Springer Polar Sciences

Eva Pongrácz
Victor Pavlov
Niko Hänninen *Editors*

Arctic Marine Sustainability

Arctic Maritime Businesses and the Resilience of the Marine Environment

Springer

Chapter 4
Oil Vulnerability Index, Impact on Arctic Bird Populations (Proposing a Method for Calculating an Oil Vulnerability Index for the Arctic Seabirds)

Nina J. O'Hanlon, Alexander L. Bond, Neil A. James, and Elizabeth A. Masden

Abstract In recent decades, political and commercial interest in the Arctic's resources has increased dramatically. With the projected increase in shipping activity and hydrocarbon extraction, there is an increased risk to marine habitats and organisms. This comes with concomitant threats to the fragile Arctic environment especially from oil, whether from shipping accidents, pipeline leaks, or sub-surface well blowouts. Seabirds are among the most threatened group of birds, and the main threats to these species at-sea are commercial fishing and pollution. Seabirds are vulnerable to oil pollution, which can result in mass mortality events. Species are affected to a differing extent, therefore it is important to objectively predict which species are most at risk from oil spills and where. Assessing the vulnerability of seabirds to oil is achieved through establishing an index for the sensitivity of seabirds to oil – Oil Vulnerability Index (OVI). This incorporates spatial information on the distribution and density of birds as well as on species specific behaviours and other life history characteristics. This chapter focuses on the threat of oil to seabirds, especially in the Arctic, and how an OVI can be used to highlight which species are most at risk and where within the Arctic region.

Keywords Marine · North Atlantic · Pollution

N. J. O'Hanlon (✉) · N. A. James · E. A. Masden
Environmental Research Institute, North Highland College UHI,
University of the Highlands and Islands, Thurso, UK
e-mail: nina.ohanlon@uhi.ac.uk; Neil.James@uhi.ac.uk; Elizabeth.Masden@uhi.ac.uk

A. L. Bond
Environmental Research Institute, North Highland College UHI,
University of the Highlands and Islands, Thurso, UK

Department of Life Sciences, The Natural History Museum, Tring, UK
e-mail: alex.bond@uhi.ac.uk

E. Pongrácz et al. (eds.), *Arctic Marine Sustainability*,
Springer Polar Sciences, https://doi.org/10.1007/978-3-030-28404-6_4

Over the last century, ice cover and thickness in the Arctic has decreased, resulting in increased opportunities for marine access. With the associated projected increase in shipping activity and hydrocarbon extraction in this region, there is an increased risk of negative ecological impacts on the marine environment. Seabirds are particularly vulnerable to oil pollution. Following a spill, seabirds frequently come in to contact with crude oil floating on the sea's surface, which can affect seabirds in many direct and indirect ways. Due to their ecology, some seabird species are more likely to be affected by oil than others. Therefore, we can estimate the vulnerability of different seabird species to oil by taking into account their behaviour and life history characteristics. This method allows us to create an index for the sensitivity of seabirds to oil – Oil Vulnerability Index (OVI). In this chapter we describe how we made small changes to the UK's Seabird Oil Sensitivity Index (SOSI) to assess seabird vulnerability to oil within the eastern North Atlantic to help identify which seabirds may be most sensitive to potential oil pollution associated with the predicted future increase in shipping and hydrocarbon exploration in the Arctic.

4.1 Introduction

In recent decades, political and commercial interest in the Arctic's resources have increased dramatically. Over the last century, Arctic ice cover and thickness have decreased, especially during the summer months, and is likely to decrease further as predicted global annual surface temperatures continue to rise with climate change (IPCC 2013). The increased melting of sea-ice in the Arctic increases the opportunities for marine access to this region, opening new shipping trade routes and access to unexploited oil and gas resources (Wilkinson et al. 2017). Trans-arctic shipping routes, such as the Northern Sea Route, provide a cheaper and quicker alternative than traditional, longer routes (Miller and Ruiz 2014). With the projected increase in shipping activity and hydrocarbon extraction in northern waters, there is an increased risk of negative ecological impacts on marine habitats and organisms. With this come the potential threats to the Arctic environment from those wanting to exploit these resources, especially oil, whether from shipping accidents, pipeline leaks or sub-surface well blowouts (Wilkinson et al. 2017).

Oil can enter the marine environment through natural seeps, however substantial quantities of oil enter from anthropogenic activities associated with sea-going vessels and oil exploration, extraction and accidental or deliberate discharge of oil during transportation (Clark 2001). The largest contribution of oil entering our oceans is from at-sea vessels (Committee on Oil in the Sea 2003). Large oil spills from tankers and routine hydrocarbon extraction operations are generally the most high-profile incidents, however sizeable quantities are discharged, mostly illegally, from washing vessel tanks and removing ballast (Committee on Oil in the Sea 2003).

4.2 Threat of Oil to Seabirds with Particular Focus on the Arctic

Seabirds are among the most threatened group of bird species, with 28% of the world's seabird species categorised as globally threatened (Birdlife 2012), and pollution being a key threat (Croxall et al. 2012). Seabirds are particularly vulnerable to oil pollution, which can cause mass mortality events, with even minor oil spills causing problems (Piatt and Ford 1996; Votier et al. 2005; Munilla et al. 2011). Seabirds generally encounter oil on the sea surface where it forms a thin film. Oil can affect seabirds directly through lethal and sub-lethal effects; it can suffocate individuals or destroy the insulating properties of feathers, as oil droplets adsorb to the feathers of birds because of their hydrophobic properties. The damage this causes to the feathers' microstructure reduces a bird's ability to insulate and waterproof itself resulting in hypothermia and reduced buoyancy, which can lead to starvation where individuals cannot fly or forage (Jenssen et al. 1985; Jenssen 1994; O'Hara and Morandin 2010).

If ingested, for example during preening when an individual attempts to clean its feathers, the oil and associated toxins can damage internal organs and affect metabolism, leading to dehydration and poisoning (Miller et al. 1978; Burger and Fry 1993; Paruk et al. 2016). Polycyclic aromatic hydrocarbons (PAHs) are a group of organic pollutants with mutagenic and carcinogenic properties released into the environment by the incomplete combustion of fossil fuels and the burning of organic matter. Paruk et al. (2016) found that exposure to PAHs found in oil resulted in lower body mass of adult and immature Common Loons *Gavia immer*. Seabirds can also be exposed to PAHs after major oil spills through ingesting contaminated prey (Alonso-Alvarez et al. 2007; Paruk et al. 2014). Even individuals that successfully preen themselves of oil have experienced negative consequences on their subsequent productivity (Corkhill 1973; Esler et al. 2000) and long-term survival (Esler et al. 2000; Peterson et al. 2003; Esler and Iverson 2010; Fraser and Racine 2016). Esler et al. (2000) found that 6–9 years after the Exxon Valdez oil spill there was a reduction in female Harlequin Duck *Histrionicus histrionicus* winter survival in oiled compared to unoiled areas; however, after 11–14 years no difference was observed indicating that it took over a decade for survival of Harlequin Ducks to recover (Esler and Iverson 2010).

Seabirds can also be impacted by oil spills indirectly through displacement from foraging habitats and reduced food availability where prey species are affected (Peterson et al. 2003; Velando et al. 2005). During the winter following the Sea Empress oil spill in Wales, Common Scoters *Melanitta nigra* were displaced from favoured foraging locations with individuals instead feeding in areas with energetically less profitable prey (Banks et al. 2008). Seabirds can also be affected negatively by clean-up efforts, through disturbance, and toxicity of dispersants (Jenssen 1994; Whitmer et al. 2018).

The productive, cooler temperature waters of the eastern North Atlantic Ocean hold large concentrations of seabirds (Wong et al. 2014), and internationally important numbers of many species (Birdlife 2019). However, these colder higher latitude waters can also increase seabirds' vulnerability to oil pollution (Fraser and Racine 2016). In cold water, oil can persist at the sea surface for extended periods as a more viscous, solidified form (Buist et al. 2000; Brandvik and Faksness 2008), whilst seabirds are more vulnerable due to potentially already being at a higher thermal stress (Ellis and Gabrielsen 2001). Consequently, only small amounts of oil may cause hypothermia and therefore increase mortality risk (Hartung 1967; Jenssen et al. 1985; Wiese and Ryan 2003). Wiese and Ryan (2003) found higher incidences of oiled birds in periods of colder ambient air temperatures, high winds and periods of increased onshore winds, which caused greater thermal stress for compromised birds.

