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Draft Offshore Wind Pathways of Effect Model
for the Atlantic Regional Assessment of Offshore
Wind Energy Development

13	Contents	
14	Executive Summary.....	3
15	Introduction	3
16	Pathways of Effects Background	4
17	ECCC-CWS Approach.....	5
18	Phases and Activities	7
19	Endpoints	8
20	Stressors	8
21	Potential Effects	10
22	Limitations with the PoE Framework.....	11
23	Pre-Construction Phase	12
24	[SS] Site Surveys.....	12
25	Construction Phase	15
26	[SP] Site Preparation	15
27	[II] Infrastructure Installation	17
28	Operation Phase	19
29	[EG] Electricity Generation	19
30	[RM] Routine Maintenance	25
31	Decommissioning Phase	28
32	[FR] Full Removal.....	29
33	[PR] Partial Removal	31
34	Accidents Associated with All Phases.....	33
35	References	39
36		
37		
38		

39 Executive Summary

40 International capacity for offshore wind energy is growing in light of recent commitments to
41 maintain global average temperatures below the 1.5/2-degree threshold. An undertaking
42 such as this introduces new and existing stressors to wildlife in the marine environment,
43 and consequently, in 2023, the Canadian government began a regional assessment of
44 offshore wind energy development in Atlantic Canada (hereafter referred to as the RA). As
45 part of the RA, a sector-based Pathways of Effects (PoE) model for offshore wind energy
46 development was developed to visualize the cause-effect pathways between project
47 activities, environmental stressors, and the resulting effects to aerofauna (birds and bats).
48 Seven PoE models are presented for the major activities identified across all phases of
49 offshore wind energy development (pre-construction, construction, operation, and
50 decommissioning). Descriptions of the cause-effect pathways are reported by stressor.
51 Key knowledge gaps are identified and related back to the stressors and effects pathways
52 in each PoE model. These findings support ongoing information procurement, identify key
53 knowledge gaps, and can contribute to cumulative effects work related to the development
54 of the offshore wind industry in Canada.

55 Introduction

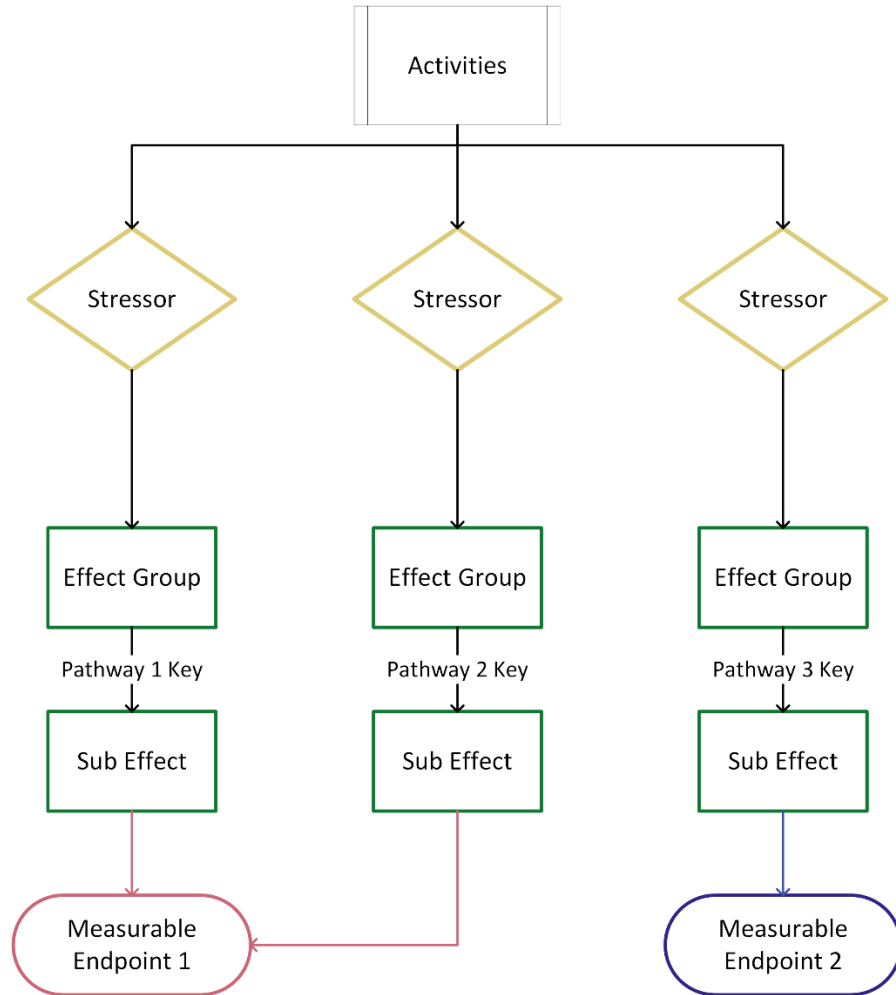
56 In the fight against climate change, meeting global energy demands requires the enhanced
57 capacity of renewable energy sources. Like many countries worldwide, Canada has set
58 renewable energy targets to contribute to keeping global temperatures below to 1.5-degree
59 threshold. Offshore wind (OSW) energy generation is one of the renewable types proposed
60 to substantially aid in achieving Canadian renewable energy targets. Similar to terrestrial
61 wind energy, OSW energy developments comprise of an array of wind turbines and
62 generators that deliver clean energy to the electrical grid. OSW energy developments can
63 also include offshore platforms for substations and export cables that connect them to
64 landfall stations for transmittance to the grid. Although OSW energy development is still in
65 the planning stages in Canada, many countries internationally have operated OSW energy
66 for decades. At present, two provinces have announced their intent to pursue OSW energy
67 development, triggering two RAs in the Canadian Atlantic region, one in Newfoundland and
68 Labrador (NL) and one in Nova Scotia (NS) (IAAC, 2022b, 2022a).

69 As the number of OSW energy developments increase on a global scale, it has become
70 clear that effects to wildlife and associated habitat, both positive and negative, exist from
71 its introduction to the marine environment (Boehlert & Gill, 2010). Migrating and foraging
72 birds and bats are especially at risk of effects due to the long-standing presence of offshore

73 structures and vessel-related maintenance (Drewitt & Langston, 2006; Fox et al., 2006;
74 Williams et al., 2024). Marine birds are disproportionately at risk as they spend a significant
75 portion of their life offshore, which may coincide with OSW energy developments.
76 Environment and Climate Change Canada-Canadian Wildlife Service (ECCC-CWS) is
77 responsible for safeguarding and protecting migratory birds, species at risk, and associated
78 habitats through the Migratory Birds Convention Act and the Species at Risk Act. Significant
79 work during the RA process has also been contributed by ECCC-Science and Technology
80 Branch (STB). ECCC-CWS has developed a Pathways of Effects (PoE) model for birds and
81 bats (hereafter referred to as aerofauna) for the NS and NL committees. The PoE model
82 aims to visualize the linkages between OSW energy development activities, ecological
83 stressors, and effects. PoE models have been used as a national risk assessment aid for
84 decades, although at present, ECCC is in its early stages of adopting PoE into the risk
85 assessment process.

86 Pathways of Effects Background

87 A PoE model is a tool used to describe the cause-and-effect relationship of federally
88 designated projects. The model consists of a visual diagram and an accompanying
89 narrative report describing the specific cause-effect pathways between a human activity,
90 an environmental stressor, and a potential effect. In PoE diagrams, cause-effect pathways
91 are represented using lines that connect activities to ecological stressors, and a potential
92 effect on a measurable endpoint (Figure 1). Such models aid decision-makers make
93 scientifically informed decisions and help identify appropriate mitigation measures
94 (Government of Canada, 2012). The Department of Fisheries and Oceans Canada (DFO)
95 uses PoE models and defines them as: “Diagrams that describe development proposals in
96 terms of the activities that are involved, the type of cause-effect relationship that are
97 known to exist for that activity, and the mechanisms by which stressors ultimately lead to
98 effects” (Fisheries and Oceans Canada, 2006, p. 24).



99

100 *Figure 1: Example of a generic Pathways of Effects diagram.*

101 PoE models have been used in risk assessments for anthropogenic activities in coastal and
 102 marine environments (e.g. Boehlert & Gill, 2010; Hannah et al., 2020; Isaacman & Daborn,
 103 2011). Previously published models for marine renewable energy have been developed by
 104 the Government of Canada, however, none to date have focused exclusively on the cause-
 105 effect pathways generated by OSW energy development with respect to the effects on
 106 aerofauna and their habitat.

107 **ECCC-CWS Approach**

108 Generally, ecological risk models are developed using information about stressors,
 109 exposure pathways, and the potential effects on the habitat and survivability/ reproduction
 110 (EPA, 1998). A similar method was used to develop the OSW energy development PoE,
 111 which took a sector-based approach. Sector-based PoEs scope the model to a specific
 112 sector or industry, and can provide valuable information to further identify cumulative
 113 effects that can affect measurable endpoints (Government of Canada, 2012). Sector-

114 specific activities induce stressors on ecosystems, which then lead to effects that can
 115 impact specific ecosystem components, environmental goods and services, and socio-
 116 economic cultural values (Government of Canada, 2012). In the case of OSW energy
 117 development, only the ecosystem-specific components were assessed which include
 118 aerofauna and their respective habitats according to the CWS mandate.

119 The model was developed using previous work developed by DFO for commercial shipping
 120 and in collaboration with the national PoE task team. Since ECCC is currently in the
 121 process of developing its own national guidance for developing PoEs, national guidance
 122 from DFO was used to develop the OSW energy development PoE. Potential pathways were
 123 identified first using guidance provided by other marine-sector PoEs developed by Hannah
 124 et al. (2020). A systematic search of scientific literature was conducted to find evidence for
 125 a sector-specific effect using the Tethys database and Google Scholar (*Tethys Knowledge*
 126 *Base*, n.d.). Countries such as the United States and European countries have numerous
 127 OSW energy developments currently in the operational phase. Existing literature reviews
 128 have summarized the effects of these developments on aerofauna and aerofauna habitat
 129 (e.g. Fox et al., 2006; Drewitt & Langston, 2006; Williams et al., 2024). Information was also
 130 compiled from other sectors that provided evidence for stressor-effect pathways in the
 131 Atlantic region, such as Offshore Oil and Gas. All cause-effect pathways were then
 132 grouped by OSW energy development project phase and activity to develop individual
 133 activity-based models (Hannah et al., 2020; Isaacman & Daborn, 2011).

134 Many disciplines study the effects of human-derived stressors on the environment with
 135 terms such as stressor, factor, and driver used to define similar phenomena across
 136 disciplines (Orr et al., 2020). The Pathways of Effects National Guidelines provide many of
 137 the definitions used for developing the model, which are summarized in Table 1.

138 *Table 1: Components of a Pathways of Effects model and associated definitions.*

Model Component	Definition	Source
Measurable endpoint	Environmental state indicators used to measure and track changes over time with respect to the objective.	Government of Canada, 2012
	An explicit expression of the environmental value that is to be protected, operationally defined by an ecological entity and its attributes.	EPA, 1998
Activity	Activities and sub-activities are human-induced undertakings that may result in impacts to the environment.	Government of Canada, 2012

Stressor	Any natural or anthropogenic variable (a chemical, physical or biological entity) that causes a quantifiable change (increase or decrease) in a biological response or measurable endpoint(s).	EPA, 1998; Government of Canada, 2012; Orr et al., 2020
Effect	Any change that the project may cause in the environment.	CEAA, 2009
Impact	A measurable change to an ecosystem component/function (e.g., loss of spawning habitat) as a result of human-induced pressures. An impact can be positive or negative.	Boehlert & Gill, 2010; Government of Canada, 2012
Pathway	A line used to represent a cause-effect relationship between an activity, a stressor, and an effect.	Fisheries and Oceans Canada, 2006

139

140 Phases and Activities

141 OSW energy development consists of multiple phases in an individual project, including
 142 pre-construction, construction, operation, and decommissioning. Activities are grouped by
 143 project phase (Table 2). An additional project phase classification has been included for
 144 accidents and spills that might occur throughout each project phase. The OSW energy
 145 development activities are further categorized into associated sub-activities to further
 146 detail each cause-effect pathway.

