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REPORT ON THE INTERPRETATION OF THE TERM "BARRIER" IN THE CONTEXT OF MIGRATORY SPECIES CONSERVATION

(Prepared by JNCC, with support from the Expert Workshop and the Working Group on Climate Change)

Summary:

Report on the interpretation of the term "barrier" in the context of migratory species conservation, covering physical, ecological, environmental, social and regulatory factors that may disrupt or inhibit migratory pathways. This Information Document complements Document UNEP/CMS/COP15/Doc.28.12 *Climate Change.*

Migratory Species and Climate Change

Report on the interpretation of the term "barrier" in the context of migratory species conservation

(Based on a document prepared by the UK Government)

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Report on the interpretation of the term “barrier” in the context of migratory species conservation

Purpose:

This document has been prepared to offer a comprehensive interpretation of the term **“barrier”** in the context of migratory species conservation under the Convention on the Conservation of Migratory Species (CMS). The objective is to provide conceptual clarity and consistency regarding the obligations of Parties to remove or mitigate barriers impeding the free movement of migratory species between critical habitats necessary for their life cycles. This addresses CMS *Decision 14.214 h* directed to the Scientific Council: ‘develop an interpretation of the term “barrier”, so that there is consistency in the obligation to remove barriers to migratory species’.

Context and Terminology:

The terminology employed within the CMS text predominantly references the term **“obstacle”** when addressing impediments to the movement of migratory species. This document, however, employs the term **“barrier”** for conceptual clarity and broader ecological applicability, which includes physical, ecological, environmental, social, and regulatory factors that disrupt or inhibit migratory pathways. The terms “barrier” and “obstacle” are acknowledged as closely interrelated, and this interpretation seeks to standardise their application in the context of CMS obligations. This interpretation aligns with the CMS’s overarching objective to promote the conservation and sustainable management of migratory species by addressing all forms of impediments that may restrict their natural migratory behaviours.

Intended Use:

This interpretation is intended to serve as a guidance tool for Parties, the Scientific Council, and other relevant stakeholders in identifying, categorising, and prioritising barriers to migration. Furthermore, it provides a foundational framework to inform the development and implementation of mitigation measures and to promote standardised policy approaches across regions and species.

Next Steps:

Following consideration by the Scientific Council, it is anticipated that this document will support deliberations at the Conference of the Parties (COP) and contribute to the enhancement of CMS guidance and action plans aimed at the effective removal or mitigation of barriers to migratory species.

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 to 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.

Definition and approach [1-15]

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, social, or regulatory framework, feature, or modification that disrupts, blocks, or impedes the natural migratory movements of species, or novel dispersal / colonising movements as a response to changing environmental conditions.**

Regulatory frameworks, where inconsistent or inadequate across borders, may present as impediments, and parties are encouraged to ensure that these frameworks are robust and responsive to address possible shifting ranges of migratory species, enabling conservation actions and mitigating emerging barriers. Social barriers (people-based) may interact with these frameworks (institution-based), arising from societal behaviours, values, or perceptions rather than from formal governance structures. They can influence the implementation or effectiveness of regulations, and in some cases, may restrict species movement even where policy support exists. This can be addressed through targeted education, outreach, or incentive-based approaches. The focus of this document is to understand 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.

Four types of barriers, permeability and porosity

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, which refers to the degree to which barriers inhibit or allow passage. Permeability affects individual or population-level movement, where barriers may be crossed but not circumnavigated without cost. At the scale of ecological realms (encompassing landscapes, seascapes, and airspaces), the term porosity extends the idea of permeability by considering how the overall structure of these realms facilitates or hinders species movement (see **Table 2.**). While individual barriers may obstruct movement, a porous realm provides alternative pathways or routes. Therefore, the porosity of an ecological realm indicates how well it supports migration across multiple interconnected habitats, even if those habitats are not physically connected. A more porous realm offers better opportunities for movement despite the presence of barriers, by providing accessible routes or corridors that facilitate connectivity. All the terms are specific to specific species. Ecological connectivity can be achieved even when habitats are not physically connected, if the realm allows species to navigate between them effectively. For example, vegetation patches acting as 'stepping stones' which help some species move through otherwise fragmented realms.