Although large oil spills and disasters can affect and kill large numbers of individuals, chronic oil pollution is thought to have the greatest impact on seabirds because of its persistent nature over time (Wiese and Robertson 2004; O'Hara and Morgan 2006; Ronconi et al. 2015). Systematic beached bird surveys have occurred in the North Sea since the 1970s predominantly to monitor chronic oil pollution, which has revealed that seabird oiling rates (the number of oiled birds divided by the total number of birds found) have declined in this region, largely due to implemented legislation, such as the MARPOL protocol of 1973, and the amended protocol of 1978 (Jones 1980; Camphuysen 1998; Heubeck 2006; Stienen et al. 2017). In Canada, seabird oil rates also declined from 1984–2006, but remained high relative to other areas (Wilhelm et al. 2009).

4.2.1 Direct Monitoring of Seabird Vulnerability to Oil Via Beached Bird Surveys

To determine the extent to which, and mechanism of how oil affects seabirds we must be able to assess its impacts. One method for doing so is to search systematically for oiled individuals that have washed up on the shoreline (Camphuysen and Heubeck 2001; Wiese and Ryan 2003; Heubeck 2006). These "beached bird surveys" can provide details on the risk to different species of at-sea oiling, as well as monitor variation in the amount of oil at sea among years and locations (Furness and Camphuysen 1997; Heubeck et al. 2003).

From the data collected during beached bird surveys it is possible to derive a species-specific 'oiling rate', which can be defined as the number of birds found per km of coastline and the proportion of birds found oiled (Camphuysen 2007). These values can then be used to identify spatial and temporal variation in seabird vulnerability to oil, as survey methods are standardised (Wiese and Elmslie 2006). Beached bird surveys have shown that species with the highest oiling rates were those that would be expected from their behaviour of spending a large amount of time on the sea surface, such as auks (Alcidae) and eiders *Somateria* spp. (Camphuysen and Heubeck 2001; Wiese and Ryan 2003), whilst more aerial species and those that stay closer to the coast had lower rates of oiling (Wiese and Ryan 2003). However, it is possible that predatory and scavenging species, such as gulls or terns (Laridae), might have a higher risk if they are attracted to dead or incapacitated oiled individuals.

Beached bird surveys provide a relatively cost-effective way of monitoring oil pollution and the effect of spills on seabirds, with small changes in oiling rates successfully detected. This means that beached bird surveys can also be used to assess the effectiveness of measures to reduce oil pollution in the marine environment (Heubeck 2006). In addition to monitoring oiling rates, the surveys also increase public awareness of the issue. Beached bird surveys can, however, result in biases in the data collected. It is possible that birds that died from oil ingestion with no external signs of oiling are missed (Leighton 1995; Briggs et al. 1997), while there is also the possibility that birds become oiled after death. At times of reduced food availability or during severe winters, which increase seabird mortality generally, oiling rates can often be lower (Camphuysen and Heubeck 2001). Furthermore, not all oiled birds will reach land and a large proportion remain at sea. Many factors influence the number of clean and oiled birds that are found during beached bird surveys, including wind speed and direction, surface currents, sea surface temperatures (Camphuysen and Heubeck 2001), and other sources of mortality such as fishing effort or hunting pressure (Wilhelm et al. 2009). Finally, even if the birds do reach the coastline, they might still not be detected if they are scavenged before being found (Ford and Zafonte 2009) or if washed up in a remote area with lower survey effort. This final point is particularly relevant in the Arctic.

For the information gained from beached bird surveys to be useful to decision makers, an accurate number of all oiled birds needs to be established; however, this is not possible at present as only small areas are monitored, meaning assumptions need to be made if extrapolating to large, unsurveyed areas (Wiese and Elmslie 2006). It is also difficult to establish the effects of oil pollution on seabirds at the population level, as we generally do not have reliable estimates of seabird population numbers, and the effect of oil would need to be disentangled from other natural and anthropogenic mortality sources (Wiese and Elmslie 2006). It is very difficult to determine how the numbers of oiled birds that wash up oiled relate to those affected at sea and never recorded, and therefore current oiling rates have high levels of associated uncertainty.

4.2.2 Introduction to Oil Vulnerability Indices

Beached bird surveys provide information on the number of birds that have been affected by oil retrospectively. However, it is also useful to be able to predict the likely impacts of an oil spill on seabird populations and communities. Such predictions are useful, for example, in the planning of oil and gas developments, the opening of new shipping routes, and establishing environmental monitoring programmes.

Due to their ecology, some seabird species are likely to be affected to a greater extent than others. For example, pursuit diving seabirds such as seaducks (Anatidae: Mergiini), loons (Gaviidae) and auks are likely more susceptible to oiling than more aerial species such as gulls and terns because they spend a greater proportion of time on the sea surface and therefore are more likely to come into contact with oil (Camphuysen and Heubeck 2001; Heubeck 2006). Species that congregate together in large numbers, like many seaducks, those in polynyas, or those that undergo periods of flightlessness (or are naturally so) are also at high risk (Westphal and Rowan 1969; Burger 1993).

Assessing the vulnerability of seabirds to oil spill incidents incorporates information on the spatial abundance of seabirds as well as species-specific behaviours and other life history characteristics. To date, this has been achieved through modelling mortality based on behavioural characteristics, spatial distributions, and oil spill size (Fifield et al. 2009), or calculating an index for the sensitivity of seabirds to oil – Oil Vulnerability Index (OVI) (King and Sanger 1979; Williams et al. 1994), which we focus on here. Indices incorporate factors that affect the survival of a species in relation to oil spills using a scoring system, which varies depending on the study. The factors that contribute to the OVI are theoretically assessed and scored based on expert judgements, prior information, and knowledge about the behaviour of a species, foraging strategies, and demography. The OVI scores can range from low values indicating no or very little vulnerability to oil, to maximum scores, indicating high vulnerability (Camphuysen 2007). Furthermore, the OVI scores can be used to create a spatial OVI by combining them with species distribution and density data within areas of potential oil spill or oiling risk. For example, Renner and Kuletz (2015) created a spatial–seasonal analysis of the oiling risk from shipping traffic to seabirds in the Aleutian Archipelago, as did Wong et al. (2018) for the eastern Canadian Arctic. The OVI methodology has been further developed by Certain et al. (2015) to provide a mathematical argument for the combination of the factors used when producing a single sensitivity index. Earlier efforts (Williams et al. 1994) have also been refined for the United Kingdom continental shelf area after a thorough review of the contributing factors and spatial density data (Webb et al. 2016), resulting in the Seabird Oil Sensitivity Index (SOSI).

4.3 Case Study: Assessing the Feasibility of an Oil Sensitivity Index for the Eastern North Atlantic

Given the predicted increase in extractive hydrocarbon activity and traffic associated with trans-arctic shipping routes in northern Europe, and the Arctic more broadly, there is a need to assess the vulnerability of seabirds to oil in these areas using a unified and comparable approach. Although there are country-specific vulnerability indices for seabirds and oil within this region (Gavrilo et al. 1998; Clausen et al. 2016), not all jurisdictions have methods for assessing risks to seabirds from oil, and there is no region-wide assessment. Given the migratory nature of many seabirds in the eastern North Atlantic (Guilford et al. 2011; Frederiksen et al. 2012, 2016), an understanding of risk can only be done at the regional scale, where mortality often occurs away from breeding colonies (Harris and Wanless 1996; Tasker et al. 2000).

Here we discuss the rationale behind using the UK's SOSI approach as the foundation for a region-wide index of seabirds' oil sensitivity by examining how the SOSI can be modified to meet the requirements of the larger region, and its limitations. We then undertake a sensitivity analysis to establish which of the factors used to construct the current SOSI contribute the most to the final species-specific SOSI to guide the quality of data required, and data gaps that may limit our ability to apply the SOSI approach across the eastern North Atlantic region (Table 4.1).