147 Although OSW energy development includes activities in both offshore and onshore
 148 environments, this PoE model only focuses on addressing the knowledge gap for the
 149 activities in the offshore environment. For cause-effect pathways associated with onshore
 150 activities, the proponent is directed to the national PoE models developed by the national
 151 PoE task team (in prep.).

152 *Table 2: Offshore Wind Energy Development project phases, commonly associated activities, and*
 153 *sub-activities.*

Project Phase	Activity	Sub-Activity
Pre-Construction	Site surveys	Vessel and equipment use
Construction	Site preparation	Vessel and equipment use
		Ice-breaking
		Pile driving and excavation
	Infrastructure installation	Vessel and equipment use
Operation	Electricity generation	Rotor blade rotation

		Turbine presence
	Routine maintenance	Vessel and equipment use
Decommissioning	Partial wind farm removal	Leave cables, foundations, scour protection
		Vessel and equipment use
	Full wind farm removal	Removal of all wind farm infrastructure
		Vessel and equipment use
Accidents	Accidental discharge (chemical) into environment	Turbine presence Vessel use
	Accidental discharge (solid) into environment	Vessel use
	Accidental species introduction to the environment	Vessel use; Turbine presence

154 **Endpoints**

155 Endpoints are practical and well-defined, and incorporate an ecological entity and
 156 measurable attribute (Government of Canada, 2012; See Table 1). The selected endpoints
 157 are of ecological importance, are susceptible to stressors and are relevant in managing risk
 158 to aerofauna associated with OSW energy development. Additionally, factors of survival
 159 and reproduction were considered in terms of the stressors in determining the endpoints
 160 (EPA,1998).

161 The two measurable endpoints considered in the OSW energy development PoE are:

- 162 1. Aerofauna habitat availability and distribution, including quality, quantity and
- 163 connectivity. Habitat consists of locations used throughout life stages for foraging,
- 164 breeding, roosting, resting, and migration.
- 165 2. Aerofauna species survival and reproduction.

166 **Stressors**

167 Many terms are used interchangeably across disciplines to refer to factors that arise
 168 consequentially from human activities (EPA, 1998; Orr et al., 2020). These are summarized
 169 in Table 3. In this approach, the term stressor refers to any chemical, physical or biological
 170 entity that can cause an adverse effect on a measurable endpoint (Government of Canada,
 171 2012).

172 *Table 3: An overview of the various terms used to refer to factors elicited by human activities that*
 173 *may cause environmental effects.*

Term	Organization	Definition	Source
Impact-producing factor (IPF)	NS Committee	Identify factors associated with an offshore wind (OSW) development project that may cause impacts to valued physical, biological, economic or cultural components.	IAAC, 2022b
IPF	BRI	Alternative term for pressures with negative effects.	BOEM, 2020, 2024
Agent	EPA	Any physical, chemical, or biological entity that can induce an adverse response (synonymous with stressor).	EPA, 1998
Stressor	BRI	Alternative term for pressures with negative effects.	Stelzenmüller et al., 2018
Stressor	DFO	An agent, condition, or other stimulus that causes stress to an organism.	Fisheries and Oceans Canada, 2006
Stressor	EPA	Any physical, chemical, or biological entity that can induce an adverse response (synonymous with agent).	EPA, 1998
Pressure	Government of Canada	Any chemical, physical or biological entity that can cause an adverse effect on a measurable endpoint(s).	Government of Canada, 2012
Pressure	BRI	External abiotic or biotic factor exerted by an activity or other source that causes an effect.	Willstead et al., 2018
Hazard	BRI	Alternative term for pressures with negative effects.	Goodale & Milman, 2016

174

175 The PoE model identified stressors based on the activities required of an OSW energy
 176 development project and are summarized in Table 4.

177 *Table 4: A summary of the stressors identified in the Pathways of Effects model associated with*
 178 *Offshore Wind activities and sub-activities.*

Stressor	Project Phase	Activity	Sub-Activities
Artificial Lighting	Pre-Construction, Construction, Operation, Decommissioning	<ul style="list-style-type: none"> • Site Surveys • Site Preparation • Electricity Generation • Routine Maintenance • Partial and Full Wind Turbine Removal 	<ul style="list-style-type: none"> • Vessel and Equipment Use • Turbine Presence

Artificial Structures	Pre-Construction, Construction, Operation, Decommissioning	<ul style="list-style-type: none"> • Site Surveys • Site Preparation • Electricity Generation • Routine Maintenance • Partial and Full Wind Turbine Removal 	<ul style="list-style-type: none"> • Vessel and Equipment Use • Rotor Blade Rotation • Turbine Presence
Noise	Pre-Construction, Construction, Operation, Decommissioning	<ul style="list-style-type: none"> • Site Surveys • Site Preparation • Infrastructure Installation • Routine Maintenance • Partial and Full Wind Farm Removal 	<ul style="list-style-type: none"> • Pile Driving and Excavation • Vessel and Equipment Use
Habitat Loss	Construction, Operation, Decommissioning	<ul style="list-style-type: none"> • Site Preparation • Infrastructure Installation • Electricity Generation • Partial and Full Wind Turbine Removal 	<ul style="list-style-type: none"> • Ice-Breaking • Pile-Driving and Excavation • Vessel and Equipment Use • Turbine Presence • Leave Cables, Foundations, Scour Protection • Removal of All Wind Farm Infrastructure
Invasive Species Introduction	Accidents	<ul style="list-style-type: none"> • Substance Spills and Accidental Introduction 	<ul style="list-style-type: none"> • Vessel Use
Physical Hazard Introduction	Accidents	<ul style="list-style-type: none"> • Substance Spills and Accidental Introduction 	<ul style="list-style-type: none"> • Vessel Use
Chemical Hazard Introduction	Accidents	<ul style="list-style-type: none"> • Substance Spills and Accidental Introduction 	<ul style="list-style-type: none"> • Vessel Use • Turbine Presence

179

180 Potential Effects

181 To reiterate, an effect is the measurable change to an ecosystem component due to
182 stressors induced by humans (Government of Canada, 2012). Although the term is often
183 used interchangeably with the word “impact”, effect does not imply any magnitude or
184 significance as to the outcome (Boehlert & Gill, 2010). The effects were simplified into

185 categories for applicability between projects (Table 5), similar to the model for commercial
 186 shipping developed by Hannah et al. (2020). Detailed sub-effects were then elaborated in
 187 the diagrams and narrative. Only potential effects to aerofauna and their habitat were
 188 considered in the model, according to the measurable endpoints defined above. Migratory
 189 birds, marine birds, sea ducks, shorebirds, and bats were included in the effects
 190 assessment. Due to a lack of data, monarch butterflies were not included in the PoE
 191 assessment.

192 *Table 5: The effects groupings used in the Pathways of Effects model.*

Effect Category	Detailed Effects	Source
Change in Habitat	Change in the physical habitat of the marine environment. It includes habitat loss and changes (increase or decrease) in habitat quality.	Hannah et al., 2020
Change in Individual Fitness	Non-lethal change to the physiological condition of an organism that improves or reduces the ability to grow, survive to reproductive age, and/or produce or rear offspring. Included are behavioural effects, changes to organism health and reproduction, and injury.	Adapted from Hannah et al., 2020
Mortality	Refers to the death of an organism or group of organisms. Mortality can be an immediate or delayed response after exposure to a stressor. Mortality can also occur due to a change in individual fitness.	Adapted from Hannah et al., 2020

193 **Limitations with the PoE Framework**

194 Although PoE models are useful decision-making tools, it is important to recognize that
 195 there are limitations with the approach. First, none of the models considered in the PoE for
 196 aerofauna consider cumulative effects, as PoE frameworks consider cause-effect
 197 pathways independently (Clarke Murray et al., 2014; Hannah et al., 2020). As a result, all

198 the effects considered in the models are only explained by the activities of OSW, though it
199 is anticipated that effects of other offshore industries will interact with those generated by
200 OSW, along with other OSW projects. PoEs are simplified conceptual models of complex
201 interactions that often involve multiple stressors. Further analyses will be required to
202 examine the cumulative effects from OSW energy development.

203 Second, none of the effects imply any quantification. For instance, collision as an effect to
204 aerofauna has no more implication than effective habitat loss on aerofauna species
205 survivability and reproduction. As Boehlert and Gill (2010) pointed out, it is important to
206 distinguish between the terms *effect* and *impact*. An impact implies magnitude and
207 significance, while an effect does not. Therefore, no one cause-effect pathway should be
208 prioritized over another based on the PoE and a lack of consideration for cumulative
209 effects.

210 A final limitation of the PoE model to consider is site- and species-specific pathways. Each
211 OSW project will have site-specific variables that can alter cause-effect pathways (e.g. the
212 number of turbines or platforms installed). These variables are not considered in the model
213 as the OSW industry is in its infancy in Canada. Thus, activities are generalized across all
214 phases, independent of site specifications. Moreover, different effects have varying levels
215 of knowledge and evidence. Species-specific effect pathways are limited to the state of the
216 present research, which, for aerofauna in the offshore environment, can be constrained by
217 anthropogenic valuation of the species (e.g. whether it is of conservation value, economic
218 value, cultural value). Where appropriate, a list of species with important vulnerability or
219 sensitivity classification results or further species-specific reviews on the subject are
220 identified.

221 Pre-Construction Phase

222 Considering the planning required of an OSW energy development project, the pre-
223 construction phase of OSW energy development is considered separately from
224 construction and subsequent phases. It mainly consists of environmental surveys to
225 collect data about the OSW energy development area which can include seismic surveys,
226 wildlife monitoring, and other site-related data.

