost@nina.no
Organization Number: 9500 37 687
http://www.nina.no

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