Table 4.1 Seabird species commonly occurring as breeding or migrants in the eastern North Atlantic

Common name	Scientific name	Status	Birdlife red list category
Red-throated Loon	*Gavia stellata*	Breeding	Least concern
Arctic Loon	*Gavia arctica*	Breeding	Least concern
Common Loon	*Gavia immer*	Breeding	Least concern
Yellow-billed Loon	*Gavia adamsii*	Breeding	Near-threatened
Red-necked Grebe	*Podiceps grisegena*	Breeding	Least concern
Great-crested Grebe	*Podiceps cristatus*	Breeding	Least concern
Horned Grebe	*Podiceps auritus*	Breeding	Vulnerable
Black-necked Grebe	*Podiceps nigricollis*	Breeding	Least concern
Northern Fulmar	*Fulmarus glacialis*	Breeding	Least concern
Cory's Shearwater	*Calonectris borealis*	Migrant	Least concern
Great Shearwater	*Ardenna gravis*	Migrant	Least concern
Sooty Shearwater	*Ardenna grisea*	Migrant	Near-threatened
Manx Shearwater	*Puffinus puffinus*	Breeding	Least concern
Balearic Shearwater	*Puffinus mauretanicus*	Migrant	Critically endangered
European Storm-petrel	*Hydrobates pelagicus*	Breeding	Least concern
Leach's Storm-petrel	*Hydrobates leucorhous*	Breeding	Vulnerable
Northern Gannet	*Morus bassanus*	Breeding	Least concern
Great Cormorant	*Phalacrocorax carbo*	Breeding	Least concern
European Shag	*Phalacrocorax aristotelis*	Breeding	Least concern
Common Eider	*Somateria mollissima*	Breeding	Near-threatened
King Eider	*Somateria spectabilis*	Breeding	Least concern
Steller's Eider	*Polysticta stelleri*	Breeding	Vulnerable
Harlequin Duck	*Histrionicus histrionicus*	Breeding	Least concern
Long-tailed Duck	*Clangula hyemalis*	Breeding	Vulnerable
Common Scoter	*Melanitta nigra*	Breeding	Least concern
Velvet Scoter	*Melanitta fusca*	Breeding	Vulnerable
Goldeneye	*Bucephala clangula*	Breeding	Least concern

(continued)

Table 4.1 (continued)

Common name	Scientific name	Status	Birdlife red list category
Goosander	*Mergus merganser*	Breeding	Least concern
Red-breasted Merganser	*Mergus serrator*	Breeding	Least concern
Greater Scaup	*Aythya marila*	Breeding	Least concern
Red-necked Phalarope	*Phalaropus lobatus*	Breeding	Least concern
Red Phalarope	*Phalaropus fulicarius*	Breeding	Least concern
Pomarine Jaeger	*Stercorarius pomarinus*	Breeding	Least concern
Arctic Jaeger	*Stercorarius parasiticus*	Breeding	Least concern
Long-tailed Jaeger	*Stercorarius longicaudus*	Breeding	Least concern
Great Skua	*Catharacta skua*	Breeding	Least concern
Mediterranean Gull	*Larus melanocephalus*	Breeding	Least concern
Little Gull	*Hydrocoloeus minutus*	Breeding	Least concern
Sabine's Gull	*Xema sabini*	Migrant	Least concern
Black-headed Gull	*Larus ridibundus*	Breeding	Least concern
Mew Gull	*Larus canus*	Breeding	Least concern
Lesser black-backed Gull	*Larus fuscus*	Breeding	Least concern
European herring Gull	*Larus argentatus*	Breeding	Least concern
Yellow-legged Gull	*Larus michahellis*	Migrant	Least concern
Iceland Gull	*Larus glaucoides*	Breeding	Least concern
Glaucous Gull	*Larus hyperboreus*	Breeding	Least concern
Great black-backed Gull	*Larus marinus*	Breeding	Least concern
Ross's Gull	*Rhodostethia rosea*	Breeding	Least concern
Black-legged Kittiwake	*Rissa tridactyla*	Breeding	Vulnerable
Ivory Gull	*Pagophila eburnea*	Breeding	Near-threatened
Sandwich Tern	*Thalasseus sandvicensis*	Breeding	Least concern
Roseate Tern	*Sterna dougallii*	Breeding	Least concern
Common Tern	*Sterna hirundo*	Breeding	Least concern
Arctic Tern	*Sterna paradisaea*	Breeding	Least concern
Little Tern	*Sternula albifrons*	Breeding	Least concern
Black Tern	*Chlidonias niger*	Breeding	Least concern
Common Murre	*Uria aalge*	Breeding	Least concern
Thick-billed Murre	*Uria lomvia*	Breeding	Least concern
Razorbill	*Alca torda*	Breeding	Near-threatened
Black Guillemot	*Cepphus grylle*	Breeding	Least concern
Little Auk	*Alle alle*	Breeding	Least concern
Atlantic Puffin	*Fratercula arctica*	Breeding	Vulnerable

Common names and taxonomy follows Birdlife (2019)

4.3.1 Regional Sensitivity Indices

The production of the SOSI in the UK underwent a thorough review process to determine which factors would be most effective for oil pollution contingency planning and emergency response within UK waters (Webb et al. 2016). The SOSI has therefore been adopted by the UK's Joint Nature Conservation Committee (JNCC) to advise necessary actions when and where oil spills occur within the waters around the UK (JNCC 2017). We therefore used this most recent assessment of seabird vulnerability to oil to develop a regional approach for the eastern North Atlantic region.

The SOSI used in the UK incorporates eight factors that represent three principles to assess the sensitivity of seabird species to oil: (1) how likely individuals are to be affected by oil due to their behaviour (factors 1–3); (2) how vulnerable a population/species is (factors 4–6); and (3) how quickly a population or species might recover from an oil incident (factors 7–8). The eight factors are scored on a scale of 0.2–1.0 in increments of 0.2, from low to high sensitivity, and determined for each species (Webb et al. 2016) with total scores ranging from 1.6 to 8.0:

1. Proportion of time spent sitting on the water (using European Seabird at Sea data from 1995 to 2015). Species that more often sit on the ocean's surface are at greater risk of oiling and therefore have a higher score.
2. Percentage of tideline corpses contaminated with oil (based on Williams et al. 1994). Species with higher oiling rates (where a high percentage of tideline corpses are contaminated with oil) are assumed to be more sensitive to oil pollution and have a higher score.
3. Habitat flexibility (taken from Furness et al. 2013), defined as the range of habitats a species uses, scored from 0.2 (high habitat flexibility: tend to forage over large marine areas with little known association with particular marine features) to 1 (low habitat flexibility: tend to feed on very specific habitat features, such as shallow banks with bivalve communities, or kelp beds).
4. Percentage of biogeographical population within the UK continental shelf; a measure of how vulnerable a species is to mortality. Species with a high percentage of biogeographical population within the UK continental shelf are scored higher as this indicates the importance of the UK's population of a species globally.
5. Listing in Birds of Conservation Concern (BOCC) (scored depending on status levels from BOCC 2, BOCC 3 (Eaton et al. 2009) and BOCC 4 (Eaton et al. 2015). Species of higher conservation concern are scored higher.
6. Presence on EU Birds Directive Annexes; a third measure of how vulnerable a species is to mortality (with scores taken from Furness et al. 2012). Scored as 1 where species are listed in Annex 1 of the Directive (species of particular conservation concern, which have the highest level of protection), 0.6 where species are not listed on Annex 1 but are listed as a migratory species and 0.2 where species are not listed on Annex 1 or are not listed as migratory (European Commission 2009).
7. Potential annual productivity, score based on maximum and mean clutch size & age at first breeding, based on Williams et al. 1994 (a high score reflects a small maximum and mean clutch size with a high age of first breeding, whilst a low score reflects a large maximum and mean with a low age of first breeding). Species with high scores are expected to recover from an oil incident more slowly.

8. Adult annual survival rate, also a measure of how quickly a species may recover from an oil incident, with species with high scores (reflecting high annual survival rates) expected to take longer to recover from an oil incident.