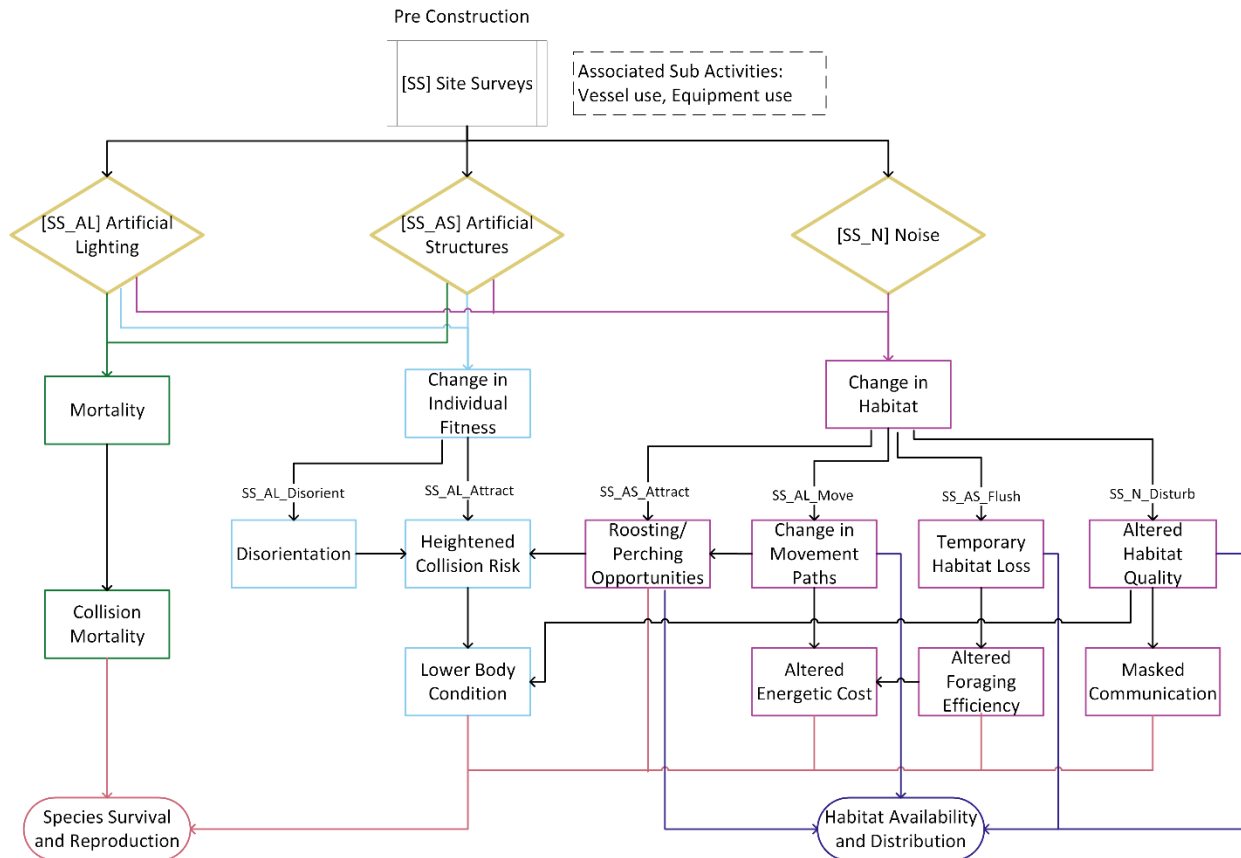
227 [SS] Site Surveys

228 Pre-construction activities include site-related assessments during the planning of an
229 OSW energy development project. Due to the remoteness of OSW locations, site
230 assessments require vessels and/or aircraft for transportation to and from the proposed
231 development area. Additional equipment is also needed at the site to gather baseline data,

232 which could include drones. Which equipment is used varies depending on the targeted
 233 ecological component and chosen method of data collection.

234 Three stressors were identified related to pre-construction site surveys:

- 235 • Artificial Lighting
- 236 • Artificial Structures
- 237 • Noise



238
 239 *Figure 2: Pathways of Effects model for site surveys during the Offshore Wind Energy Development*
 240 *pre-construction phase.*

241 **[SS_AL] Artificial Lighting**

242 Vessels used for transportation of personnel and monitoring equipment to conduct site
 243 surveys and related assessments will introduce artificial lighting. Aerofauna behaviour (e.g.
 244 attraction, avoidance) can be influenced by lighting offshore. Seabirds and bats are known
 245 to be attracted to illuminated offshore platforms and vessels (Gjerdrum et al., 2021;
 246 Montevecchi, 2006; Voigt et al., 2018). Attraction to lit offshore structures heightens the
 247 risk of collision with vessels, aircraft, and equipment that directly affects aerofauna

248 survivability and reproduction [\[SS_AL_Attract\]](#). Environmental conditions, species-specific
249 factors, lighting characteristics, and other factors can influence attraction.

250 Conversely, movement pathways can be altered away from vessels and associated
251 equipment for aerofauna that avoid in response to artificial lighting (Syposz et al., 2021).
252 Avoidance responses in-flight alter habitat connectivity and increase energetic cost
253 [\[SS_AL_Move\]](#). Aerofauna habitat availability and distribution is affected by avoidance
254 behaviour and collision mortality or injury due to attraction can lead to consequences for
255 species survivability and reproduction.

256 See [\[EG_AL\]](#) for a related description of the effects of offshore lighting on aerofauna.

257 [\[SS_AS\]](#) Artificial Structures

258 Vessels, aircraft or equipment used in monitoring introduce artificial structures into the
259 offshore environment. The presence of these structures can alter movement pathways by
260 attracting aerofauna to roosting or perching opportunities, especially seabirds and bats
261 (Ahlén et al., 2009; Dierschke et al., 2016). As a result, structures can heighten collision
262 mortality or injury [\[SS_AS_Attract\]](#). Vessels are also sources of physical disturbance which
263 can lead to changes in foraging habitat and movement pathways due to flushing, resulting
264 in altered energetic cost [\[SS_AS_Flush\]](#) (Byrnes & Dunn, 2020). Effects depend on species'
265 behavioural response and vessel speed (Schwemmer et al., 2011). Therefore, vessel
266 presence and traffic can affect both species survivability and reproduction and habitat
267 availability and distribution.

268 See related [\[EG_AS\]](#) for additional details of the effects of vessel presence on aerofauna.

269 [\[SS_N\]](#) Noise

270 Baseline monitoring equipment, such as drones, transportation vessels, and aircraft can
271 disturb aerofauna. Noise disturbance affects aerofauna behaviour and alters the quality of
272 habitat [\[SS_N_Disturb\]](#). Many behavioural responses are possible due to noise, including
273 startle, escape or flushing, and abandonment (Brown, 1990; Schwemmer et al., 2011).
274 Escape and abandonment can increase energetic cost and risk of predation, especially for
275 breeding birds (Brown, 1990). Consistent noise disturbance can mask vocal
276 communication between individuals or auditory cues from predators and/or prey species,
277 leading to consequences for species survivability and reproduction, as well as habitat
278 availability and distribution.

279 See [\[RM_N\]](#) for a detailed description of the effects of noise disturbance on birds.

280 Construction Phase

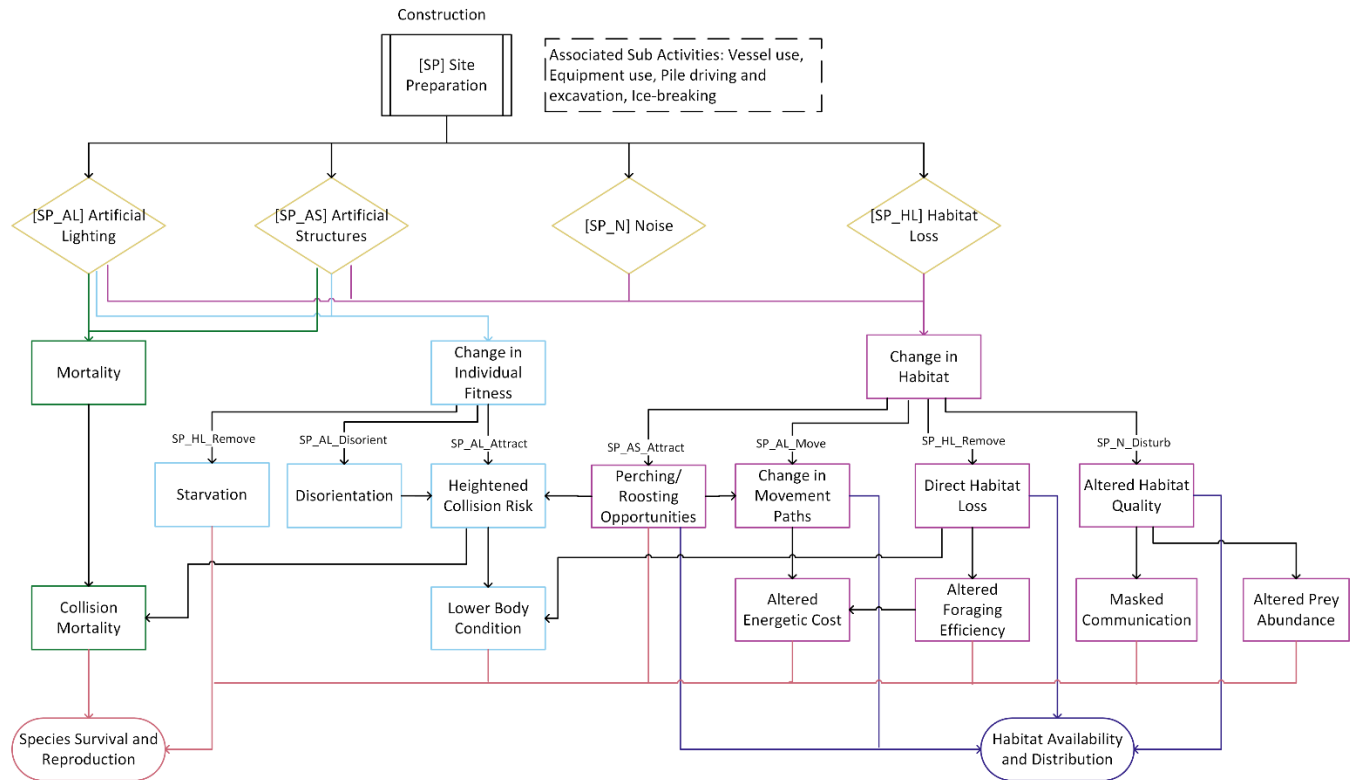
281 The construction phase of OSW energy development introduces many habitat-altering
282 stressors. Activities take place over a smaller period of time compared to the operations
283 phase, with stressors having less temporal emphasis for generated effects on aerofauna.
284 However, it is worth noting that many effects from construction-related stressors still affect
285 habitat quality, aerofauna behaviour, and can cause direct mortality. The potential effects
286 due to stressors are discussed irrespective of the magnitude associated with them.

287 [SP] Site Preparation

288 Preparing an OSW farm site includes any activity that is required prior to installing the
289 offshore infrastructure at the OSW project site. This could include preparation of the
290 seabed to install turbines, platforms, and array and export cables. Specific sub-activities
291 are icebreaking, excavation, and pile driving, which require specialized jack-up vessels.
292 Construction activities vary between OSW energy development projects and many
293 activities and sub-activities are site-specific.

294 Four main stressors were identified related to construction phase site preparation:

- 295 • Artificial Lighting
- 296 • Artificial Structures
- 297 • Habitat Loss
- 298 • Noise



299

300 *Figure 3: Pathways of Effects model for site preparation during the Offshore Wind Energy*
 301 *Development construction phase.*

302 [SP_AL] Artificial Lighting

303 Vessels, aircraft, and equipment needed to complete construction sub-activities require
 304 artificial lighting. Artificial lighting can cause attraction or avoidance responses from
 305 aerofauna [See [SS_AL](#)]. Attracted aerofauna is vulnerable to collision mortality or injury
 306 [[SP_AL_Attract](#)]. Aerofauna that avoid OSW areas in response to artificial lighting can cause
 307 disorientation, altering movement pathways and energetic cost [[SP_AL_Move](#);
 308 [SP_AL_Disorient](#)].

309 [SP_AS] Artificial Structures

310 Specialized vessels equipped with cranes and jacks are required for offshore site
 311 preparation. As previously discussed, vessels alter aerofauna behaviour and movement
 312 pathways and can increase risk of collision mortality or injury and energetic cost
 313 [[SP_AS_Attract](#)]. These effects would result in consequences to species survivability and
 314 reproduction, and habitat availability and distribution. See related pathway [[SS_AS](#)].

