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WORKSHOP IV ON: 'DEVELOP AN INTERPRETATION OF THE TERM 'BARRIER', TO ENSURE CONSISTENCY IN THE OBLIGATION TO REMOVE BARRIERS TO MIGRATORY SPECIES'

(Based on a document prepared by the UK Government)

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Note: *This document has been developed to facilitate discussion on the use and interpretation of the term 'barrier' in the context of migratory species and their movement. It aims to provide a critical assessment of the barriers that impede migration, with the intention of agreeing a shared understanding and promoting informed decision-making.*

The provided definition of 'barrier' is intended as a starting point for dialogue and is not definitive. It is anticipated that this definition will evolve as further input and perspectives are incorporated. Additionally, the examples presented in this document are not exhaustive and are offered primarily stimulate discussion.

The mitigation needs suggested throughout this document are intended to highlight opportunities for adaptation or intervention. While some of these practices may already be implemented as local, regional, or global scales, they are included here to emphasise their relevance and to encourage the identification of gaps or enhancements in current efforts.

Workshop IV on: ‘Develop an interpretation of the term ‘barrier’, to ensure consistency in the obligation to remove barriers to migratory species’

This document aims to explore the term ‘barrier’, and the impact of barriers on migratory species and their ability to move freely between critical habitats. A ‘barrier’ refers to as any physical, ecological, environmental, or regulatory structure, feature, or modification that disrupts, blocks, or impedes the natural migratory movements of species. The focus is on understanding how these barriers affect connectivity between two or more functional areas (regions essential for completing a species’ lifecycle by providing critical resources at specific times, such as essential habitats for breeding, feeding, or resting), and if they increase resistance to movement.

For migratory species, a barrier may take the form of four types: permeable, impermeable, impediment, and blockage (see **Table 1**.). The distinction between these categories is based on their permeability. Barriers may be crossed but not circumnavigated without cost, and their permeability (the degree to which they inhibit movement) varies. Barriers can prevent or reduce movement between two or more functional areas (regions essential for completing a species’ lifestyle by providing critical resources at specific times). The presence of barriers can lead to fragmented populations, increasing risks such as higher mortality rates, exposure to other threats like disease, reduced genetic diversity, and decreased population resilience. However, the severity of these impacts often depends on the species’ adaptability, with generalist species typically better equipped to adapt to changes compared to specialists.

This document categorises barriers into three primary types: physical anthropogenic, physical natural, and non-physical. Noting that uncoordinated legal or policy frameworks and gaps in knowledge and capacity, can exacerbate or drive these barriers. For some species, the negative effects of some barriers can be partially mitigated through improved landscape design. Strategies such as barrier concealment, which reduces visual and auditory disturbances, or other design elements that minimise the perception of a barrier's presence, can help restore connectivity and reduce resistance. These approaches aim to enable species to navigate altered landscapes more effectively, promoting resilience and maintaining ecological balance.

Table 1. The four types of barriers.

Type	**Explanation**
Permeable	Barriers that partially inhibit movement but still allow passage under certain conditions.
Impermeable	Barriers that entirely block movement, preventing passage through, under, or over, and does not change over time.
Impediment	Barriers that slow movement, creating difficulty but not total blockage. Often represents a trade-off/cost.
Blockage	Barriers that completely obstruct movement, imposing absolute limits that are time-limited, transitionary, or situational.

Examples of physical anthropogenic barriers

1. Fences and walls

Fences and walls are artificial barriers constructed to set boundaries of land, prevent access, or control movement. They are particularly problematic for **terrestrial migratory species** like ungulates, large mammals, and some reptiles, especially when they are designed to be impermeable. These barriers can **block migratory paths**, fragment habitats, and force animals to **detour long distances**, which may lead to **energy exhaustion**, **increased mortality**, and heightened **vulnerability to predators**.

Mitigation needs – **Increase the permeability** of barriers, potentially using **wildlife corridors**, **gaps**, or **passageways** in fences (e.g. urban garden fences for small mammals), or the use of **electrified fences** that allow safe passage for smaller animals while deterring larger species. **Landscape modifications** can help create more natural routes.