There are several other factors that may influence the sensitivity of a species to oil, which are not included in the SOSI calculation, for example: ability to withstand oiling (Burger and Gochfield 2002), foraging/feeding behaviour (Schreiber and Burger 2002), aggregation at sea (Stone et al. 1995; Reid et al. 2001), coloniality at breeding sites (Schreiber and Burger 2002); and the extent to which species are attracted to vessels based on interactions with fisheries vessels (Wahl and Heinemann 1979; Skov and Durinck 2001). Increasing the number of factors used to calculate a sensitivity index may allow it to be more representative if it incorporates all aspects that might influence species' sensitivity to oil. However, obtaining adequate data to score these factors accurately is unlikely for many species, which will increase the uncertainty of index values. Having fewer and more broad factors may therefore prevent a false sense of precision in the index values. There is also an additional management cost of changing the current method and establishing whether alternative factors are appropriate. Effort may be better spent applying the current SOSI more widely, given its utility in a UK context. Furthermore, as the SOSI is an index, rather than an absolute value with a degree of certainty, applying it consistently, using the same method across regions, will make its caveats better understood by those using it. Due to the potential difficulty of obtaining sufficient data, both temporal and spatial, for species, especially in more remote areas such as across the Arctic, we used the SOSI used in the UK as a starting point for calculating an oil vulnerability index for species in the eastern North Atlantic Ocean, with a particular focus on the Northern Periphery of Europe and Arctic region: Denmark, England, the Faroe Islands, Finland, Greenland, Iceland, Ireland, Northern Ireland, Norway, Scotland, Svalbard (including Bjørnøya & Jan Mayan), Sweden, and Wales (Fig. 4.1).

Outside of the UK, the extent to which information on seabirds' vulnerability to oil exists across the eastern North Atlantic Ocean is currently variable (Camphuysen 2007). The Faroe Islands are relatively well covered, though there is limited winter seabird distribution data (Skov et al. 2002). The Baltic Sea has extensive data on seabird distribution and abundance at sea, however no oil sensitivity index has been established (Camphuysen 2007). The Norwegian Seas and those around Svalbard and Greenland are partly covered, but have incomplete data; for example, around Svalbard there are recent summer seabird at sea data for the Barents Sea to the south but not for northern waters (Camphuysen 2007). Data on at-sea distribution of seabirds in this region, particularly focused on the non-breeding season, have been collected through SEATRACK, an international seabird tracking programme covering the Barents, Norwegian and North Seas (http://www.seapop.no/en/seatrack/). Neither has looked at a comprehensive seabird vulnerability index for oil in their jurisdictions, but Greenland does have an oil vulnerability atlas for the west coast (Mosbech et al. 2004; Stjernholm et al. 2011; Clausen et al. 2016), with a similar atlas in preparation for east Greenland. Icelandic waters, as well as the high

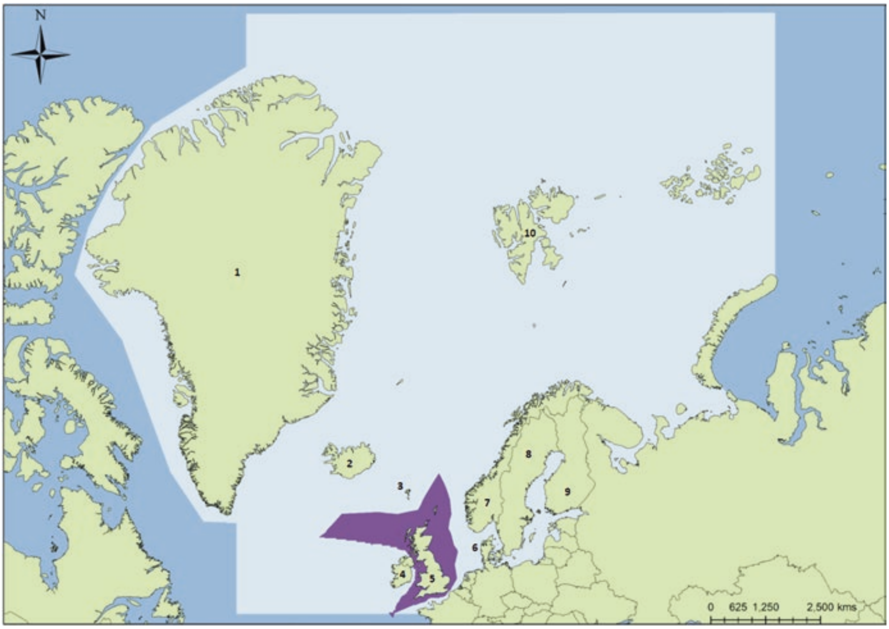

Fig. 4.1 The current spatial coverage of SOSI (Webb et al. 2016) in the United Kingdom Continental Shelf, shown in dark purple. We discuss expanding this to cover the Northern Periphery of Europe and Arctic region, shown in light blue, with a focus on *1* Greenland, *2* Iceland, *3* Faroe Islands, *4* Ireland, 5 United Kingdom (England, Northern Ireland, Scotland, Wales), *6* Denmark, *7* Norway, *8* Sweden, *9* Finland, and *10* Svalbard (including Bjornoya & Jan Mayan)

seas around Greenland, west of Ireland and around Svalbard are data deficient due to limited seabirds at sea data and having no assessment of seabird or habitat sensitivity to oil pollution.

4.3.2 Sensitivity Analysis of the SOSI Factors

Before expanding the SOSI to the eastern North Atlantic Ocean, we must assess the relative importance of the current SOSI factors. Developed in the UK, with a long history of seabird monitoring (Reid et al. 2001; Mitchell et al. 2004), data may not be necessarily available for all factors from all species across the entire region. A sensitivity analysis can therefore identify which factors are the most influential, and therefore where to focus future data collection, or use surrogate values from other species. As the SOSI adopts a binned approach, with individual parameter values scored from 0.2 to 1.0 for each factor, changing parameter values may not actually make any material difference to the overall result.

Factors used to calculate the SOSI do not consider variability in parameter values, which can be especially important for factors 1 (proportion of time spent on water), 2 (proportion of tideline corpses contaminated with oil), 7 (potential annual productivity), and 8 (annual adult survival rate). The latter two are demographically important for seabirds, and differ greatly among sites, reflecting local as well as more regional pressures (Lavers et al. 2009; Bond et al. 2011). Undertaking a sensitivity analysis will therefore also allow us to establish whether this variability needs to be considered when applying the parameter values to the larger geographical area. The sensitivity analysis will also establish how the current factors are weighted in the calculation, and whether this is appropriate for the quality of data available for individual factors. For example, data on the percentage of tideline corpses contaminated with oil are unlikely to be available for offshore species that seldom appear on beached bird surveys (Camphuysen and Heubeck 2001) and coastlines across the eastern North Atlantic that do not currently collect these data.

All analyses were carried out in R 3.5.1 (R Development Core Team 2018). We determined the relative importance of the eight SOSI factors on the SOSI calculation using a sensitivity analysis with Latin Hypercube Sampling (McKay 1992; Blower and Dowlatabadi 1994), in the R package *pse* (Chalom and Prado 2017). This analysis ranks input variables based on their influence on the model output, in this case the SOSI calculation, to identify the factors which have the most influence. We produced 200 random parameter combinations, with each factor value drawn from a uniform distribution between 0.2 and 1 at 0.2 increments, where all factors could vary. One parameter, at intervals of 0.2 between 0.2 and 1, was selected at random for each factor and combined with values from the other factors. We calculated partial rank correlation coefficients (PRCC) to determine the relative importance of each factor to the SOSI calculation (Blower and Dowlatabadi 1994). PRCC values reflect the estimated relative importance of each factor in the SOSI calculation, with PRCC values closer to 1 having the strongest influence.

The factors with the greatest impact on the final SOSI scores were factors 1 (proportion of time spent on water), 2 (proportion of tideline corpses contaminated with oil) and 3 (habitat flexibility), with all having high PRCC values >0.50 (Taylor 1990, Fig. 4.2). These factors with the most influence on the SOSI were those reflecting how likely individuals are to be affected by oil due to their behaviour. Factors 7 and 8, which reflect species demography (potential annual productivity, and adult annual survival rate), had the least influence on the final SOSI scores.