315 [\[SP_HL\] Habitat Loss](#)

316 Ice-breaking, pile driving, and excavation activities cause direct habitat loss by removing
317 aerofauna habitat within the OSW farm area. Vulnerable species to disturbance such as
318 sea ducks and seabirds can depart from, or not enter, their preferred or important habitats
319 due to these activities (Hemery et al., 2024). This mainly affects foraging habitat for marine
320 bird species. Ice-breaking to further facilitate site preparation activities causes direct
321 habitat loss as some seabird species rely on sea ice, or polynyas, for foraging during
322 breeding and/or migration [\[SP_HL_Remove\]](#) (Mallory et al., 2019; Stirling, 1997). Direct
323 habitat loss can alter energetic cost depending on species-specific factors (Masden et al.,
324 2010). Altered energetic cost affects habitat availability and distribution and species
325 survivability and reproduction.

326 See [\[EG_HL\]](#) for a related description of the effects of habitat loss on aerofauna.

327 [\[SP_N\] Noise](#)

328 Marine vessels and equipment needed for site preparation introduce frequent noise from
329 drilling and excavation. Noise disturbance can affect aerofauna communication and
330 breeding success by changing habitat quality [\[SP_N_Disturb\]](#). Noise disturbance related to
331 construction activities changes habitat for aerofauna. Lower foraging activity has been
332 recorded inside OSW farm areas during construction (Harwood et al., 2017). Pile driving
333 specifically can indirectly affect foraging habitat for piscivorous birds species due to lower
334 prey availability (Perrow et al., 2011a). Consequences of noise disturbance can have
335 measurable effects on species survival and reproduction and habitat distribution and
336 availability.

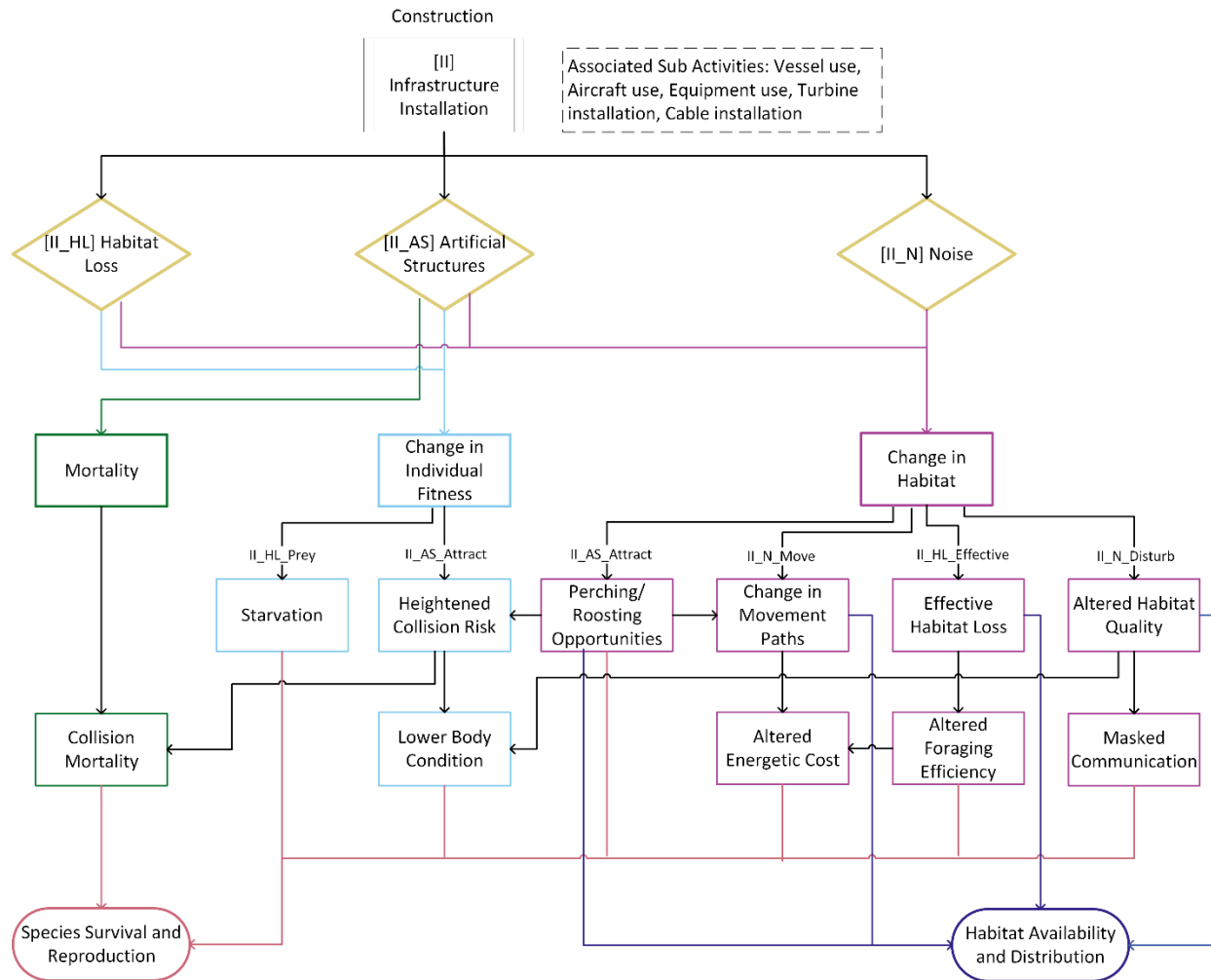
337 See [\[RM_N\]](#) for a related description of the effects of noise on birds.

338 [\[II\] Infrastructure Installation](#)

339 This activity includes sub-activities in the offshore environment. Offshore infrastructure
340 includes array and export cables, substation platforms, and wind turbines. Constructing
341 the wind turbines mostly takes place on land (Defingou et al., 2019).

342 Three main stressors were determined for installing infrastructure associated with OSW
343 farms:

- 344 • Artificial Structures
- 345 • Habitat Loss
- 346 • Noise



347

348 *Figure 4: Pathways of Effects model for infrastructure installation during the Offshore Wind Energy*
 349 *Development construction phase.*

350 [II_AS] Artificial Structures

351 During construction, large, specialized vessels are required for turbine, foundation, and
 352 scour protection installation. Depending on project constraints, many vessels can be used
 353 with features such as cranes and jack-ups allow for lifting offshore wind components and
 354 installing foundations (Perrow, 2019). Vessels can attract certain species and increase
 355 collision risk that could cause injury or mortality, with measurable effects to both
 356 endpoints [II_AS_Attract].

357 See [RM_AS] and [EG_AS] for a related description of the effects of artificial structures on
 358 aerofauna.

359 [\[II_HL\] Habitat Loss](#)

360 Specialized vessels and equipment increase human disturbance in the offshore
361 environment. Installing turbine foundations and scour protection further alters foraging
362 habitat quality which can cause habitat loss (Drewitt & Langston, 2006). As discussed
363 previously, construction activities affect foraging habitat by lowering prey availability for
364 marine birds [\[II_HL_Prey\]](#) (Perrow et al., 2011a). Subsequent energetic consequences due
365 to habitat loss can alter breeding success and in severe cases, cause mortality
366 [\[II_HL_Effective\]](#). The effects of habitat loss caused by infrastructure installation can affect
367 both measurable endpoints.

368 See [\[EG_HL\]](#) for a related description of the effects of habitat loss on aerofauna.

369 [\[II_N\] Noise](#)

370 Noise disturbance caused by installing wind turbines, foundations, and scour protection
371 can displace aerofauna or affect individual fitness and impede communication
372 [\[II_N_Disturb\]](#). Aerofauna behavioural responses can disrupt movement and breeding
373 success. Nest departure in response to noise disturbance can have further negative
374 implications for breeding success and negative energetic consequences (Brown, 1990;
375 Mooney et al., 2019; Ortega, 2012).

376 See [\[RM_N\]](#) for a related description of the effects of noise on birds.

377 **Operation Phase**

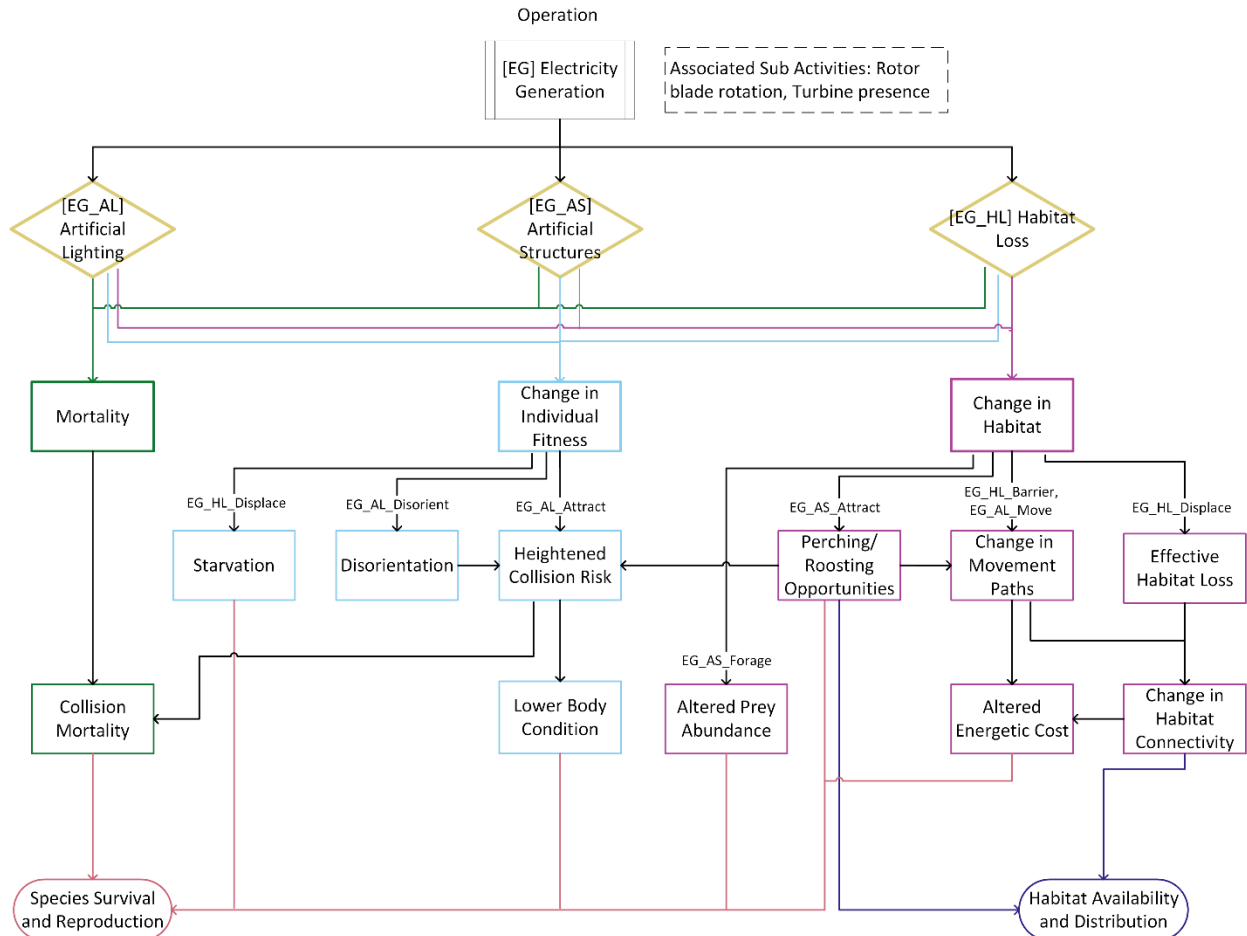
378 The operation phase is the most researched phase of OSW energy developments, offering
379 the most knowledge of effects on aerofauna and associated habitat. It includes activities
380 centered around electricity generation, which involves sub-activities such as turbine
381 presence and moving rotor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

385 [\[EG\] Electricity Generation](#)

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

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

- 392 • Artificial Lighting
- 393 • Artificial Structures
- 394 • Habitat Loss



395
396 *Figure 5: Pathways of Effects diagram for electricity generation during the Offshore Wind Energy*
397 *Development operation phase.*

398 [EG_AL] Artificial Lighting

399 OSW energy development introduces a source of artificial light in the offshore
400 environment. Wind turbines are required to have lighting during operation for safe
401 navigation as specified in Chapter 12 of the Canadian Aviation Regulations (2016). As such,
402 platforms and turbines associated with OSW energy development will become sources of
403 artificial lighting in the marine environment, which can trigger a behavioural response (e.g.,
404 attraction, avoidance) and leave individuals more susceptible to mortality through indirect
405 pathways (personal communication, R. Thomas, July 22, 2024). Depending on the

406 response, collision mortality and injury can occur. The extent of the effect depends on
407 species, weather conditions, the lighting characteristics, and other factors.

