Operation Phase

The operation phase is the most researched phase of OSW energy developments, offering the most knowledge of effects on aerofauna and associated habitat. It includes activities centered around electricity generation, which involves sub-activities such as turbine presence and moving rotor blades. It also includes regular maintenance activities that require vessels or aircraft to access OSW energy sites for inspections. Various equipment is needed to ensure the upkeep of turbines, cables, and platforms in the harsh marine environment.

[EG] Electricity Generation

The main activity associated with offshore wind (OSW) energy development is electricity generation. Rotor blades on each wind turbine are in motion while actively generating electricity. Energy is then transported to the onshore electrical grid through sub-sea export cables. The scope of this section is stressors related to the offshore features for generating electricity at an operational OSW energy development.

The stressors identified with potential effects to aerofauna species and habitat include:

- Artificial Lighting
- Artificial Structures
- Habitat Loss

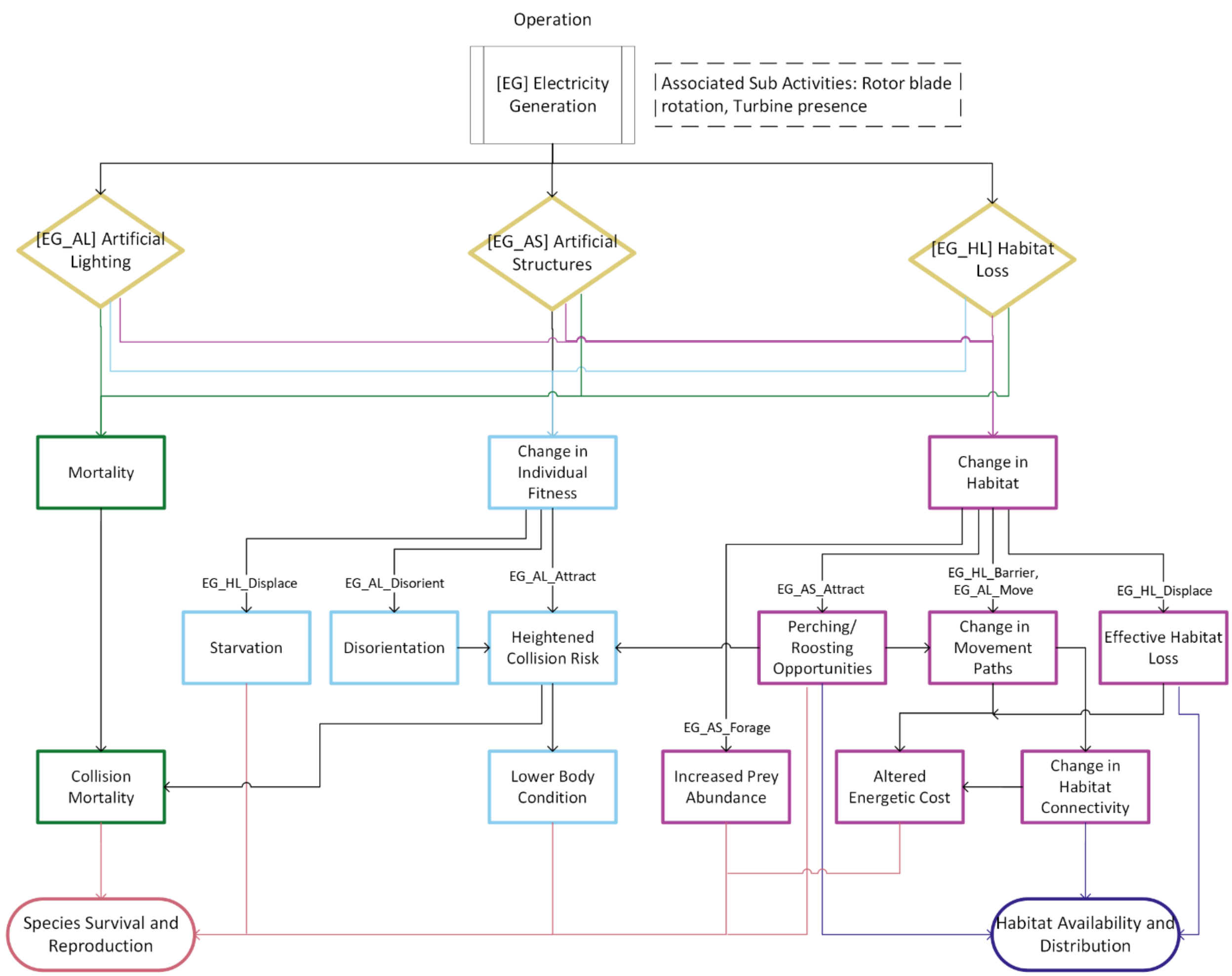

Figure 5: Pathways of Effects diagram for electricity generation during offshore wind energy development operation.