This highlights the importance of obtaining accurate parameter values and associated variability across the region of interest for factors 1–3 relating to behaviour given their relative importance in calculating species SOSI scores. The results also partially allay concerns that the SOSI does not consider spatial and temporal variation in seabird demography, with variability observed in the maximum and mean clutch size, age at first breeding and adult survival rate (Horswill and Robinson 2015). The relatively low influence of demographic factors suggests that it may not be essential to account for this variation, or uncertainty in these parameter values for understudied populations, or species, and that data from surrogate species, expert opinion, or local ecological knowledge may be an appropriate alternative when data

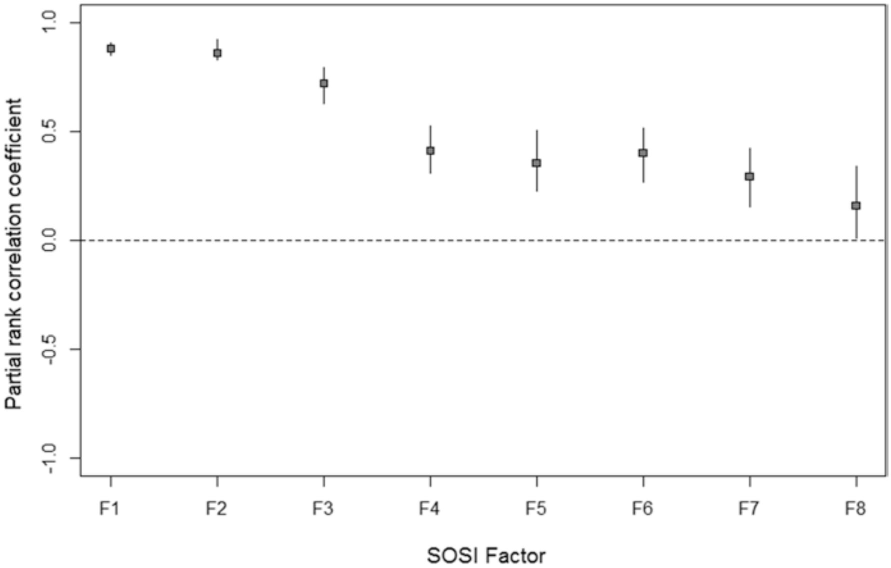

Fig. 4.2 The partial rank correlation coefficient (PRCC) for the eight SOSI factors (see text, Webb et al. 2016) with confidence intervals produced by bootstrapping. The PRCC values reflect the strength of the linear associations between the result and each of the input factors, after removing the linear effect of the other factors

are lacking. Additionally, it means that it may not be necessary to account for the spatial and temporal variation observed in seabird demographic variables, especially as these parameter values are placed in bins with increments of 0.2 before inputting into the SOSI calculation.

4.3.3 Expanding the SOSI to the Eastern North Atlantic

If the application of the SOSI is to be extended into other areas, then we must first explore whether the eight factors relevant to assessing oil sensitivity in the UK are also relevant for the wider eastern North Atlantic region.

Factors 1 and 2 have the greatest influence on the overall SOSI score used in the UK, therefore it is important that the data on which these factor values are based are as accurate as possible. Where possible it would be beneficial to account for any variability in these factors across the region. The proportion of time individuals spend on the sea surface is likely consistent within species as this is largely driven by behaviour. To some extent, this consistency will also be the case for the proportion of tideline corpses contaminated with oil as this will also be related to seabirds' behaviour, with species that spend more time on the sea surface having higher oiling rates (Camphuysen 1998). Although the ranking of oiling rates for species are generally similar across different locations, the exact parameter values do differ (Camphuysen 1998). Current oiling rates are also skewed geographically with data from standardised beached bird surveys largely collated from around the North Sea, although there are also some beached bird surveys in Scandinavia (Camphuysen and Heubeck 2001), but these data are largely absent from more inaccessible coastlines (e.g., Greenland, Iceland or Svalbard). Factors 1 and 2 both reflect how likely individuals are to be affected by oil due to their behaviour and show a significant positive correlation ($r_s = 0.69$, $P < 0.001$, $N = 50$). Given this relationship and the challenges of accurately determining the number of tideline corpses, one option is to remove factor 2 and only include factor 1, where more robust data exist. Removing the proportion of oiled tideline corpses from the calculation increased the species' SOSI scores, apart from species that had the highest proportion of oil corpses (factor 2 score of 1), for which final scores stayed the same. However, the extent to which removing factor 2 increased a species' SOSI score varied, therefore the ranking of species' sensitivity did change.

Factor 3, reflecting how habitat flexibility influences the likelihood that individuals will be affected by oil due to their behaviour, also has an important influence on the overall SOSI score used in the UK. This factor considers the range of habitats a species uses and is therefore relatively straightforward to determine for most species. There may be some subjectivity in scoring this factor and therefore it is important that additional species in the eastern North Atlantic Ocean, not covered by the UK SOSI, are scored considering already published values (Garthe and Hüppop 2004, Furness et al. 2012) and expert judgement to ensure consistency.

To expand the SOSI used in the UK to a wider region factors 4–6 need to be replaced as these are specifically related to the UK (factors 4 and 5) or the European Union (factor 6), which does not encompass all jurisdictions in the eastern North Atlantic Ocean. These three factors refer to the conservation status of species and reflect how vulnerable a population or species is to threats such as oil pollution within the smaller region of the UK and European Union. One option could be to include, for each species, the percentage of biogeographical population within the eastern North Atlantic Ocean, however this will likely be difficult to determine as there is considerable uncertainty in regional and global population estimates of many species. Instead, it arguably makes more sense to use a species' global conservation status, as determined by the IUCN Red List (Birdlife 2019). Alternatively, as the countries in the study region are in Europe, the European Red List could be used (Birdlife 2015). By using the IUCN Red List categories, the index would be expandable to other regions, or even globally. This does have the disadvantage of removing any spatial or temporal variability in the factors associated with species' status and vulnerability, however.

We compared the actual winter (October – March) and summer (April – September) SOSI index scores for 50 UK seabird species against those calculated using scores for the IUCN Red list categories instead of factors 4, 5 and 6. In general, the resulting IUCN SOSI scores were lower than the original winter and summer scores. This is largely attributed to most species being listed on the IUCN Red List as Least Concern, which resulted in these species having the lowest score of 0.2 (species listed as Near-Threatened were scored as 0.4, Vulnerable as 0.6, Endangered as 0.8 and Critically Endangered as 1). The extent to which using these scores based on ICUN Red List categories changed a species' SOSI score varied, therefore the ranking of species' sensitivity did change.

In the UK's SOSI, factors 7 and 8 relate a species' demographic vital rates and reflect how quickly a population or species might recover from an oil incident. Relevant demographic data are available for the majority of the 62 seabird species that commonly occur within the eastern North Atlantic, although there are gaps for some species in the Arctic such as the Yellow-billed Loon *Gavia adamsii*, Ross's Gull *Rhodostethia rosea* and Iceland Gull *Larus glaucoides*, and demographic rates have high inter-annual variation. However, given their low influence in calculating the SOSI used in the UK, data from surrogate species may be helpful where this information is not available for specific species, but should be used cautiously.

Using ducks as an example, we calculated scores incorporating the above adaptations and compared these with the scores calculated by Webb et al. (2016), see Table 4.2. First, we calculated scores using the IUCN Red List status as a replace-

Table 4.2 A comparison of the species-specific winter and summer SOSI scores for the duck (Anatidae) species from Webb et al. (2016) and the scores calculated using the proposed adapted SOSI approach

Species	Winter SOSI scores (rank)	Summer SOSI scores (rank)	Scores where factors 4, 5 & 6 are replaced by the IUCN Red List category	Scores where factors 4, 5 & 6 are replaced by the IUCN Red List category, and factor 2 is removed
Velvet scoter *Melanitta fusca*	0.657 (2)	0.657 (2)	0.657 (1)	0.727 (1)
Long-tailed duck *Clangula hyemalis*	0.570 (5)	0.570 (4)	0.570 (2)	0.694 (2)
Common Eider *Somateria mollissima*	0.651 (3)	0.651 (3)	0.542 (3)	0.659 (3)
Common scoter *Melanitta nigra*	0.712 (1)	0.667 (1)	0.336 (4)	0.366 (6)
Goldeneye *Bucephala clangula*	0.597 (4)	0.555 (5)	0.300 (5)	0.366 (6)
Greater Scaup *Aythya marila*	0.561 (6)	0.529 (6)	0.287 (6)	0.409 (4)
Red-breasted merganser *Mergus serrator*	0.396 (8)	0.396 (8)	0.270 (7)	0.409 (4)
Goosander *Mergus merganser*	0.427 (7)	0.427 (7)	0.260 (8)	0.317 (7)

Species are ranked by the scores where factors 4, 5 & 6 are replaced by the IUCN Red List category, reflecting most (1) to least (8) vulnerable to oil ment for factors 4, 5 and 6. Secondly, we calculated scores incorporating the IUCN Red List status as well as removing factor 2. Making these alterations to the SOSI used in the UK does alter the resulting scores and ranks among species, particularly for those with the highest scores. The IUCN Red List scores are generally lower than those calculated by Webb et al. (2016), as the global conservation status of these species is Least Concern, with the exception of the Long-tailed Duck *Clangula hyemalis* and Velvet Scoter *Melanitta fusca*, which have a global status of Vulnerable. The change in SOSI score and ranking for the Common Scoter is particularly large, as it is included on the Birds of Conservation Concern Red List in the UK (Eaton et al. 2015). Focusing on the rankings of the scores, the greatest change is for the Common Scoter and Long-tailed Duck, due to their differing conservation status on a local versus global scale.