2. Roads and railways

Roads and railways create **high-traffic pathways**, often intersecting with migratory routes of **terrestrial** and **avian species**, forcing them to **cross** or **avoid** these structures. These can lead to **direct mortality** from **vehicle collisions**, cause stress, and create **noise** and **visual disturbances** that deter animals. They also **fragment habitats**, isolating populations and leading to **decreased genetic diversity**. For **amphibians** and **reptiles**, which may require specific environmental conditions to migrate, roads are particularly lethal.

Mitigation needs – Construction of **wildlife overpasses** or **underpasses**, to allow safer passage. Reducing **traffic speed** in areas of known migration routes or implementing **barrier concealment** strategies. These would create eco-friendly transportation networks that consider migration patterns.

3. Bridges and tunnels

Bridges and tunnels are designed to **avoid natural obstacles** like rivers or to allow transportation through mountainous or urban areas. While they may facilitate human travel, they can act as barriers for animals, especially for **aquatic species**. They can create **altered micro-environments**, such as **changes in light**, **temperature**, and **noise**, which disrupt natural movement patterns. They can also **alter water flow** and **sediment patterns**.

While bridges and tunnels can disrupt movement patterns, they can also be **designed to facilitate animal migration**. **Wildlife overpasses** and **underpasses** are examples of structures built specifically to allow animals to cross safely over or under roads, railways, or other barriers. These structures can be tailored to the needs of specific species, with **naturalistic features** such as **vegetation cover** that mimic their natural habitats, ensuring safe passage. Similarly, bridges can be designed with respect to aquatic ecosystems.

Mitigation needs – Incorporate **wildlife passageways** into infrastructure projects, **designing aquatic passages**, **wildlife corridors**, and **naturalistic landscaping** to increase permeability of human-made structures. Focus on **noise** and **light management** to minimise disturbance.

4. Energy infrastructure: Power lines and wind turbines

Power lines, wind turbines, and other energy infrastructures are increasingly common as countries invest in and expand their energy network. These structures **occupy land** areas,

with some turbines present **offshore** too. Power lines and wind turbines are particularly dangerous for **birds** and **bats**, causing **collision-related injuries** and **fatalities**. Power lines can also **fragment habitats** for **terrestrial species** and deter them from certain areas. Impacts may arise not just when the infrastructure is being built, but also during its operation and maintenance.

Mitigation needs – Modify power lines to **increase visibility to birds**, slowing down turbine **speeds** during known high migration periods, or avoiding use when wind speed is low (e.g. below 6m/s when insects and bats are likely to be in-flight, but only small amounts of energy will be generated), **strategic placement** and **landscape planning** of these structures to avoid known migration routes. Additionally, monitoring and evaluating **wildlife mortality hotspots**.

5. Dams and hydroelectric installations

Dams are large human-made structures built across rivers to store water or generate hydroelectric power. They can completely alter river ecosystems by impeding the natural flow of water. Dams obstruct migratory **fish species**, such as salmon, eels, and sturgeon, which rely on free-flowing rivers to migrate between **spawning** and **feeding grounds**. Dams also disrupt **sediment transport**, **water temperature**, and **nutrient flow**, further degrading river habitats for both aquatic and terrestrial species.

Mitigation needs – **Modifying water management practices** to allow more **natural river flow** patterns and **sediment transport**. Creation of **fish friendly dams** with **passageways** or **fish ladders** to improve permeability, restoring connectivity between habitats.

6. Shipping lanes and marine traffic *(Do planes do the same for birds?)*

Shipping lanes are designated routes for marine vessels, affecting migration paths of **aquatic species** such as whales, dolphins, and sea turtles. **Heavy marine traffic** can lead to **direct collisions** with large marine animals, often resulting in **injury** or **death**. **Noise pollution** from ships can also disrupt species that rely on echolocation, like cetaceans, affecting their navigation, foraging, and communication.