[EG_AL] Artificial Lighting

OSW energy development introduces a source of artificial light in the offshore environment. Wind turbines are required to have lighting during operation for safe navigation as specified in Chapter 12 of the Canadian Aviation Regulations (2016). As such, platforms and turbines associated with OSW energy development will become sources of artificial lighting in the marine environment, which can trigger a behavioural response (e.g., attraction, avoidance) and leave individuals more susceptible to mortality through indirect pathways (personal communication, R. Thomas, July 22, 2024). Depending on the response, collision mortality and injury can occur. The extent of the effect depends on species, weather conditions, the lighting characteristics, and other factors.

Attraction is the primary cause-effect pathway associated with artificial lighting as aerofauna can be attracted to lit platforms in the offshore environment [EG_AL_Attract]. Especially at night, seabirds and nocturnal migrants can be attracted to artificial light (Hüppop et al., 2006; Montevecchi, 2006; Rebke et al., 2019). Maturity can also influence attraction, as 94% of petrels attracted to artificial lighting were fledglings and high incidences of stranded individuals aligned with fledgling flights of Leach's Storm-Petrels (Gjerdrum et al., 2021; Rodríguez & Rodríguez, 2009). However, avoidance (e.g., negative phototaxis) is also a potential response in petrels [EG_AL_Avoidance] (Syposz et al., 2021).

Attraction to OSW energy developments can directly lead to mortality from collision with the turbine, offshore platforms, or rotor blades [EG_AL_Attract]. Indirect effects can change body condition by stranding or disorienting individuals, resulting in increased energetic cost [EG_AL_Move] (Deakin et al., 2022; Gjerdrum et al., 2021; Hüppop et al., 2006; Marques et al., 2014; Montevecchi, 2006). Based on observations from oil and gas and research platforms, birds may circle aimlessly around artificial light sources until exhaustion, which increases the likelihood of collision mortality or injury [EG_AL_Disorient] (Hüppop et al., 2006; Ronconi et al., 2015). Changes in migration routes or ideal habitat distributions through attraction can have negative consequences on aerofauna survivability and reproduction if it results in substantial numbers of collisions or increases to energetic cost. Further, these changes directly influence habitat availability and distribution as connectivity between habitat locations is altered.

The extent of both direct and indirect effects are dependent on fog, wind speed, cloud cover, lunar phase and star visibility altering the degree of visibility offshore (Deakin et al., 2022; Gjerdrum et al., 2021; Hüppop et al., 2016; Montevecchi, 2006; Rebke et al., 2019). For example, when it is cloudy with no other sources of illumination, birds can be attracted to lit offshore platforms [EG_AL_Move].

Additionally, characteristics of the lighting can attract more nocturnal migrating aerofauna (Rebke et al., 2019; Voigt et al., 2018). For instance, current U.S. guidance on lighting at OSW farms recommends flashing yellow light for intermediate and peripheral structures, and only directing light where it is needed (BOEM, 2021). Birds can be more attracted to continuous blue, green or white light, and less attracted to blinking blue, yellow, or green light (Rebke et al., 2019). Similarly, some migratory bat species can be more attracted to red LED light compared to warm-white LED light, independent of hunting opportunity and dependent on species behaviour (Voigt et al., 2018). Contrasting bright light and the surrounding dark marine environment could heighten attraction and subsequent collision mortality or injury [EG_AL_Attract] (Solick & Newman, 2021). The characteristics discussed above are not meant to be an exhaustive list for attraction to artificial light. Attraction may differ depending on species, habitat, environmental conditions, and other factors (R. Ronconi, personal communication, July 15, 2024).

Foraging habitat quality can change due to artificial lighting, indirectly affecting aerofauna species survivability and reproduction and habitat availability and reproduction [See EG_AS_Forage]. Aerofauna prey species can also be attracted to light (C. Gjerdrum, personal communication, July 16, 2024; Lieske et al., 2020). Habitat enhancing effects are discussed in the next section.