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

416 Attraction to OSW energy developments can directly lead to mortality from collision with
417 the turbine, offshore platforms, or rotor blades [EG_AL_Attract]. Indirect effects can
418 change body condition by stranding or disorienting individuals, resulting in increased
419 energetic cost [EG_AL_Move] (Deakin et al., 2022; Gjerdrum et al., 2021; Hüppop et al.,
420 2006; Marques et al., 2014; Montevecchi, 2006). Based on observations from oil and gas
421 and research platforms, birds may circle aimlessly around artificial light sources until
422 exhaustion, which increases the likelihood of collision mortality or injury [EG_AL_Disorient]
423 (Hüppop et al., 2006; Ronconi et al., 2015). Changes in migration routes or ideal habitat
424 distributions through attraction can have negative consequences on aerofauna
425 survivability and reproduction if it results in substantial numbers of collisions or increases
426 to energetic cost. Further, these changes directly influence habitat availability and
427 distribution as connectivity between habitat locations is altered.

428 The extent of both direct and indirect effects are dependent on fog, wind speed, cloud
429 cover, lunar phase and star visibility altering the degree of visibility offshore (Deakin et al.,
430 2022; Gjerdrum et al., 2021; Hüppop et al., 2016; Montevecchi, 2006; Rebke et al., 2019).
431 For example, when it is cloudy with no other sources of illumination, birds can be attracted
432 to lit offshore platforms [EG_AL_Move].

433 Additionally, characteristics of the lighting can attract more nocturnal migrating aerofauna
434 (Rebke et al., 2019; Voigt et al., 2018). For instance, current U.S. guidance on lighting at
435 OSW farms recommends flashing yellow light for intermediate and peripheral structures,
436 and only directing light where it is needed (BOEM, 2021). Birds can be more attracted to
437 continuous blue, green or white light, and less attracted to blinking blue, yellow, or green
438 light (Rebke et al., 2019). Similarly, some migratory bat species can be more attracted to
439 red LED light compared to warm-white LED light, independent of hunting opportunity and
440 dependent on species behaviour (Voigt et al., 2018). Contrasting bright light and the
441 surrounding dark marine environment could heighten attraction and subsequent collision

442 mortality or injury [[EG_AL_Attract](#)] (Solick & Newman, 2021). The characteristics discussed
443 above are not meant to be an exhaustive list for attraction to artificial light. Attraction may
444 differ depending on species, habitat, environmental conditions, and other factors (R.
445 Ronconi, personal communication, July 15, 2024).

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

451 For nocturnal migrating birds, movement pathways can lead to less direct effects on
452 mortality and individual fitness. Though the mechanisms are less clear, migratory
453 stopovers of nocturnal migrating birds are influenced by artificial lighting (McLaren et al.,
454 2018). Nocturnal migrating birds can potentially become lost at sea or more susceptible to
455 predation due to increases in energetic cost, and migration can be short-stopped, forcing a
456 longer migration or altering paths (R. Thomas, personal communication, July 22, 2024). As
457 additional effects are possible through attraction to artificial light, indirect mortality
458 pathways can affect aerofauna species survivability and reproduction and habitat
459 availability and distribution.

460 Species that might be vulnerable to attraction to artificial lighting include petrels (Leach's
461 Storm-Petrel, Cory's Shearwater) Herring Gull, migrating shorebirds, nocturnal migrating
462 landbirds and migratory bats (Gjerdrum et al., 2021; Hüppop et al., 2016; Rebke et al.,
463 2019; Rodríguez & Rodríguez, 2009; Schwemmer et al., 2023; Voigt et al., 2018).

464 [[EG_AS](#)] Artificial Structures

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

477 Mortality can occur from the visual disturbance of offshore artificial structures that can
478 attract aerofauna (Drewitt & Langston, 2006). Individuals may collide with the supporting
479 structure, the blades (stationary or rotating), or be swept up in the wake of the rotor blades
480 (Fox et al., 2006; Hüppop et al., 2006, 2016). Collisions can directly cause mortality or
481 injury [EG_AS_Collision] based on species-specific, site-specific (e.g. siting location, prey
482 availability) and development-specific factors (e.g. OSW farm configuration, lighting), as
483 well as poor weather conditions that affect visibility (Hüppop et al., 2006; Marques et al.,
484 2014). Lower body condition may also lead to mortality by affecting the ability to fly to other
485 habitat areas to forage or recover.

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

488 Each wind turbine requires scour protection at the base. Scour protection is usually in the
489 form of rock piles placed on the seabed around the turbine, introducing a hard substrate
490 into a previous soft sediment habitat (Fox & Petersen, 2019; Perrow, 2019). The hard
491 substrate from scour protection and turbine foundations creates an artificial reef effect by
492 introducing new and replacement benthic habitat (Bishop et al., 2017; Degraer et al., 2020;
493 Perrow, 2019; Wilson & Elliott, 2009). Post-construction monitoring of offshore wind farms
494 in the Belgian North Sea show evidence of improvements to the benthic habitat, with
495 higher biomass and epibenthos density observed (De Backer et al., 2020; in Degraer et al.,
496 2020).

497 OSW turbines change foraging and resting habitat for marine birds. Within OSW farm areas,
498 they can potentially increase prey availability and foraging habitat for aerofauna,
499 particularly seabirds [EG_AS_Forage] (Degraer et al., 2020; Dierschke et al., 2016; Drewitt &
500 Langston, 2006; Williams et al., 2024). For instance, it has been documented that some
501 gull species have taken advantage of increased prey abundance due to the artificial reef
502 effect (Vanermen et al., 2015). As well, species with strong attractance indicate changes in
503 prey availability might enhance foraging opportunities (Dierschke et al., 2016). Conversely,
504 since artificial reefs alter community structure, effective habitat loss could occur if prey
505 availability decreases from competition or loss of preferred prey [EG_HL_Displace]. Above
506 the ocean surface, turbines introduce new habitat for perching or roosting [EG_AS_Attract]
507 (Ahlén et al., 2009; Dierschke et al., 2016). Although offshore structures can provide
508 additional resting and foraging habitat, it can lead to negative effects by heightening
509 collision mortality or injury.

510 [EG_HL] Habitat Loss

511 OSW energy developments introduce habitat loss as a stressor that can affect aerofauna.
512 Behavioural responses to the turbines cause habitat loss through avoidance responses

513 that can cause displacement and barriers to movement. In flight, bird species avoid wind
514 farm areas at multiple spatial scales (micro, meso, macro) (Cook et al., 2018). Micro and
515 meso avoidance are smaller scale avoidance behaviours that take place inside OSW farm
516 areas, such as evasion of rows of turbines within the wind farm and last-second escape of
517 turbine blades, respectively (Cook et al., 2018; May, 2015). Macro avoidance is the focus of
518 the discussion as it relates to habitat loss and displacement (Cook et al., 2018; May, 2015).
519 This section focuses on the subsequent habitat loss due to displacement and barriers to
520 movement due to OSW farm areas. Displacement from ideal habitat distributions refers to
521 changes in habitat use and habitat loss (May, 2015; Williams et al., 2024). The effects that
522 change habitat due to attraction from artificial structures (e.g., artificial reef effect,
523 improving habitat and prey abundance) are described in the preceding section.

524 Displacement removes birds from ideal foraging distributions, causing effective habitat
525 loss that can have energetic consequences [[EG_HL_Displace](#)] (Fox et al., 2006; Garthe et
526 al., 2023). In the worst case, habitat loss can lead to starvation due to compounding
527 energetic cost and shift to less optimal foraging habitat preventing effective foraging
528 (Garthe et al., 2023). Species-specific behaviour influences the extent of the effect and can
529 often be related to vessel-related stressors during maintenance activities (Dierschke et al.,
530 2016; Furness et al., 2013). See [RM_AS](#) for vessel-related pathways.

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

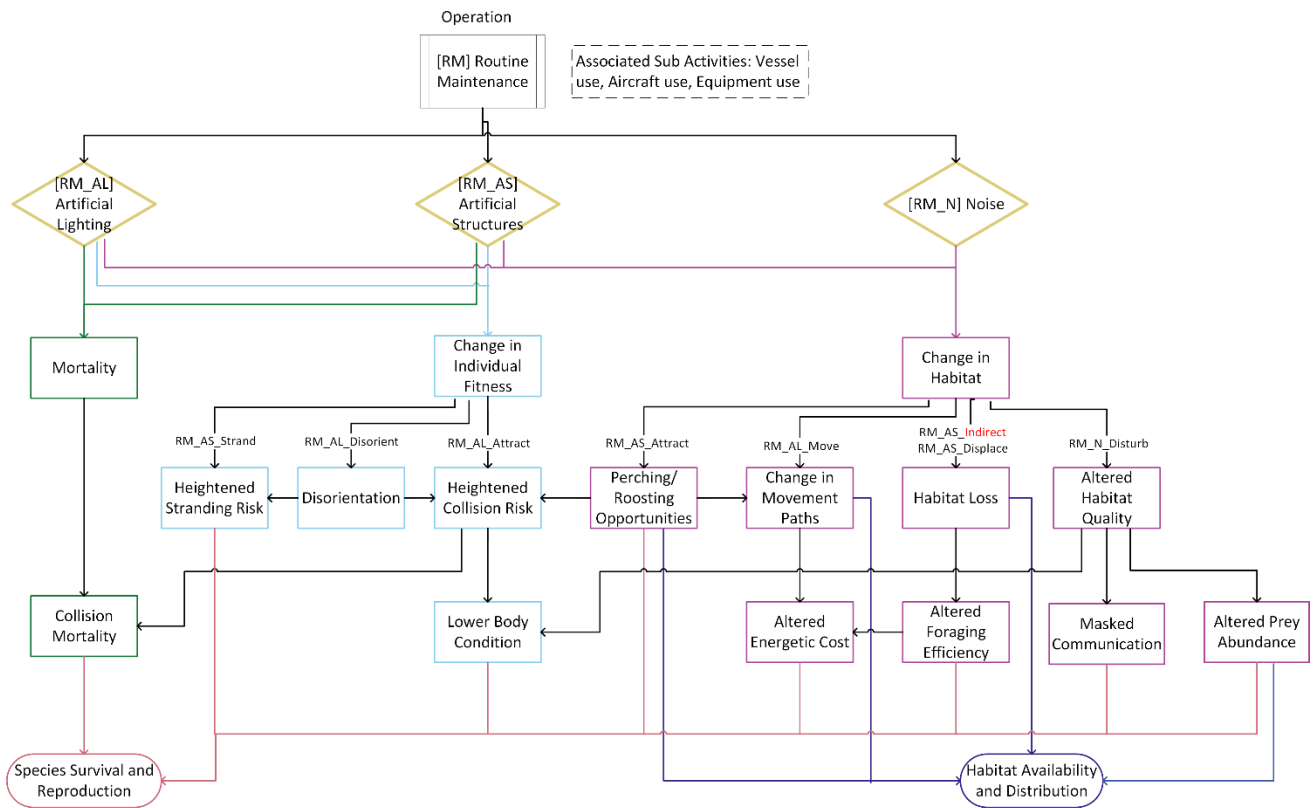
539 Since essential habitats for foraging, breeding, and migrating become fragmented (barrier
540 effect) or completely lost (displacement), it can have consequences for aerofauna species
541 survivability and reproduction by reducing habitat availability and distribution. These
542 pathways reduce connectivity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