Mitigation needs – Creation of marine protected areas (**MPAs**) that avoid migratory routes and promote connectivity. Reduced **speed limits** of vessels to reduce the risk of collisions, and reduced sound / **sound muffling technology** for vessels to decrease noise pollution.

7. Canals and water diversion projects (in arid areas)

Canals are human-made waterways constructed to facilitate navigation, irrigation, or drainage. They often constrain natural wetlands and connect bodies of water that wouldn't naturally intersect, altering local ecosystems. Canals can serve as **physical** and **ecological barriers**. They may be too deep, wide, or chemically unsuitable for some **terrestrial species** to cross. Additionally, canals can alter migration routes by introducing **invasive species** that compete with or prey on native migratory species.

In arid and semi-arid areas, dams and water diversion projects are designed to retain or redirect water for agriculture, industrial use, or urban supply. In regions where migratory species depend on **seasonal water sources**, these projects can reduce water availability, making it harder for animals to complete migrations. They can alter the ecosystem by changing the flow and availability of water, which impacts species reliant on temporary water sources in dry seasons.

Mitigation needs – Ensuring water flows are maintained or **re-routed** and eco-friendly water management practices that prioritise the preservation of **seasonal water sources**.

8. Dredging activities

Dredging involves removing sediment and debris from the bottom of lakes, rivers, harbours, and other water bodies to maintain navigable waterways or extract resources. Dredging can alter aquatic habitats by disturbing **sediment layers**, releasing **pollutants**, and changing **water depth** and **flow patterns**, which can interfere with fish and other **aquatic species**. It can also destroy **spawning grounds** and **feeding habitats**, with various species requiring undisturbed riverbeds for spawning.

Mitigation needs – Incorporate **environmental monitoring** to assess the effects of dredging on local species and habitats to reduce sediment disturbance and avoiding dredging activities during breeding and migration periods. **Restore** and **preserve aquatic habitats** affected by dredging can contribute to the creation of migration corridors for affected species.

9. Sea walls and coastal infrastructure

Sea walls and coastal structures are built to protect shorelines from erosion, coastal land creation, or to facilitate human access to the sea. These structures can disrupt coastal habitats and migration routes for **marine** and **shore species**. Coastal infrastructure can **block the migration** of species that rely on **tidal flats**, **estuaries**, and **sandy shores**. For instance, sea turtles can have trouble accessing nesting beaches due to sea walls, while migratory shorebirds may lose **feeding grounds** because of beach and estuary modification or **erosion**. **Detours** can increase **energy expenditure** and **mortality rates**.

Mitigation needs – Incorporate **soft engineering designs** such as **living shorelines** (planting vegetation e.g. mangroves or oyster reefs to absorb wave energy). Create **wildlife friendly zones** such as turtle-friendly nesting beaches.

10. Urban and industrial development

Urban areas and industrial zones are highly developed landscapes with infrastructure, buildings, and facilities that often extend across previously natural habitats. They create **fragmented habitats with little vegetation or suitable terrain**, making it challenging for many species to traverse these areas safely. Industrial sites can have **toxic runoffs** and other **pollutants** that **discourage species** from using these corridors. Birds, for instance, may be deterred by high-rise buildings or attracted by **artificial lights**, leading to potential **collisions** or **exhaustion**.

Mitigation needs – Incorporate natural spaces through **green infrastructure**, **wildlife corridors**, **vegetated roofs**, and **eco-bridges** to improve **connectivity** in **urban planning**. Reduced **light pollution** and managing other pollution levels in industrial areas.

11. Agricultural fields and plantations

Agricultural areas replace natural vegetation often with large-scale **monocultures** which may additionally involve **fencing** or extensive **irrigation systems** that physically **block/impede migration**. Large herbivores struggle to travel through agricultural landscapes as they find **less suitable food**, are exposed to potential **conflicts** with **humans**, or face dangerous encounters with **machinery** or **domestic animals**. They reduce habitat connectivity and increase the distance between essential resources.