For nocturnal migratory bird species, movement pathways can lead to less direct effects on mortality and individual fitness. Though the mechanisms are less clear, migratory stopovers of nocturnal migrating birds are influenced by artificial lighting (McLaren et al., 2018). Nocturnal migrating birds can potentially become lost at sea or more susceptible to predation due to increases in energetic cost, and migration can be short-stopped, forcing a longer migration or altering paths (R. Thomas, personal communication, July 22, 2024). As additional effects are possible through attraction to artificial light, indirect mortality pathways can affect aerofauna species survivability and reproduction and habitat availability and distribution.

Species that might be vulnerable to attraction to artificial lighting include petrels (Leach's Storm-Petrel, Cory's Shearwater) Herring Gull, nocturnal migrating landbirds and migratory bats (Gjerdrum et al., 2021; Hüppop et al., 2016; Rebke et al., 2019; Rodríguez & Rodríguez, 2009; Voigt et al., 2018).

[EG_AS] Artificial Structures

Once operational, OSW energy developments include site-specific numbers of wind turbines that introduce anthropogenically engineered structures, or artificial structures, into the marine environment (Bishop et al., 2017). The cause-effect pathways linked to artificial structures are dictated by behavioural responses (e.g. avoidance or attraction) of aerofauna species to developments (Marques et al., 2014). Visual disturbances from artificial structures can lead to behavioural responses that change habitat use (Drewitt & Langston, 2006; Fox et al., 2006). As previously discussed, lighting on the structures can invoke attraction to structures. Similarly, attraction can be due to effects (e.g. artificial reef effect) introduced by the structures themselves. Flight paths can be modified by attraction to OSW farm areas [This section], or alternatively, barriers to movement through avoidance [See EG_HL] (Bishop et al., 2017; Drewitt & Langston, 2006; Fox et al., 2006).

Mortality can occur from the visual disturbance of artificial structures that can attract aerofauna (Drewitt & Langston, 2006). Individuals may collide with the supporting structure, the blades (stationary or rotating), or be swept up in the wake of the rotor blades

(Fox et al., 2006; Hüppop et al., 2006, 2016). Collisions can directly cause mortality or injury [EG_AS_Collision] based on species-specific, site-specific (e.g. siting location, prey availability) and development-specific factors (e.g. OSW farm configuration, lighting), as well as poor weather conditions that affect visibility (Hüppop et al., 2006; Marques et al., 2014). Lower body condition may also lead to mortality by affecting the ability to fly to other habitat areas to forage or recover.

For species-specific collision vulnerability models, additional readings that may be useful: (Furness et al., 2013).

Each wind turbine requires scour protection at the base. Scour protection is usually in the form of rock piles placed on the seabed around the turbine, introducing a hard substrate into a previous soft sediment habitat (Fox & Petersen, 2019; Perrow, 2019). The hard substrate from scour protection and turbine foundations creates an artificial reef effect by introducing new and replacement benthic habitat (Bishop et al., 2017; Degraer et al., 2020; Perrow, 2019; Wilson & Elliott, 2009). Post-construction monitoring of offshore wind farms in the Belgian North Sea show evidence of improvements to the benthic habitat, with higher biomass and epibenthos density observed (De Backer et al., 2020; in Degraer et al., 2020).

Artificial reefs change foraging habitat for marine birds. Within OSW farm areas, they can potentially increase prey availability and foraging habitat for aerofauna, particularly seabirds [EG_AS_Forage] (Degraer et al., 2020; Drewitt & Langston, 2006; Williams et al., 2024). It has been documented that some gull species have taken advantage of increased prey abundance due to the artificial reef effect (Vanermen et al., 2015). Conversely, since artificial reefs alter community structure, effective habitat loss could occur prey availability decreases from competition or loss of preferred prey [See EG_HL_Displace].

Above the ocean surface, turbines introduce new habitat for perching or roosting [EG_AS_Attract] (Ahlén et al., 2009; Dierschke et al., 2016). Although offshore structures can provide additional resting habitat, it can lead to negative effects by heightening collision mortality or injury.

Further, habitat changes from the artificial reef effect can attract aerofauna. Consequently, improving habitat can lead to mortality and injury by heightening the risk of collision with turbines and alter energetic cost by changing movement patterns.