546 [RM] Routine Maintenance

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

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

- 557 • Artificial Lighting
- 558 • Artificial Structures
- 559 • Noise



560

561 *Figure 6: Pathways of Effects diagram for routine maintenance during the Offshore Wind Energy*
 562 *Development operation phase.*

563 [\[RM_AL\] Artificial Lighting](#)

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

572 See [\[EG_AL\]](#) for a related description of the effects of artificial lighting.

573 [\[RM_AS\] Artificial Structures](#)

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

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

588 Mortality or injury due to collision can occur from increased vessel traffic around OSW
589 energy developments. With vessel-related activities, aerofauna behaviour around vessels
590 can increase collision and stranding risk (Gjerdrum et al., 2021). Stranding itself can lead to
591 mortality [\[RM_AS_Strand\]](#) (R. Ronconi, personal communication, July 15, 2024). Introduced
592 roosting or feeding opportunities on offshore vessels and maintenance equipment can
593 attract bats and enhance the risk of collision mortality or injury [\[RM_AS_Attract\]](#) (Ahlén et
594 al., 2009; Solick & Newman, 2021). Similar risk of collision and subsequent mortality or
595 injury can occur in seabirds, as they are also attracted to marine vessels (Montevecchi,
596 2006).

597 Vessels disturb aerofauna, particularly seabirds and sea ducks, in the marine environment.
598 Responses to disturbance include displacing species present in the vicinity of the vessel
599 (e.g., foraging, swimming or resting), which can cause temporary habitat loss, especially if
600 the displacement leads to less ideal foraging habitat [RM_AS_Displace] (Dehnhard et al.,
601 2019; Leemans & Collier, 2022; Schwemmer et al., 2011). Foraging efficiency may
602 decrease and the energetic cost can increase due to displacement (Schwemmer et al.,
603 2011). Vessels also cause energetically costly escape behaviours such as taking flight or
604 diving that reduce foraging and resting time (Dehnhard et al., 2019; Jarrett et al., 2018;
605 Larsen & Laubek, 2005; Mendel et al., 2019; Schwemmer et al., 2011). Escape behaviour is
606 influenced by the speed of the vessel and wave conditions (Jarrett et al., 2018). Such
607 behaviours lead to changes in habitat use and can negatively affect individual fitness. It
608 may also cause mortality due to lower foraging efficiency to make up for additional
609 energetic cost (Schwemmer et al., 2011).

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

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

622 [RM_N] Noise

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

630 Noise disturbance can affect aerofauna. Seabirds, particularly Red-breasted Merganser,
631 can be displaced from foraging habitat by vessel noise (Jarrett et al., 2018). Breeding
632 seabirds respond to aircraft noise at various volumes, ranging from head turning to flying

633 away (Brown, 1990). Noise from passing aircraft or equipment use can potentially interfere
634 with auditory cues (e.g., communication between individuals or predator detection) and
635 breeding success, especially in environments where ambient noise levels are typically
636 much quieter and temporal exposure is extended [RM_N_Disturb] (Iasiello & Colombelli-
637 Négrel, 2023; Ortega, 2012; A. B. Smith et al., 2023).

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

647 Decommissioning Phase

648 Once an OSW farm reaches its operational end-of-life, it is either re-powered to extend its
649 operational life or the decommissioning phase begins. With decommissioning, the OSW
650 farm is closed, and activities focus on dismantling infrastructure. Similar to the rest of an
651 OSW project, decommissioning is site-specific and decisions are highly influenced by
652 commercial monitoring and maintenance costs, environmental, and social values
653 (Kerkvliet & Polatidis, 2016).

654 As few OSW farms have been decommissioned, one of the main challenges of this phase is
655 the “leaving in situ dilemma” (Hall et al., 2022; Hernandez Carrascal et al., 2021; Topham
656 et al., 2019). Two options exist: the infrastructure is fully or partially removed (Fowler et al.,
657 2020; Hernandez Carrascal et al., 2021; Kerkvliet & Polatidis, 2016; Topham et al., 2019).
658 Recent discourse on the subject argues that removing infrastructure completely would
659 produce more unnecessary disturbance to the marine environment, mainly to the artificial
660 reefs on the offshore infrastructure (Fowler et al., 2020; Topham et al., 2019).

661 Some of the potential effects of decommissioning OSW farms are analogous to the
662 construction phase (Hall et al., 2022). However, any habitat-mediated changes that occur
663 during the operation phase are excluded if the decommissioning PoE is not considered
664 individually. Therefore, full and partial wind farm removal decommissioning activities
665 consider additional PoEs related to the anticipated activities of each decommissioning
666 phase scenario.

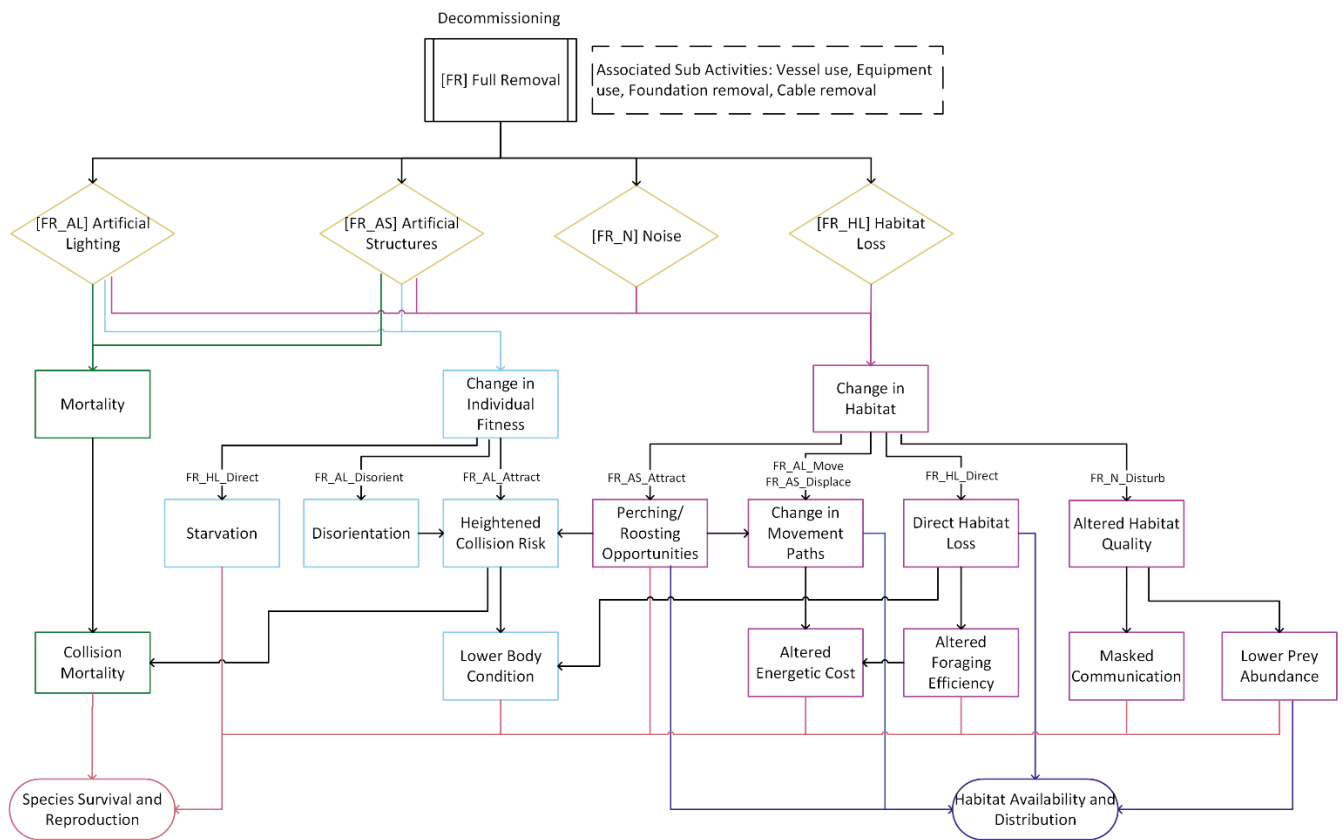
667 **[FR] Full Removal**

668 All infrastructure, including turbines, scour protection, foundations, and cables, will be
 669 disassembled and transported to onshore recycling and waste management facilities that
 670 increases trucking traffic. Depending on the type of turbines foundations, explosives might
 671 be used to remove turbines foundations (Kerkvliet & Polatidis, 2016). The associated sub-
 672 activities are infrastructure removal, vessel use, and equipment use.

673 Four main stressors were identified with the full OSW farm removal activity:

- 674 • Habitat Loss
- 675 • Noise
- 676 • Artificial Lighting
- 677 • Artificial Structures

678



679

680 *Figure 7: Pathways of Effects diagram for full removal during the Offshore Wind Energy Development*
 681 *decommissioning phase.*

682 [\[FR_HL\] Habitat Loss](#)

683 Full wind turbine removal can cause potential habitat loss for marine birds. Full removal of
684 the wind farm can alter aerofauna habitat quality and distribution which can displace
685 species from ideal habitat distributions. It is assumed that after remaining operational for
686 20-30 years, habitat disrupted by the installation of turbines and platforms will have
687 colonized and become productive foraging habitat for marine birds (Dierschke et al., 2016;
688 Smyth et al., 2015). Full removal of the structures (e.g. turbine foundations, platforms,
689 cables, scour protection) will cause direct habitat loss for benthic marine species (Hall et
690 al., 2022; Topham et al., 2019). Depending on habitat use, effective habitat loss can occur
691 as a result of lower prey abundance [\[FR_HL_Direct\]](#). Structure removal or reintroducing
692 commercial fisheries into OSW farm areas could both contribute to effective habitat loss
693 (Fowler et al., 2020; Hall et al., 2022). This can result in changes in energetic cost, breeding
694 success, and in extreme cases, mortality. Habitat loss can affect both measurable
695 endpoints.

696 [\[FR_N\] Noise](#)

697 Offshore, linked to aircraft, vessel and equipment use during infrastructure removal.
698 Effects would be similar to the construction phase and depend on the species-specific
699 sensitivity to vessel disturbance (Hall et al., 2022). Noise can affect both measurable
700 endpoints [\[FR_N_Disturb\]](#). See [\[RM_N\]](#) for a related description of the effects of noise on
701 birds.