Mitigation needs – Create **wildlife corridors**, **buffer zones**, or **green bridges** to provide movement routes. Promote **sustainable agricultural practices**, such as **agroforestry** and **wildlife friendly fencing** to increase permeability and enhance connectivity.

12. Mining and quarrying operations

Extractive industries often involve mining and quarrying which can **create large pits**, **excavations**, and **waste dumps** that **alter the landscape** significantly. These operations can fragment habitats and **create impassable areas** within migratory routes. Open pits, piles of waste material, and **pollution** from these activities can impede migration for **terrestrial species**. Additionally, **noise** and **light** from mining operations can discourage animals from passing through affected areas. This also applies to **underwater mining** and associated disturbance.

Mitigation needs – The use of **habitat restoration**, **noise-reducing technology**, **wildlife corridors**, and minimising the environmental damage and footprint of operations, ensuring better connectivity.

13. Oil and gas pipelines

Pipelines are large-scale infrastructure projects used to transport oil, gas, and other resources across long distances, often intersecting wildlife habitats. Pipelines may require cleared areas that fragment habitats, creating **physical** and **sensory barriers** for migratory species. **Terrestrial species** may avoid crossing cleared pipeline areas due to **noise**, **vibration**, or the presence of **human activity**. **Underwater pipelines** can disrupt the migration of **marine species** due to noise, construction disturbances and habitat alterations. For example, the Trans-Alaska Pipeline, including its continued maintenance, in the US, impacts caribou migration.

Mitigation needs – Installation of **wildlife crossings** (both above and below ground). **Soundproofing** or **vibration dampening technologies** to reduce disturbance. Ensure pipeline routes **avoid critical migration routes** and implement regular maintenance practices to minimise disruptions.

14. Warzones and military areas

Active warzones may be large-scale areas, which destroy vast habitats, with ongoing conflicts removing migration pathways (e.g. **migratory birds** in the Russia/Ukraine warzone and cetaceans in the Black Sea). Bombings can physically alter the landscape causing **direct changes to the terrain**, acting like a roadblock or a dam. The construction of fortifications, military bases etc can **obstruct migration routes**, create **noise** and **light pollution**, and often cause **mass population displacement** due to absence of habitat and **wildlife corridors**. **Chemical warfare**, **oil spills**, and destruction of ecosystems (e.g. **deforestation** from military activity) physically alter habitats and create zones that animals cannot travel through due to the risks of pollution or the loss of habitat.

Mitigation needs – Focus on **habitat restoration** and **post-conflict wildlife conservation**, leading to the creation of safe or **designated wildlife zones** in non-conflicted areas. Implement **international cooperation** and **peacebuilding** efforts that include environmental protection to minimise impacts in vulnerable regions.

15. Plastic Pollution (e.g. fishing ghost gear and plastic waste in the ocean)

Plastic and other pollution in the ocean presents both a **physical** and **non-physical barrier** to **marine species'** migration. Large pieces of plastic or other materials, such as abandoned

fishing nets (ghost nets), can **entangle** marine animals like sea turtles, whales, and seabirds, causing **injury** or **death**. Marine species **ingest plastic debris**, mistaking it for food, which can lead to internal blockages, malnutrition, or poisoning. The accumulation of **microplastics** in marine food chains also exacerbates these risks, affecting species at multiple trophic levels. **Microplastic pollution**, found in high concentrations in warming ocean gyres, further disrupts marine migration and feeding. The presence of **plastic debris** in these concentrated areas can create hazardous zones where animals must either avoid migration or alter their usual routes, leading to long-term disruptions in **feeding patterns** and **habitat connectivity**. This disruption not only affects the species directly interacting with the pollution but can also have cascading effects on entire ecosystems by interfering with the natural migration cycles of marine species.

Furthermore, areas like the Great Pacific Garbage Patch, a vast region of concentrated plastic debris, can act as a physical obstruction, forcing animals to avoid these polluted zones, thereby altering their migratory paths. These impacts not only threaten individual species but also interfere with their ability to access **vital feeding** and **breeding grounds**.