Removing factor 2 from the calculation further changes the IUCN Red List scores, and more importantly the species rankings. All the included duck species have a maximum score of 1 for factor 1, as they are sensitive to oiling based on their at sea behaviour of spending a large proportion of time on the sea surface. However, the factor 2 scores, reflecting species-specific oiling rates, range from 0.4 (low oiling rates – Red-breasted Merganser *Mergus serrator* and Greater Scaup) to 0.8 (high oiling rates – Common and Velvet Scoter). Within the SOSI calculation, factor 2 is an aggravation factor (Certain et al. 2015; Webb et al. 2016), therefore removing factor 2 increases the scores for species where a low proportion of tideline corpses have been found contaminated with oil, as factor 1 is multiplied by factor 2 (Eq. 4.1, Webb et al. 2016). As removing factor 2 does change the ranking of how sensitive species are to oil pollution, it is important to consider the pros and cons of removing this factor as opposed to using data that are potentially biased to certain locations within the region of interest.

$$SOSI_i = \left(F_1 \times F_2\right)^{1-\frac{F_3}{F_3+0.5}} \times \left(\frac{F_4+F_5+F_6}{3}\right)^{1-\frac{\left(\frac{F_7+F_8}{2}\right)}{\left(\frac{F_7+F_8}{2}\right)+0.5}} \tag{4.1}$$

To create an oil vulnerability index suitable for the eastern North Atlantic Ocean based on the UK's SOSI method, changes will need to be made to the eight contributing factors. This should be achievable if firstly, factors 4, 5 and 6, concerning species' conservation status, are replaced by a single global assessment, specifically the IUCN Red List. Secondly, if there are no data on the proportion of oiled tideline corpses then there may be the option of removing this factor if it is thought that using parameter values for the North Sea would not be representative. However, it should be noted that making these changes did change the oil vulnerability scores, and more importantly the ranking of species, compared to using the existing SOSI method (median rank change for replacing factors 4, 5 and 6 with the IUCN Red List value = 3; median rank change for removing factor 2 from the proposed adapted SOSI calculation using the IUCN Red List values = 4). Nonetheless, this option is still likely the most comparative to the SOSI used in the UK compared to creating an entirely different method of assessing species sensitivity to oil.

4.4 Conclusion

Given that certain seabird species are more sensitive to oil pollution than others, understanding this variability, and where these species are concentrated is important to identify areas at sea where seabirds as a group are particularly vulnerable to threats such as oil pollution. This can then inform management decisions on the location of an extraction site, a sea-vessel transportation route, or mitigation and response measures for when spills do occur. Seabird vulnerability assessments can be accomplished by objectively predicting which seabird species are most at risk from oil pollution. Expanding the SOSI currently used in the UK, with some small modifications, should provide an applicable and useful oil vulnerability index for seabirds across the eastern North Atlantic region. Omitting the percentage of tideline corpses contaminated with oil (factor 2) from the calculation would remove the issues regarding biases in beached bird surveys, and poor spatial coverage of such surveys in the Arctic. Species' IUCN Red List status could easily substitute the three factors involving regional or national conservation status. By making these small changes we can use the SOSI method of assessing seabird vulnerability to oil within areas of the eastern North Atlantic in a way which should be comparable to the current SOSI for the UK, and which will improve our regional assessments of seabirds' vulnerability to oil spills. Incorporating this modified SOSI method with seabird at sea distribution and density data will allow important seabird concentrations to be identified within the eastern North Atlantic region. Producing a spatial SOSI will enable stakeholders to identify where seabirds may be most sensitive to potential oil pollution associated with the predicted future increase in shipping traffic and hydrocarbon exploration and extraction, especially if this approach is expanded across the Arctic.

Acknowledgements We would like to thank all the participants of the seabird and oil workshop held in Inverness, September 2017 where we discussed the benefits and limitations of expanding the UK's SOSI approach to the wider eastern North Atlantic region. The ERDF Interreg VB Northern Periphery and Arctic (NPA) Programme funded this activity through the APP4SEA project. Comments from anonymous reviewers improved this chapter.

References

Alonso-Alvarez, C., Munilla, I., López-Alonso, M., & Velando, A. (2007). Sublethal toxicity of the Prestige oil spill on yellow-legged gulls. *Environment International, 33*, 773–781.

Banks, A. N., Sanderson, W. G., Hughes, B., Cranswick, P. A., Smith, L. E., Whitehead, S., Musgrove, A. J., Haycock, B., & Fairney, N. P. (2008). The Sea Empress oil spill (Wales, UK): Effects on Common Scoter *Melanitta nigra* in Carmarthen Bay and status ten years later. *Marine Pollution Bulletin, 56*, 895–902.

BirdLife International. (2012). *Spotlight on seabirds. Presented as part of the BirdLife state of the world's birds website*. Available from: http://www.birdlife.org/datazone

BirdLife International. (2015). *European red list of birds*. Luxembourg: Office for Official Publications of the European Communities.

BirdLife International. (2019). *BirdLife data zone*. URL http://datazone.birdlife.org. Accessed 12 Feb 2019.

Blower, S., & Dowlatabadi, H. (1994). Sensitivity and uncertainty analysis of complex models of disease transmission: An HIV model, as an example. *International Statistical Review, 62*, 229–243.

Bond, A. L., Jones, I. L., Sydeman, W. J., Major, H. L., Minobe, S., Williams, J. C., & Byrd, G. V. (2011). Reproductive success of planktivorous seabirds in the North Pacific is related to ocean climate on decadal scales. *Marine Ecology Progress Series, 424*, 205–218.

Brandvik, P. J., & Faksness, L. G. (2008). Weathering processes in Arctic oil spills: Meso-scale experiments with different ice conditions. *Cold Regions Science and Technology, 55*, 160–166.

Briggs, K. T., Gershwin, M. E., & Anderson, D. W. (1997). Consequences of petrochemical ingestion and stress on the immune system of seabirds. *ICES Journal of Marine Science, 54*, 718–725.

Buist, I., Belore, R., Dickins, D., Hackenberg, D., Guarino, A., & Zhendi, W. (2000). Empirical weathering properties of oil in ice and snow. In *Proceedings of the thirty- second AMOP technical seminar on environmental contamination and response* (pp. 67–107). Vancouver: Environment Canada.

Burger, A. E. (1993). Estimating the mortality of seabirds following oil spills: Effects of spill volume. *Marine Pollution Bulletin, 26*(3), 140–143.

Burger, A. E., & Fry, D. M. (1993). Effects of oil pollution on seabirds in the Northeast Pacific. In *The status, ecology and conservation of marine birds of the North Pacific* (pp. 254–263). Ottawa: Canadian Wildlife Service.

Burger, J., & Gochfield, M. (2002). Effects of chemicals and pollution on seabirds. In J. Schreiber & E. A. Burger (Eds.), *Biology of marine birds* (pp. 485–525). New York: CRC Press.

Camphuysen, K. C. J. (1998). Beached bird surveys indicate decline in chronic oil pollution in the North Sea. *Marine Pollution Bulletin, 36*, 519–526.

Camphuysen, K. C. J. (2007). *Chronic oil pollution in Europe*. Brussels: IFAW.

Camphuysen, C. J., & Heubeck, M. (2001). Marine oil pollution and beached bird surveys: The development of a sensitive monitoring instrument. *Environmental Pollution, 112*, 443–461.

Certain, G., Jørgensen, L. L., Christel, I., Planque, B., & Bretagnolle, V. (2015). Mapping the vulnerability of animal community to pressure in marine systems: Disentangling pressure types and integrating their impact from the individual to the community level. *ICES Jornal of Marine Science, 72*, 1470–1482.

Chalom, A. & de Prado, P. I. K. L. (2017). *pse: Parameter space exploration with Latin Hypercubes. R package version 0.4.7*.

Clark, R. B. (2001). *Marine pollution* (5th ed.). Oxford: Oxford University Press.