702 [\[FR_AL\] Artificial Lighting](#)

703 Artificial lighting from aircraft, vessel and equipment use for offshore infrastructure
704 removal is similar to the cause-effect pathways described in the construction phase. The
705 complete removal of offshore platforms and turbines should eliminate aerofauna
706 attraction and avoidance effects. Lighting from vessels may attract and disorient birds and
707 increase risk of collision mortality, injury, and risk of stranding [\[FR_AL_Attract;](#)
708 [FR_AL_Disorient\]](#) depending on the duration of increased vessel traffic to decommission
709 the OSW farm. Altered movement paths and subsequent energetic cost [\[FR_AL_Move\]](#)
710 would also depend on the duration of the full removal decommissioning. Artificial lighting
711 can affect both measurable endpoints. See [\[EG_AL\]](#) for a detailed description of the effects
712 of artificial lighting on aerofauna.

713 [\[FR_AS\] Artificial Structures](#)

714 The cause-effects pathways will be similar to artificial structure use described in the
715 construction phase. However, with the removal of wind turbines and other platforms,
716 attraction to these structures should diminish, lowering collision mortality or injury over the

717 long-term (Hall et al., 2022). The energetic cost due to vessel attraction and avoidance
718 [\[FR_AS_Attract; FR_AS_Displace\]](#) should further be reduced once the full removal
719 decommissioning is complete as the OSW site may not require regular monitoring. Vessel
720 disturbance can affect aerofauna species survivability and reproduction and habitat
721 availability and distribution. See [\[RM_AS\]](#) for a detailed description of the effects of vessel
722 activity on aerofauna.

723 [\[PR\] Partial Removal](#)

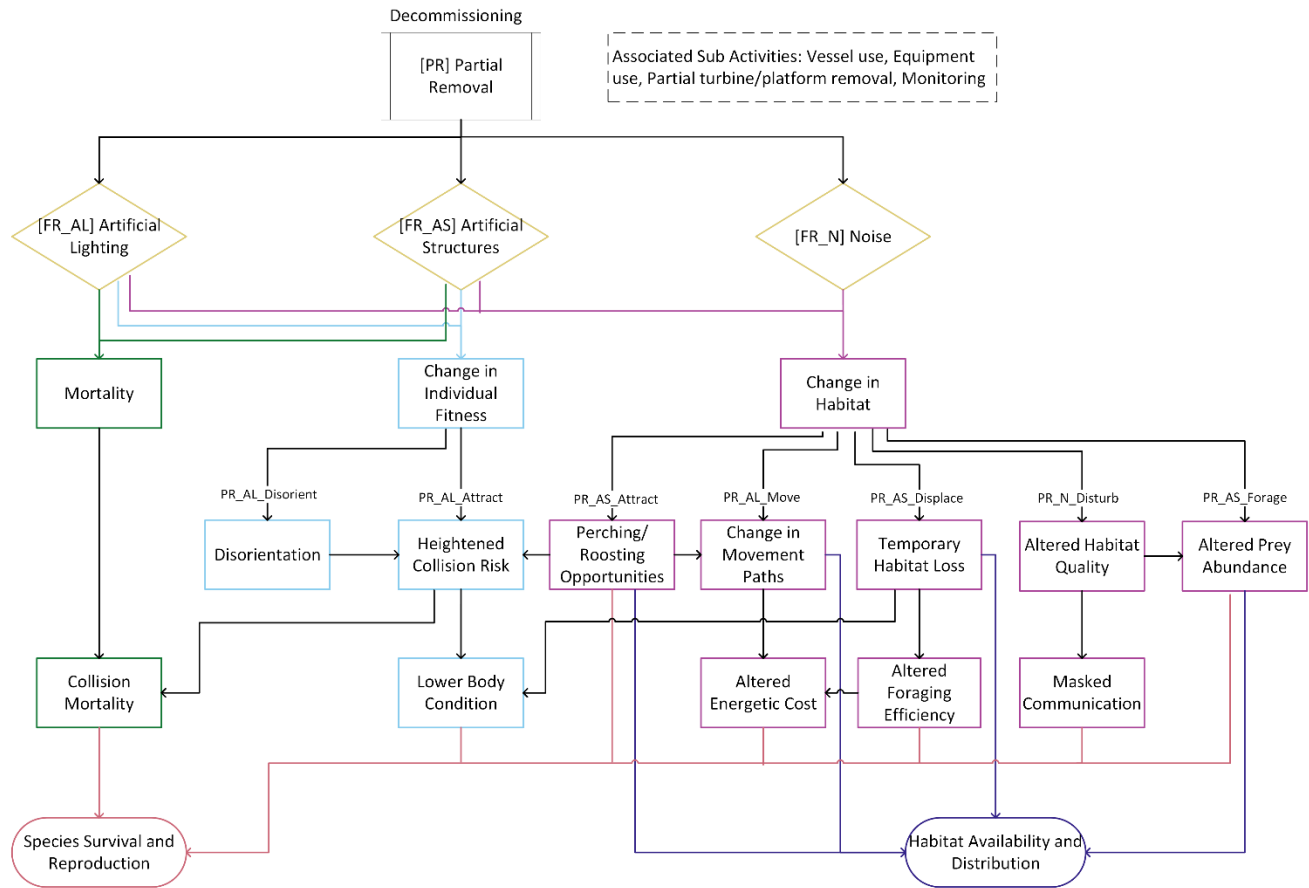
724 Partial OSW farm removal involves a degree of infrastructure remaining in the OSW farm
725 area. The blades, nacelle and hub are removed from the wind turbines and the monopile is
726 cut to a minimum height of 25 meters above the foundation (Fowler et al., 2020; Kerkvliet &
727 Polatidis, 2016). Explosives are less preferred for partial foundation removal since most of
728 the foundation will remain (Kerkvliet & Polatidis, 2016).

729 Sub-activities will be based on site-specific factors (e.g. floating or monopile foundation
730 turbines) and regulatory requirements. It is unclear if any monitoring will be needed since
731 legislation for decommissioning requirements are incomplete and variable for OSW farms
732 abroad (Fowler et al., 2020). It is assumed that regular monitoring of the infrastructure left
733 offshore will be required to ensure that no further environmental effects occur in the
734 decommissioning of the OSW farm. Thus, sub-activities include routine monitoring, as well
735 as infrastructure removal.

736 Four main stressors were identified from the partial OSW farm removal activity:

- 737 • Noise
- 738 • Artificial Lighting
- 739 • Artificial Structures

740



741

742 *Figure 8: Pathways of Effects diagram for partial removal during the Offshore Wind Energy*
 743 *Development decommissioning phase.*

744 **[PR_N] Noise**

745 The noise disturbance cause-effect pathway due to vessel and equipment use will be
 746 similar to the construction phase. Both measurable endpoints will be affected
 747 [\[PR_N_Disturb\]](#). See [\[RM_N\]](#) for a related description of the effects of noise on birds.

748 **[PR_AL] Artificial Lighting**

749 The cause-effect pathways for artificial lighting in the partial removal will be similar to the
 750 construction and operation phases [See [EG_AL](#)]. Depending on the height of the remaining
 751 infrastructure, lighting may be required for navigational safety and will be associated with
 752 monitoring vessels. Attraction to lighting alters movement pathways and energetic cost
 753 [\[PR_AL_Move\]](#). It also increases collision or stranding risk with monitoring vessels or
 754 collision risk with remaining infrastructure [\[PR_AL_Attract; PR_AL_Disorient\]](#).

755 [PR_AS] Artificial Structures

756 The cause-effect pathway of artificial structures in partial removal will be similar to the
757 construction and operation phases [See [SP_AS](#)], depending on the size and height of the
758 remaining infrastructure. Foundation transition pieces and marking buoys can offer
759 roosting or perching opportunities for aerofauna [[PR_AS_Attract](#)] (Harwood et al., 2017).
760 Although, the behavioural response to these structures would depend on the height of the
761 remaining structures above water and whether buoys are required.

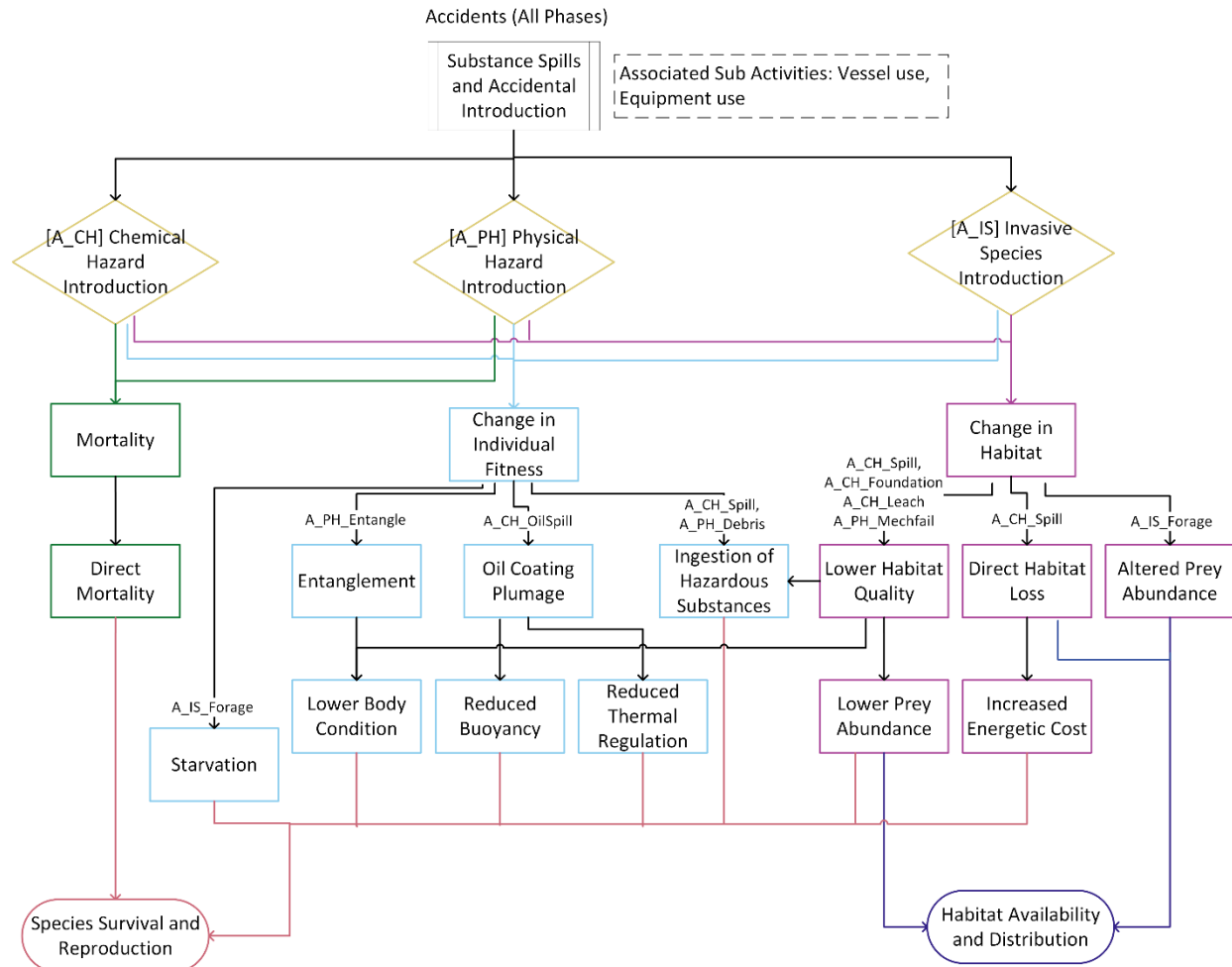
762 Partial removal of artificial structures can present habitat restorative opportunities
763 [[PR_AS_Forage](#)]. For instance, some initiatives are aimed at preserving the artificial reefs
764 created by OSW structures, or “renewables-to-reefs” (Smyth et al., 2015). Further eco-
765 engineering opportunities may also use the habitat-creating potential of hard substrates,
766 placing oyster tables and reef balls that can enhance the artificial reefs introduced by OSW
767 farms (Smyth et al., 2015; see [The Rich North Sea: Oysters and artificial reefs for](#)
768 [underwater nature restoration | Van Oord](#)).