[EG_HL] Habitat Loss

OSW energy developments introduce habitat loss as a stressor that can affect aerofauna. Behavioural responses to the turbines cause habitat loss through avoidance responses that can cause displacement and barriers to movement. In flight, bird species avoid wind farm areas at multiple spatial scales (micro, meso, macro) (Cook et al., 2018). Micro and meso avoidance are smaller scale avoidance behaviours that take place inside OSW farm areas, such as evasion of rows of turbines within the wind farm and last-second escape of turbine blades, respectively (Cook et al., 2018; May, 2015). Macro avoidance is the focus of the discussion as it relates to habitat loss and displacement (Cook et al., 2018; May, 2015). This section focuses on the subsequent habitat loss due to displacement and barriers to movement due to OSW farm areas. The effects that change habitat due to attraction from artificial structures (e.g., artificial reef effect, improving habitat and prey abundance) are described in the preceding section.

OSW energy development operation can cause habitat loss for aerofauna. As the result of macro avoidance of OSW energy developments, permanent displacement of a species can lead to direct habitat loss (Drewitt & Langston, 2006; Fox et al., 2006; Williams et al., 2024). Displacement from ideal habitat distributions is presented here in terms of the changes in habitat use and habitat loss (May, 2015; Williams et al., 2024).

Displacement removes birds from ideal foraging distributions, causing effective habitat loss that can have energetic consequences [EG_HL_Displace] (Fox et al., 2006; Garthe et al., 2023). In the worst case, habitat loss can lead to starvation due to compounding energetic cost and shift to less optimal foraging habitat preventing effective foraging (Garthe et al., 2023). Species-specific behaviour influences the extent of the effect and can often be related to vessel-related stressors during maintenance activities [See RM_AS] (Dierschke et al., 2016; Furness et al., 2013).

Additionally, OWS energy developments can impede connectivity between habitats used for foraging, nesting, breeding, and resting through the barrier effect [EG_HL_Barrier] (Fox & Petersen, 2019). Some species avoid OSW energy development areas entirely (macro avoidance) due to disturbance caused by the turbines, as recorded by studies at operational developments (e.g. Garthe et al., 2023; Vanermen et al., 2015). Consequently, turbines can act as barriers to movement between habitat locations (e.g. movement between feeding and nesting areas) that can alter energetic cost (Exo et al., 2003; Masden et al., 2009).

Since essential habitats for foraging, breeding, and migrating become fragmented (barrier effect) or completely lost (displacement), it can have consequences for aerofauna species survivability and reproduction by reducing habitat availability and distribution. These pathways reduce connectivity between populations that can hinder reproduction by causing extinction and loss of genetic diversity (Cristofari et al., 2019). Such effects of habitat loss from OSW farm electricity generation will be long term and can vary between species.

[RM] Routine Maintenance

Offshore wind energy development operations include routine maintenance such as regular inspections or repairs. Associated sub-activities that are involved with maintenance are the use of vessels, aircraft, or other construction equipment depending on the nature of the specific maintenance undertaking. For instance, if a turbine is malfunctioning, the equipment required will vary depending on the diagnostic results of the issue. Routine maintenance is a necessary activity to ensure that all components of the development are functioning according to operational requirements. The scope of this section is constrained to components introduced in carrying out maintenance at OSW energy development sites.

The stressors identified that can lead to potential effects to aerofauna species and habitat include:

- Artificial Lighting
- Artificial Structures
- Noise

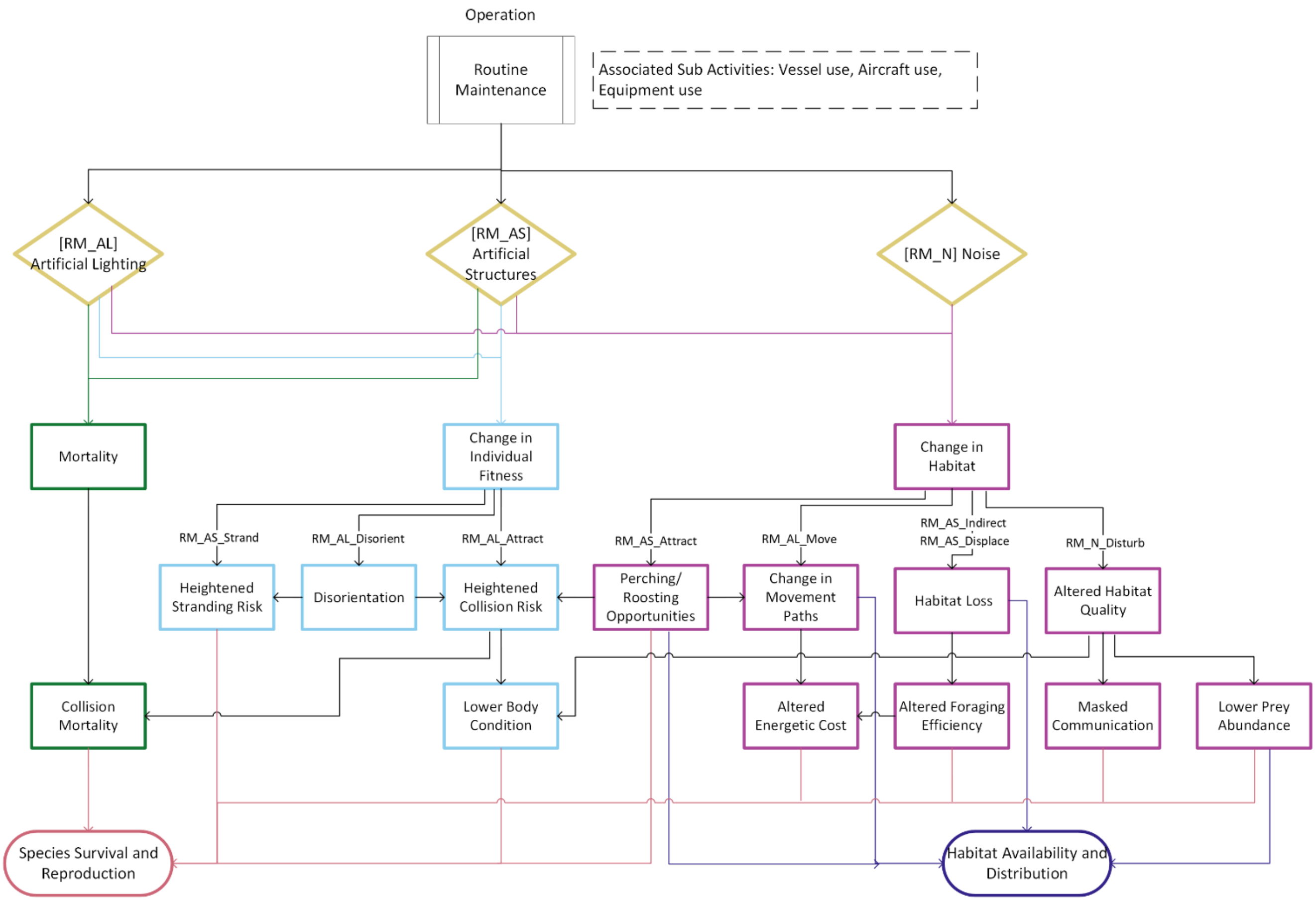

Figure 6: Pathways of Effects diagram for routine maintenance during offshore wind energy development operation.

[RM_AL] Artificial Lighting

Maintenance or repairs to OSW energy infrastructure such as turbines, scour protection, and cables, will require vessels, aircraft, and equipment. Vessels and aircraft are equipped with lighting for navigation and safety purposes. Additionally, completion of work could require additional lighting if visibility is poor. Because birds can be attracted to artificial lighting in the offshore environment, it can cause mortality and changes in individual fitness by enhancing collision risk and energetic cost by displacing or disorienting aerofauna from movement paths [RM_AL_Attract; RM_AL_Move] (Gjerdrum et al., 2021; Montevecchi, 2006).

See [EG_AL] for more details of the effects of artificial lighting.

[RM_AS] Artificial Structures

Maintenance could involve inspection or replacement of turbine or cable components. Equipment such as cranes for lifting and vessels for transportation of components, equipment, and personnel may be required depending on the type and extent of maintenance. Shipping and vessels, as artificial structures, temporarily disturb the marine environment, which can become a regular occurrence in and around OSW energy developments. Studies of the disturbance effects of shipping on birds often classify shipping as a source of human disturbance (e.g., Schwemmer et al., 2011). Since disturbance caused by vessels is not often attributed solely to one stressor, the cause-effect pathways between vessels and effects on aerofauna have been incorporated into artificial structures.

Aerofauna may respond to artificial structures with attraction or avoidance behaviours that are species-specific. By affecting bird behaviour, disturbance can alter energy intake, breeding success, and survival [RM_AS_Displace] (Goodship & Furness, 2022). It can also indirectly change behaviour through habitat loss (Goodship & Furness, 2022).