Clausen, D. S., Mosbech, A., Boertmann, D., Johansen, K. L., Nymand, J., Potter, S., & Myryp, M. (2016). *Environmental oil spill sensitivity atlas for the Northwest Greenland (68°–72° N) coastal zone* (164 pp). DCE – Danish Centre for Environment and Energy.

Committee on Oil in the Sea. (2003). *Oil in the sea III: Inputs, fates, and effects* (278 pp). Washington, DC: National Research Council.

Corkhill, P. (1973). Oiled seabirds successfully cleaning their plumage. *British Birds, 66*, 535–537.

Croxall, J. P., Butchart, S. H. M., Lascelles, B., Stattersfield, A. J., Sullivan, B., Symes, A., & Taylor, P. (2012). Seabird conservation status, threats and priority actions: A global assessment. *Bird Conservation International, 22*, 1–34.

Eaton, M., Brown, A., Noble, D., Musgrove, A., Hearn, R., Aebischer, N., Gibbons, D., Evans, A., & Gregory, R. (2009). Birds of conservation concern 3: The population status of birds in the United Kingdom, Channel Islands and the Isle of Man. *British Birds, 102*, 296–341.

Eaton, M., Aebischer, N., Brown, A., Hearn, R., Lock, L., Musgrove, A., Noble, D., Stroud, D., & Gregory, R. (2015). Birds of conservation concern 4: The population status of birds in the United Kingdom, Channel Islands and Isle of Man. *British Birds, 108*, 708–746.

Ellis, H. I., & Gabrielsen, G. W. (2001). Energetics of free-ranging seabirds. In E. A. Schreiber & J. Burger (Eds.), *Biology of marine birds* (pp. 359–484). Boca Raton: CRC Press.

Esler, D., & Iverson, S. A. (2010). Female harlequin duck winter survival 11 to 14 years after the Exxon Valdez oil spill. *Journal of Wildlife Management, 74*, 471–478.

Esler, D., Schmutz, J. A., Jarvis, R. L., & Mulcahy, D. M. (2000). Winter survival of adult female harlequin ducks in relation to history of contamination by the "Exxon Valdez" oil spill. *The Journal of Wildlife Management, 64*, 839–847.

European Commission. (2009). *European union birds directive*. Available at: http://data.europa.eu/eli/dir/2009/147/oj

Fifield, D. A., Baker, K. D., Byrne, R., Robertson, G. J., Burke, C., Gilchrist, H. G., Hedd, A., Mallory, M. L., McFarlane Tranquilla, L., Regular, P. M., Smith, A., Gaston, A. J., Montevecchi, W. A., Elliot, K. H., Phillips, R. (2009). *Modelling seabird oil spill mortality using flight and swim behaviour environmental studies research funds report no. 186*. Dartmouth, 46 p.

Ford, R. G., & Zafonte, M. A. (2009). Scavenging of seabird carcasses at oil spill sites in California and Oregon. *Marine Ornithology, 37*, 205–211.

Fraser, G. S., & Racine, V. (2016). An evaluation of oil spill responses for offshore oil production projects in Newfoundland and Labrador, Canada: Implications for seabird conservation. *Marine Pollution Bulletin, 107*, 36–45.

Frederiksen, M., Moe, B., Daunt, F., Phillips, R. A., Barrett, R. T., Bogdanova, M. I., Boulinier, T., Chardine, J. W., Chastel, O., Chivers, L. S., Guilford, T., Jensen, G. H., & Gre, D. (2012). Multicolony tracking reveals the winter distribution of a pelagic seabird on an ocean basin scale. *Diversity and Distributions, 18*, 530–542.

Frederiksen, M., Descamps, S., Erikstad, K. E., Gaston, A. J., Gilchrist, H. G., Grémillet, D., Johansen, K. L., Kolbeinsson, Y., Linnebjerg, J. F., Mallory, M. L., McFarlane Tranquilla, L. A., Merkel, F. R., Montevecchi, W. A., Mosbech, A., Reiertsen, T. K., Robertson, G. J., Steen, H., Strøm, H., & Thórarinsson, T. L. (2016). Migration and wintering of a declining seabird, the thick-billed murre *Uria lomvia*, on an ocean basin scale: Conservation implications. *Biological Conservation, 200*, 26–35.

Furness, R. W., & Camphuysen, K. C. J. (1997). Seabirds as monitors of the marine environment. *ICES Journal of Marine Science, 54*, 726–737.

Furness, R. W., Wade, H. M., Robbins, A. M. C., & Masden, E. a. (2012). Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. *ICES Journal of Marine Science, 69*, 1466–1479.

Furness, R. W., Wade, H. M., & Masden, E. A. (2013). Assessing vulnerability of marine bird populations to offshore wind farms. *Journal of Environmental Management, 119*, 56–66.

Garthe, S., & Hüppop, O. (2004). Scaling possible adverse effects of marine wind farms on seabirds: Developing and applying a vulnerability index. *Journal of Applied Ecology, 41*, 724–734.

Gavrilo, M., Bakken, V., Firsova, L., Kalyakin, V., Morozov, V., Pokrovskaya, I. & Isaksen, K. (1998). *Oil vulnerability assessment for marine birds occuring along the northern sea route area* (INSROP Working Paper), 56 pp.

Guilford, T., Freeman, R., Boyle, D., Dean, B., Kirk, H., Phillips, R., & Perrins, C. (2011). A dispersive migration in the Atlantic Puffin and its implications for migratory navigation. *PLoS One, 6*(7), e21336.

Harris, M. P., & Wanless, S. (1996). Differential responses of Guillemot *Uria aalge* and Shag *Phalacrocorax aristotelis* to a late winter wreck. *Bird Study, 43*, 220–230.

Hartung, R. (1967). Energy metabolism in oil-covered ducks. *The Journal of Wildlife Management, 31*, 798–804.

Heubeck, M. (2006). The Shetland beached bird survey, 1979–2004. *Marine Ornithology, 34*, 123–127.

Heubeck, M., Camphuysen, K. C. J., Bao, R., Humple, D., Sandoval, A., Cadiou, B., Bräger, S., & Thomas, T. (2003). Assessing the impact of major oil spills on seabird populations. *Marine Pollution Bulletin, 46*, 900–902.

Horswill, C., & Robinson, R. A. (2015). Review of seabird demographic rates and density dependence. *JNCC Report, 552*, 1–126.

IPCC. (2013). Summary for policymakers. In T. F. Stocker, D. Qin, G. K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, & V. Bex (Eds.), *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 2–23). Cambridge: Cambridge University Press.

Jenssen, B. M. (1994). Review article: Effects of oil pollution, chemically treated oil, and cleaning on thermal balance of birds. *Environmental Pollution, 86*, 207–215.

Jenssen, B. M., Ekker, M., & Bech, C. (1985). Thermoregulation in a naturally oil-contaminated black-billed Murre *Uria aalge*. *Bulletin of Environmental Contamination and Toxicology, 35*, 9–14.

JNCC. (2017). *Using the seabird oil sensitivity index to inform contingency planning* (7 pp). Peterborough: Joint Nature Conservation Committee.

Jones, P. H. (1980). Beached birds at selected Orkney beaches 1976-8. *Scottish Birds, 11*, 1–12.

King, J. G., & Sanger, G. A. (1979). Oil vulnerability index for marine oriented birds. In *Conservation of marine birds of Northern North America* (pp. 227–239). Washington, DC: U.S. Fish and Wildlife Service.

Lavers, J. L., Jones, I. L., Robertson, G. J., & Diamond, A. W. (2009). Contrasting population trends at two razorbill colonies in Atlantic Canada: Additive effects of fox predation and hunting mortality? *Avian Conservation and Ecology, 4*(2), 3.

Leighton, F. A. (1995). The toxicity of petroleum oils to birds: An overview. In L. Frink (Ed.), *Wildlife and oil spills* (pp. 10–22). Newark: Response, Research, Contingency Planning, Tri State Bird Rescue and Research.

McKay, M. D. (1992). Latin Hypercude sampling as a tool in uncertainty analysis of computer models. In J. J. Swain, D. Goldsman, R. C. Crain, & J. R. Wilson (Eds.), *Proceedings of the 24th conference on winter simulation* (pp. 557–564). New York: ACM.

Miller, A. W., & Ruiz, G. M. (2014). Arctic shipping and marine invaders. *Nature Climate Change, 4*, 413–416.