Mitigation needs – Improve **waste management practices**, **reduction in plastic production**, and increased efforts to **retrieve abandoned waste**. International agreements and local initiatives, including education and public awareness, aimed at reducing pollution and **cleaning up marine debris** are crucial to minimising these barriers, along with **sustainable fishing practices**.

Examples of physical natural barriers

Natural physical barriers that can (species dependent) act as strict barriers to migration patterns:

1. Mountain Ranges (e.g., the Himalayas, Andes, Alps)
2. Large Oceans (e.g., Atlantic Ocean, Pacific Ocean)
3. Deserts (e.g., Sahara, Gobi)
4. Frozen Landscapes (e.g., Arctic Sea ice, Antarctic ice sheets)
5. Deep Canyons and Escarpments (e.g., Grand Canyon, Great Rift Valley)
6. Large Rivers (e.g., Amazon River, Congo River)

Examples of non-physical barriers

Mitigation needs – Mitigation of non-physical barriers requires long-term, coordinated action and commitment across a species range to reduce the drivers of these barriers, such as climate change. In the case of both climate change driven barriers, and ones that are a result of anthropogenic activity e.g. light and chemical pollution, action taken to fill knowledge gaps and to change and align both national and international policy would be the most effective way to mitigate the following barriers.

Policy-related legal or regulatory frameworks may inadvertently restrict migratory movements or hinder conservation actions. This could include restrictive land-use policies, lack of policy or progress of implementation of legislation that address and/or control other non-physical barriers such as chemical pollution. There could also be a lack of cross-border coordination or inconsistent policy throughout a species migration. Another factor is knowledge gaps and lack of capacity to rectify knowledge gaps and to implement and enforce policy in place. These factors are considered to be a driver of the following barriers, not barriers in themselves.

Monitoring needs – Due to the long-term nature of the mitigation needs, monitoring efforts would be a vital tool in aiding responses to immediate impacts of non-physical barriers on a species migrating, such as extreme weather events, whilst also helping to collate the information required to increase the effectiveness of the mitigation needs above. Monitoring of both the impact of a barrier on species, and changes in habitats and migratory routes as a result of these non-physical barriers would help fill knowledge and data gaps, along with the creation and implementation of adaptive management and emergency response plans for migratory species. Monitoring efforts would also be applicable to the physical barriers previously mentioned.

1. Climate change

Migrations tend to be timed to take advantage of optimal conditions along their route and at their destination. Climate change can change/influence a number of environmental conditions that can result in **migrations no longer being aligned with optimal weather, food availability**, or even **breeding sites no longer being hospitable for breeding and rearing young**. Changes in climate can also **trigger migrations too early or late** due to shift in seasonal patterns. Climate change links to many of the following non-physical barriers.

(See **Appendix 1**. for further examples of climate change induced barriers)

2. Changes in food availability

Many migratory routes are based on food availability as the seasons change. Changes in environmental factors, such as temperature, or anthropogenic impacts, such as habitat degradation and changes in agricultural practices, can cause these **vital food resources to be unavailable** throughout a species migration or end destination.

Human provision of food throughout winter, a time when many species migrate, is being observed as a potential barrier to migration, especially for **migratory birds**. The continual provision of bird food and planting of fruit trees/bushes throughout winter has been observed as a cause for **portions of populations not migrating**.

3. Weather patterns and events

With rising global temperatures, **suitable habitats for many species are shifting** towards the poles or higher altitudes. This can affect migratory species in several ways. Migratory species may need to **modify their migratory routes** to ensure they encounter these suitable habitats along their migration, or as their end destination. The ability to do this will depend on the adaptability of the species but they could also be impeded by other barriers along this new migratory route. Changes in seasonal temperatures can also cause species to **change the time at which they start their migration**, such as birds starting their spring migrations sooner due to warmer winter temperatures, which can lead to a **mismatch with food availability and habitat suitability** throughout their migration.

Extreme weather events, such as storms, heatwaves, cold waves, and droughts can also act as barriers to migration. They can result in **changes in habitats or resources** required throughout a migration. Or the event itself could **halt a migration**, **trigger it too early** or **delay it**. Climate change is increasing the intensity and frequency of these events.