769 Accidents Associated with All Phases

770 Many unintended stressors can be introduced during OSW energy development.

771 The following stressors were identified for accidents during all phases of OSW energy
772 development:

- 773 • Chemical Hazard Introduction
- 774 • Physical Hazard Introduction
- 775 • Invasive Species Introduction



776

777 *Figure 9: Pathways of Effects diagram for potential accidents during all phases of Offshore Wind*
 778 *Energy Development.*

779 [A_CH] Chemical Hazard Introduction

780 *Pre-Construction, Construction, Operation, and Decommissioning*

781 Accidents may occur during all phases of OSW energy development. Offshore activities
 782 require fuel powered machinery, vessels, vehicles, and aircraft during all phases to
 783 transport equipment, personnel, infrastructure, and materials, prepare wind farm sites,
 784 maintain turbines and cables, and remove infrastructure once end-of-life is reached. Leaks
 785 or spills are possible from machinery during use. Vessels can be a source of chemical
 786 introduction if not managed properly.

787 Chemicals introduced to the environment directly lower habitat quality which can cause
 788 mortality and lower individual fitness in marine birds [A_CH_OilSpill]. Oil on plumage
 789 affects thermoregulation and can lead to hypothermia (Jenssen, 1994). Chemicals coating
 790 plumage lowers body condition and can cause mortality as oiled birds are less buoyant and

791 prone to drowning (D. W. Smith & Herunter, 1989). Additionally, oiled birds spend more time
792 preening and cleaning their plumage than feeding, increasing energetic cost and
793 weakening birds further (D. W. Smith & Herunter, 1989). Toxic effects from ingestion due to
794 preening or feeding on contaminated prey can directly cause mortality and lower breeding
795 success (Jenssen, 1994). Chemical spills affect both endpoints depending on the
796 chemical, seasonality, spatial extent, and weather conditions that influence the trajectory
797 of the spill (Benjarano et al., 2013).

798 *Operation-specific considerations*

799 Operational OSW farms can introduce an additional chemical introduction pathway as
800 infrastructure must sustain the harsh offshore conditions for long periods of time. The most
801 common chemical types used at operational wind farms are lubricants, fuels, biocides,
802 corrosion inhibitors, paints, and grouts, with a low release likelihood for most (Perrow,
803 2019). Electrical service platforms and wind turbine generators use and store petroleum,
804 mineral oils, glycols, and sulfuric acid (Benjarano et al., 2013). Chemical diffusion and
805 spills can affect foraging habitat quality by lowering water quality in the vicinity of the event
806 [\[A_CH_Spill\]](#). As well, lower water quality can lead to toxic effects from ingestion. As
807 discussed previously, altering habitat quality can affect aerofauna species survival and
808 reproduction by changing individual fitness and causing mortality.

809 *Decommissioning-specific considerations*

810 The full removal option involves heavy disruption of the OSW area. It is the reverse of the
811 construction phase activities, which re-disturbs the offshore environment. Unlike in the
812 partial removal option, chemical hazards are introduced by removing turbine foundations
813 [\[A_CH_Foundation\]](#). Foundation removal disturbs the drill cutting piles beneath and
814 around the footings of the jacket of the turbine (Fowler et al., 2020). It directly reduces the
815 quality of habitat for aerofauna and can lead to effects on aerofauna species abundance
816 and distribution.

817 In partial decommissioning, some potential effects could arise from leakage from
818 structures left over time [\[A_CH_Leach\]](#) (Fowler et al., 2020). For instance, flaking paint and
819 corrosion from remaining foundations could potentially lower water quality (Van Maele et
820 al., 2023). Both habitat distribution and availability and species survivability and
821 reproduction could experience effects for marine birds.

822 [\[A_PH\]](#) Physical Hazard Introduction

823 Improperly managed solid waste from vessels and equipment can be introduced to the
824 marine environment at any phase of OSW energy development. Pollution from plastics,
825 metals, and other debris directly lowers habitat quality, causing mortality and lowering

826 individual fitness. The rate of plastic ingestion in seabirds increases as more plastic is
827 introduced in the marine environment, lowering individual fitness and causing mortality
828 due to starvation or digestive tract blockage [A_PH_Debris] (Lavers et al., 2014; Wilcox et
829 al., 2015). Entanglement from released debris can lower body condition or cause mortality
830 [A_PH_Entangle]. Many seabird and coastal bird species are at risk of entanglement with
831 plastic discarded in offshore foraging habitat (Ryan, 2018). As a result of habitat pollution,
832 entanglement and ingestion effects can cause changes in aerofauna species survivability
833 and reproduction, and habitat availability and distribution.

834 *Operation-specific considerations*

835 Accidents during the operation phase may include unplanned mechanical failure.
836 Structural components of the turbines are subject to additional offshore conditions
837 including corrosion, physical loading, biological attack, and mechanical damage that can
838 result in structural failure (Price & Figueira, 2017). Although requirements exist to prevent
839 mechanical failure, unplanned events can, and have, occurred. Mechanical failure resulted
840 in sharp debris from turbine components washing ashore at Vineyard Wind (O’Laughlin,
841 2024). As discussed above, sharp fiberglass shards and debris can lower breeding and
842 foraging habitat quality, although the environmental implications of the debris are not yet
843 not clear (Arcadis US Inc, 2024). Exposure to the debris can injure and lower body condition
844 or cause direct or indirect mortality for aerofauna [A_PH_MechFail].

845 *Decommissioning-specific considerations*

846 Some considerations specific to the decommissioning phase exist. Foundation removal
847 can require using explosives in full removal decommissioning. Aerofauna mortality can be
848 caused directly if individuals were present nearby at the time of detonation. For aerofauna
849 nearby, startle and escape responses can change habitat use and remove aerofauna from
850 habitat [See SP_N]. It leads to direct habitat loss for aerofauna. Both measurable endpoints
851 are affected. Partial removal decommissioning can lower body condition or mortality of
852 diving seabirds due to secondary entanglement could be caused by ghost fishing gear
853 caught in the remaining infrastructure [A_PH_Entangle] (Benjamins et al., 2014; Maxwell et
854 al., 2022).

855 [A_IS] Invasive Species Introduction

856 All phases of OSW energy development require vessel use for transportation to and from
857 the offshore site. Invasive species can potentially cause changes to foraging habitat for
858 aerofauna in two ways. First, vessels and associated ballast water discharge can be vectors
859 for invasive species introduction to new locations, especially if they are brought in from
860 foreign ports (Gillespie, 2007; ICF, 2020; Johannessen & Macdonald, 2009). Second,
861 turbine foundations can become “stepping stones” for invasive species colonization

862 (Boehlert & Gill, 2010). Analogous with the artificial reef effect, foundations can serve as
863 invasive species vectors, especially for benthic species with free-floating larvae that can
864 travel long distances in the water column (ICF, 2020).

865 Changes to foraging habitat, and consequently, prey or forage availability for marine birds
866 and bats are possible effects of invasive species introduction [[A_IS_Forage](#)]. Invasive
867 species can alter ecosystem structure and function as they outcompete native species for
868 common resources (Bax et al., 2003). Monitoring has documented some evidence of
869 invasive species colonization in artificial reefs at OSW farms and invasive insects at
870 onshore wind farms (Coolen et al., 2020; Dudek et al., 2015). However, how invasive
871 species affect aerofauna prey remains unknown. Ultimately, mechanisms of invasive
872 species introduction may lead to effects on marine bird species survivability and
873 reproduction by potentially altering foraging habitat quality. Habitat availability and
874 distribution can also be affected by invasive species establishment.

875 Knowledge Gaps

876 Although OSW energy development is in its infancy in Canada, a wealth of information is
877 available from international experiences with OSW construction and operation. The results
878 of many years of monitoring at operational OSW farms indicate that effects are highly
879 variable depending on aerofauna species' behaviour, site characteristics, and
880 environmental conditions, among other factors. This emphasizes the critical need for
881 before studies (e.g. baseline surveys during project planning) and during/after studies (e.g.
882 continuous monitoring during operation) throughout the entire duration of OSW energy
883 development.

884 The construction and operation phases of offshore wind projects are most often the focus
885 of assessments, and less is known about the pre-construction and decommissioning
886 phases. Many reviews exist discussing the effects to aerofauna and possible pathways to
887 these effects during operation, but less is known about effects to aerofauna generated
888 during pre-construction and decommissioning. Activities during these phases are highly
889 project- and site-specific, and as such, less information is available on the potential cause-
890 effect pathways of relevant activities. Since not many OSW farms have been
891 decommissioned, this phase should be considered as early as possible during OSW energy
892 development to help address information gaps.

893 Contrasting to the wealth of knowledge available on offshore artificial structures (e.g.
894 collision and displacement effects), other stressors and species are less studied in the
895 context of OSW energy development. A clear linkage to OSW energy development activities

896 and stressors is less readily available for noise, vessel-related activities, and artificial
897 lighting, leading to a reliance on related offshore industries and activities for knowledge
898 (Isaacman & Daborn, 2011). For instance, offshore industries, such as oil and gas and
899 commercial shipping, offer insight on the cause-effect pathways for artificial lighting and
900 artificial structures (vessels) for marine birds. Moreover, the scope of stressor-specific
901 knowledge for the offshore is highly focused on attraction and avoidance of several marine
902 bird, migratory bat, and passerine species. Information gaps remain for terrestrial and
903 shorebird bird species related to pathways of effects from attraction or avoidance of
904 offshore turbines and platforms.

905 Finally, it is difficult to discern potential effects that arise due to habitat loss, as species
906 will have varying levels of adaptability to displacement-caused habitat loss (e.g. prey
907 requirements, site fidelity, etc.) (Defingou et al., 2019). Many studies report displacement
908 and avoidance at variable spatial scales, however, direct effects due to habitat loss are less
909 documented related to OSW energy development. Definitions and classifications of OSW
910 effects can differ substantially, especially for complex interactions involving multiple
911 stressors, such as avoidance and displacement (Hemery et al., 2021). It is critical to define
912 effects at relevant scales using similar definitions.

913 Research concerning other stressors related to OSW energy development is ongoing.
914 Emerging evidence indicates that terrestrial birds might be at risk of effects from OSW
915 artificial structures (Robinson Willmott et al., 2023). Moreover, while the effects of noise on
916 individual fitness is evident for marine mammals and fish, researchers are only just
917 beginning to shed light on the mechanism of hearing underwater for marine birds (e.g.
918 Anderson Hansen et al., 2020). Scarce evidence for electromagnetic fields (not considered
919 in the PoE) exists for birds and bats, though it is highly researched in marine mammals and
920 fish.

921 Further, the analysis presented demonstrates that OSW energy development can indirectly
922 influence individual fitness and mortality through habitat-mediated changes. Pathways for
923 indirect effects such as altered prey abundance are still understudied (Croll et al., 2022;
924 Garthe et al., 2023; Perrow et al., 2011b). Though it is evident that OSW energy
925 development is likely to alter energetic cost, the consequence of these cause-effect
926 pathways on individual fitness is still largely unknown (Burger et al., 2011). Indirect
927 processes might prove to be more informative to quantifying population-level responses
928 (Defingou et al., 2019).

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