Miller, D. S., Peakall, D. B., & Kinter, W. B. (1978). Ingestion of crude oil: Sublethal effects in herring gull chicks. *Science, 199*, 315–317.

Mitchell, P. I., Newton, S. F., Ratcliffe, N., Eds, T. E. D., Dunn, T. E., Poyser, A. D., & May, L. (2004). *Seabird populations of Britain and Ireland: Results of the seabird 2000 census*. London: JNCC, Poyser.

Mosbech, A., Boertmann, D., Olsen, B. Ø., Olsvig, S., von Platen, F., Buch, E., Hansen, K. Q., Rasch, M., Nielsen, N., Møller, H. S., Potter, S., Andreasen, C., Berglund, J. & Myrup, M. (2004). *Environmental oil spill sensitivity atlas for the South Greenland coastal zone*. DCE – Danish Centre for Environment and Energy, 611 pp.

Munilla, I., Arcos, J. M., Oro, D., Álvarez, D., Leyenda, P. M., & Velando, A. (2011). Mass mortality of seabirds in the aftermath of the Prestige oil spill. *Ecosphere, 2*, art83.

O'Hara, P. D., & Morandin, L. A. (2010). Effects of sheens associated with offshore oil and gas development on the feather microstructure of pelagic seabirds. *Marine Pollution Bulletin, 60*, 672–678.

O'Hara, P. D., & Morgan, K. H. (2006). Do low rates of oiled carcass recovery in beached bird surveys indicate low rates of ship-source oil spills? *Marine Ornithology, 34*, 133–140.

Paruk, J. D., Long, D., IV, Perkins, C., East, A., Sigel, B. J., & Evers, D. C. (2014). Polycyclic aromatic hydrocarbons detected in common loons (*Gavia immer*) wintering off coastal Louisiana. *Waterbirds, 37*, 85–93.

Paruk, J. D., Adams, E. M., Uher-Koch, H., Kovach, K. A., Long, D., Perkins, C., Schoch, N., & Evers, D. C. (2016). Polycyclic aromatic hydrocarbons in blood related to lower body mass in common loons. *Science of the Total Environment, 565*, 360–368.

Peterson, C. H., Rice, S. D., Short, J. W., Esler, D., Bodkin, J. L., Ballachey, B. E., & Irons, D. B. (2003). Long-term ecosystem response to the Exxon Valdez oil spill. *Science, 302*, 2082–2086.

Piatt, J. F., & Glenn Ford, R. (1996). How many seabirds were killed by the Exxon Valdez oil spill. In S. D. Rice, R. B. Spies, & D. A. Wolfe (Eds.), *Proceedings of the Exxon Valdez oil spill symposium, Anchorage, Alaska, 2–5 February, 1993* (pp. 712–719). Bethesda: American Fish Society.

R Development Core Team. (2018). *R: A language and environment for statistical computing*.

Reid, J. B., Pollock, C. M., & Mavor, R. (2001). Seabirds of the Atlantic Frontier, north and west of Scotland. *Continental Shelf Research, 21*, 1029–1045.

Renner, M., & Kuletz, K. J. (2015). A spatial-seasonal analysis of the oiling risk from shipping traffic to seabirds in the Aleutian Archipelago. *Marine Pollution Bulletin, 101*, 127–136.

Ronconi, R. A., Allard, K. A., & Taylor, P. D. (2015). Bird interactions with offshore oil and gas platforms: Review of impacts and monitoring techniques. *Journal of Environmental Management, 147*, 34–45.

Schreiber, E. A., & Burger, J. (2002). *Biology of marine birds*. Florida: CRC Press.

Skov, H., & Durinck, J. (2001). Seabird attraction to fishing vessels is a local process. *Marine Ecology Progress Series, 214*, 289–298.

Skov, H., Upton, A. J., Reid, J. B., Webb, A., Taylor, S. J., & Durinck, D. (2002). *Dispersion and vulnerability of marine birds and cetaceans in Faroese waters* (106 pp). Peterborough: Joint Nature Conservation Committee.

Stienen, E. W. M., Courtens, W., Van de walle, M., Vanermen, N., & Verstraete, H. (2017). Long-term monitoring study of beached seabirds shows that chronic oil pollution in the southern North Sea has almost halted. *Marine Pollution Bulletin, 115*, 194–200.

Stjernholm, M., Boertmann, D., Mosbech, A., Nymand, J., Merkel, F., Myrup, M., Siegstad, H., Clausen, D., & Potter, S. (2011). *Environmental oil spill sensitivity atlas for the northern West Greenland (72°–75° N) coastal zone.* DCE – Danish Centre for Environment and Energy, 798 pp.

Stone, C. J., Webb, A., & Tasker, M. L. (1995). The distribution of auks and Procellariiformes in north-west European waters in relation to depth of sea. *Bird Study, 42*, 50–56.

Tasker, M. L., Camphuysen, C. J. K., Cooper, J., Garthe, S., Montevecchi, W. A., & Blaber, S. J. M. (2000). The impacts of fishing on marine birds. *ICES Journal of Marine Science, 57*, 531–547.

Taylor, R. (1990). Interpretation of the correlation coefficient: A basic review. *Journal of Diagnostic Medical Sonography, 1*(35), 35–39.

Velando, A., Munilla, I., & Leyenda, P. M. (2005). Short-term indirect effects of the Prestige oil spill on a marine top predator: Changes in prey availabilty for European shags. *Marine Ecology Progress Series, 302*, 1–22.

Votier, S. C., Hatchwell, B. J., Beckerman, A., McCleery, R. H., Hunter, F. M., Pellatt, J., Trinder, M., & Birkhead, T. R. (2005). Oil pollution and climate have wide-scale impacts on seabird demographics. *Ecology Letters, 8*, 1157–1164.

Wahl, T. R., & Heinemann, D. (1979). Seabirds and fishing vessels: Co-occurrence and attraction. *The Condor, 81*, 390–396.

Webb, A., Elgie, M., Hidef, C. I., Pollock, C., Barton, C., Burns, S., & Hawkins, K. (2016). *Sensitivity of offshore seabird concentrations to oil pollution around the United Kingdom: Report to oil & gas UK*. 103 pp.

Westphal, A., & Rowan, M. K. (1969). Some observations on the effects of oil pollution on the Jackass Penguin. *Ostrich, 40*, 521–526.

Whitmer, E. R., Elias, B. A., Harvey, D. J., & Ziccardi, M. H. (2018). An experimental study of the effects of chemically dispersed oil on feather structure and waterproofing in Common Murres (*Uria aalge*). *Journal of Wildlife Diseases, 54*(2), 315–328. 2017-01–016.

Wiese, F. K., & Elmslie, K. I. M. (2006). Underuse and misuse of data from beached bird surveys. *Marine Ornithology, 34*, 157–159.

Wiese, F. K., & Robertson, G. J. (2004). Assessing seabird mortality from chronic oil discharges at sea. *Journal of Wildlife Management, 68*, 627–638.

Wiese, F. K., & Ryan, P. C. (2003). The extent of chronic marine oil pollution in southeastern Newfoundland waters assessed through beached bird surveys 1984–1999. *Marine Pollution Bulletin, 46*, 1090–1101.

Wilhelm, S. I., Robertson, G. J., Ryan, P. C., Tobin, S. F., & Elliot, R. D. (2009). Re-evaluating the use of beached bird oiling rates to assess long-term trends in chronic oil pollution. *Marine Pollution Bulletin, 58*(2), 249–255.

Wilkinson, J., Beegle-Krause, C., Evers, K. U., Hughes, N., Lewis, A., Reed, M., & Wadhams, P. (2017). Oil spill response capabilities and technologies for ice-covered Arctic marine waters: A review of recent developments and established practices. *Ambio, 46*, 423–441.

Williams, J. M., Tasker, M. L., Carter, I. C., & Webb, A. (1994). A method of assessing seabird vulnerability to surface pollutants. *Ibis, 137*, 147–152.

Wong, S. N., Gjerdrum, C., Morgan, K. H., & Mallory, M. L. (2014). Hotspots in cold seas: The composition, distribution, and abundance of marine birds in the North American Arctic. *Journal of Geophysical Research: Oceans, 119*, 1–15.

Wong, S. N. P., Gjerdrum, C., Gilchrist, H. G., & Mallory, M. L. (2018). Seasonal vessel activity risk to seabirds in waters off Baffin Island, Canada. *Ocean and Coastal Management, 163*, 339–351.