4. Environmental disasters

Environmental disasters, such as **volcanic eruptions**, **wildfires** and **flooding** can cause **short-term disruptions** to migration routes. They can also cause **permanent changes to habitats** or **removal of habitats** that migratory species rely upon.

5. Ocean currents and wind patterns

Changes in oceanic currents on a large-scale can be a barrier for migratory species, mainly observed for **marine mammals** and **seabirds**, due to the scale of **ecosystem alteration** it can cause. They can **alter food availability**, and in the case of changes in the frequency and intensity of El Niño and La Niña events it can **impact the distribution** and **mortality** of many **marine mammals.**

For **birds** that undergo oceanic crossings, the timing of this can be triggered by and dependent on wind speed and direction. Increasing greenhouses gas concentrations can cause changes in seasonal patterns of atmospheric circulation over oceans, which can in turn become a barrier to those species navigating migrations over oceans.

6. Habitat destruction and degradation

Habitat destruction and degradation, as a result of human activity and/or climate change, can result in the **loss of habitats** utilised by migratory species throughout their migrations or their end destination. It can also **disrupt connectivity**, **eliminating migration corridors** and stop overs, which impacts species with both fixed and variable migratory strategies. This links to other non-physical and physical barriers.

7. Light pollution

Artificial night-time lighting can disrupt the migratory behaviours of **birds**, **mammals**, **reptiles**, **amphibians**, **fish** and **invertebrates**. They can act as an **attractant or repellent**, or they can d**isorientate** migratory animals. This can become **fatal** to some species, as seen in **nocturnally migrating birds** that are attracted to and disorientated by artificial lighting, increasing the **risk of collisions** with buildings/structures.

8. Chemical pollution

Chemical pollution, such as heavy metals, oil, industrial chemicals and agricultural pesticides, can be a barrier to migrations by having a direct impact on the migratory species

or indirectly by affecting the environments and resources they rely on. For example, **marine cetacea**, **turtles** and **seabirds** are susceptible to the effects of oil spills, which can cause **mortality** and in the long-term, in the case of **aquatic mammals** inhaling, ingesting and dermally absorbing oil, can compromise their **reproduction and survival**. Agricultural and industrial activities can release **toxic chemicals** into the environment and are large contributors to **nutrient run-off**. This can **alter the balance of habitats** and have **cascading impacts** e.g. nutrient run-off is a serious threat to wetlands, contributing to **eutrophication** which can result in reduced foraging/feeding at the site. Pesticide use is recognised as a key factor in insect decline, which for insectivorous migratory bird can cause **food shortages.**

9. Noise pollution

Anthropogenic noise is recognised as a major global pollutant. Continual exposure to noise can cause **changes in spatial distribution**, deter animals from important feeding and breeding areas, and **interfere with foraging behaviours** and **conspecific communication**. For **marine species**, noise created by commercial shipping, military sonar, seismic exploitation and offshore drilling and windfarms can cause temporary or **permanent auditory threshold shifts**. This compromises their ability to communicate, detect threats and find food. Continual exposure can force migrating species to alter behaviours and can even cause **life threatening injury** e.g. stranding events seen in beaked whales, which are extremely sensitive to high-intensity sounds, which have been associated with marine sonar.

10. Water quality changes

Changes in salinity, due to altered freshwater flows, ocean acidification, due to increasing anthropogenic CO2, and ocean deoxygenation could be barriers for aquatic migratory species. Evidence of direct impacts on migratory species are limited. Although elevated **ocean CO_2 levels** are thought to have a number of short-term effects on **fish**, including **altered respiration and blood circulation**, along with some long-term ones such as **reduced growth rate and reproduction**. There is more certainty regarding how they are impacting **marine habitats** such as coral reefs, which rely on carbonate ions to build their structure, which will impact those migratory species that rely on these habitats.