Mortality or injury due to collision can occur from increased vessel traffic around OSW energy developments. With vessel-related activities, aerofauna behaviour around vessels can increase collision and stranding risk (Gjerdrum et al., 2021). Stranding itself can lead to mortality [RM_AS_Strand] (R. Ronconi, personal communication, July 15, 2024). Introduced roosting or feeding opportunities on offshore vessels and maintenance equipment can attract bats and enhance the risk of collision mortality or injury [RM_AS_Attract] (Ahlén et al., 2009; Solick & Newman, 2021). Similar risk of collision and subsequent mortality or injury can occur in seabirds, as they are also attracted to marine vessels (Montevecchi, 2006).

Vessels disturb aerofauna, particularly seabirds and sea ducks, in the marine environment. Responses to disturbance include displacing species present in the vicinity of the vessel (e.g., foraging, swimming or resting), which can cause temporary habitat loss, especially if the displacement leads to less ideal foraging habitat [RM_AS_Displace] (Dehnhard et al., 2019; Leemans & Collier, 2022; Schwemmer et al., 2011). Foraging efficiency may decrease and the energetic cost can increase due to displacement (Schwemmer et al., 2011). Vessels also cause energetically costly escape behaviours such as taking flight or diving that reduce foraging and resting time (Dehnhard et al., 2019; Jarrett et al., 2018; Larsen & Laubek, 2005; Mendel et al., 2019; Schwemmer et al., 2011). Escape behaviour is influenced by the speed of the vessel and wave conditions (Jarrett et al., 2018). Such behaviours lead to changes in habitat use and can negatively affect individual fitness. It may also cause mortality due to lower foraging efficiency to make up for additional energetic cost (Schwemmer et al., 2011).

Species that may be highly sensitive/vulnerable to disturbance by vessels include Long-tailed Duck, Red-breasted Merganser, Red-throated Loons, Common Scoter, Greater scaup, Common Eider, Common Goldeneye, Sandwich Tern, and Roseate Tern (Dehnhard et al., 2019; Goodship & Furness, 2022; Jarrett et al., 2018; Larsen & Laubek, 2005; Mendel et al., 2019). Alcids may also be sensitive to vessel disturbance based on observations of Black guillemot behaviour (Ronconi & Clair, 2002).

While marine bird foraging habitat is affected by behavioural responses, vessels can directly affect the quality of habitat [RM_AS_Indirect]. Waves from the wakes of moving vessels can destroy nests along shorelines, reducing breeding success as documented in freshwater systems (Allen et al., 2008). Although the extent of these effects is unknown in marine environments, foraging efficiency may also increase in coastal areas from wave-induced mixing that can dislodge benthic prey (Gabel et al., 2017).

[RM_N] Noise

Equipment, vessels, or aircraft that may be required for OSW energy development maintenance can introduce noise in the marine environment. Noise disturbance can affect birds by changing the quality of the surrounding habitat. The preceding section (Stressor 2: Artificial Structures) describes the effects of vessel disturbance on aerofauna in the marine environment which can introduce noise. This section will focus on describing the PoE solely attributed to noise from maintenance activities through vessel, equipment, and aircraft use.

Noise disturbance can affect aerofauna. Seabirds, particularly Red-breasted Merganser, can be displaced from foraging habitat by vessel noise (Jarrett et al., 2018). Breeding seabirds respond to aircraft noise at various volumes, ranging from head turning to flying away (Brown, 1990). Noise from passing aircraft or equipment use can potentially interfere with auditory cues (e.g., communication between individuals or predator detection) and breeding success, especially in environments where ambient noise levels are typically much quieter and temporal exposure is extended [RM_N_Disturb] (Iasiello & Colombelli-Négrel, 2023; Ortega, 2012; Smith et al., 2023).

Similarly, underwater noise from maintenance activities may cause displacement and elicit behavioural responses from aerofauna. Depending on the frequency of the noise, seabirds may elicit various responses to underwater noise (Anderson Hansen et al., 2020; Mooney et al., 2019). Potential effects could be similar to other types of disturbance from OSW energy development maintenance and operation, such as displacement from habitat and reduced foraging area. However, noise disturbance may decrease body condition by evoking physiological effects such as increasing heart rate, changing hormone levels, and weight loss (Ortega, 2012). As described in the construction phase, indirect effects of underwater noise may alter prey availability for piscivorous birds (Perrow et al., 2011).

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