11. Invasive alien species

Invasive alien species can be a non-physical barrier for migratory species in several ways. They can directly impact the migratory species by placing **predation pressure** on the species, by **competing for the same resources**, and through **genetic changes** from hybridization. They can also indirectly impact the migratory species by contributing to the **degradation of habitats** they rely on and through acting as vectors for **novel disease transmission.**

12. Pathogens and disease outbreaks

At all stages of migratory cycles, species may encounter **novel** or **greater prevalence of pathogens or disease outbreaks** that can cause **mortality** or **reduced fitness.** Drivers of pathogen emergence include habitat degradation, pollution, livestock production with climate change enhancing the survival of pathogens and expanding their range, all of which can be an increasing risk and barrier for migratory species. Another consideration could be the human response to outbreaks, especially for migratory species known to carry and spread disease and pathogens, which could act as a barrier by altering or preventing migration.

13. Hunting, overfishing and depletion of food resources

Unsustainable hunting, fishing and harvest of plants can lead to the **depletion or removal** of **food resources** that migratory species rely upon. A depletion/loss of food resources could also be due to change in land use in stopover points or end destinations. Hunting and fishing could also pose as a direct barrier if the migratory species is the **target**, with those species that return in large numbers to the same sites each year, at the same times of year, being highly susceptible to overexploitation.

14. Human disturbance

Human disturbance, caused by development, tourism, recreational activities etc can act as a barrier for migrations. The level of impact can depend on the scale of the disturbance, distance from the migratory species, the species itself (e.g. their tolerance to human disturbance), and time of year (e.g. likely to impact a species more during breeding season). Whilst generally non-lethal, disturbance can cause **risk-adverse responses** which could result in **fitness costs** by **affecting distribution**, **migration routes**, **population dynamics** and **ability to thrive**. There is also the aspect of an animal's **stress response** to human disturbance, which in the short-term can cause **changes in the physiology or behaviour** (e.g. breeding and foraging behaviours) of individuals, and in the long-term can cause **increased mortality** and **reduced breeding success** of whole populations.

Appendix 1

Examples of further climate change related barriers

Note: These are barriers which may be occurring now, or in the near future. Some of these barriers may have unknown direct or indirect effects on migratory species but should not be ignored. They may lead to mismatches in seasonal timings (breeding, food availability – e.g with bees), disrupted rainfall patterns (e.g. seasonal spawning or movement), longer migration routes (increased energy expenditure and higher mortality), rapid vegetation shifts (e.g. bush encroachment in southern Africa), emergence of new competitors, predators, invasive species, diseases and parasites.

1. Melting sea ice and glacier retreat

Loss of Arctic and Antarctic ice eliminates platforms for species like polar bears, walruses, and seals that rely on ice for hunting, resting, and migration. Shrinking glaciers reduce meltwater-dependent river systems, impacting fish migration and freshwater availability for wildlife.

2. Rising sea levels and coastal erosion

Flooding of coastal areas and mangroves removes critical stopover points for migratory birds and terrestrial species.

3. Thermal barriers in water

Warmer surface water layers create "heat blocks," forcing fish species to alter or abandon migration routes.

4. Loss of freshwater ecosystems

Droughts and reduced snowpack shrink may remove rivers and wetlands.

5. Desertification

Desertification limits migratory routes for animals like antelope and elephants and creates heat-stressed areas that are physiologically impassable.

6. Ocean acidification

Disrupts navigation in marine species by impairing sensory abilities and may impact food source.

7. Declining oxygen zones (Dead zones)

Climate-induced ocean stratification creates low-oxygen zones, making these barriers impassable.

8. Melting permafrost

Releases methane, alters tundra landscapes, and destroys habitat connectivity for species like caribou.

9. More frequent and severe wildfires, storms, heat events

Extreme events may destroy habitats and create hazardous areas, disrupting birds, mammals, and insects like monarch butterflies.

10. Altered ocean currents

Disruption of currents like the Gulf Stream forces marine species to reroute or lose access to migratory destinations.

11. Algal blooms

Warmer waters trigger toxic algae growth that creates physical and chemical barriers for fish and amphibians in rivers and lakes.

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