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, it is important to note that species may also rely on certain barriers to be successful. For example, natural barriers such as mountain ranges or seasonal environmental changes can help regulate movement patterns, preventing population over-abundance, and ensuring the species migrate or breed at optimal times. Natural barriers may be a driving force behind evolutionary adaptation and ecological balance. The severity of impacts associated with additional, mainly anthropogenic, barriers often depends on the species' adaptability, with generalist species typically better equipped to adapt to changes compared to specialists.

Temporal variability in barriers

Some barriers, such as seasonal ice coverage or mountain glaciers, are shifting due to climate change, thus creating new obstacles for species in their migratory patterns. This may result in the extension or reduction of ice cover, changing the timing and routes of migration, and may lead to range change for the species. These shifts in natural barriers can interact with or compound existing anthropogenic barriers. These changes may also lead to new anthropogenic barriers as humans may exploit new areas that were previously inaccessible.

Cumulative effects of a range of obstacles

It is also important to consider the cumulative effects of multiple barriers, where the combined impact of various obstacles across a species' migration route may significantly impact its ability to complete its life cycle. Quantifying the number and type of barriers, particularly in critical areas, is essential for assessing vulnerability and identifying priority areas for mitigation. These cumulative impacts occur across all spatial and temporal scales, from local to global, and from immediate to long-term. While large-scale, long-term processes such as climate dynamics may be less directly manageable, coordinated local and short-term actions can collectively influence them. Such actions are integral to maintaining ecological connectivity, enabling species to migrate and adapt, and should be recognised as complementary to, rather than in competition with, broader global objectives.

Examples of physical and non-physical barriers

This document provides examples of barriers under four categories: physical anthropogenic, physical natural, non-physical anthropogenic, and non-physical natural. It is important to note that there are often differences between barriers in land and sea environments, although some barriers may overlap between the two. Each sub-section contains mitigation needs, which are viewed as facilitating movement rather than removing the barriers directly. 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 realms more effectively, promoting resilience and maintaining ecological balance.

Table 1. The four types of barriers. Individual or population-level context.

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.

Table 2. Levels of porosity at landscape, seascape, and airspace levels.

Level of Porosity	General Explanation	Terrestrial Example	Marine Example	Avian Example
High Porosity	Highly interconnected areas with many accessible routes and corridors for species to move between habitats, despite barriers.	Landscapes with a high density of ecological corridors, stepping stones, nature-friendly management or low-impact infrastructure. Strong connectivity.	Uninterrupted migratory corridors with favourable conditions, low vessel traffic, and minimal acoustic disturbance.	Open flyways with minimal light/noise pollution and few tall structures.
Moderate Porosity	Some accessible routes or corridors exist, but they may be fragmented or not easily accessible for all species, depending on the type of barrier.	Partially fragmented habitats with some overpasses or restored corridors and rare stepping stones. Weaker connectivity overall.	Areas with moderate human activity or intermittent shipping lanes.	Urban areas with bird-safe architecture and some stopover sites.
Low Porosity	Highly fragmented areas with few or no accessible routes or corridors, making it difficult for species to navigate between habitats.	Landscapes dominated by roads, intensive agriculture, and fenced boundaries. Low connectivity.	Heavily trafficked shipping zones, oil platforms, or noisy marine environments.	Regions with dense urban lighting, wind farms, or tall structures blocking flight paths.

No Porosity	Completely fragmented or isolated areas where movement between habitats is effectively impossible due to a lack of connectivity.	Completely isolated habitat patches with no corridor connections. No connectivity.	Enclosed marine zones with heavy industrial activity, sonar use, or impassable current patterns.	Flyways obstructed by continuous barriers or lethal hazards.

Note: *While the concept of porosity originates in landscape (terrestrial) ecology, its application in this context extends beyond terrestrial environments. Porosity refers functionally to the degree to which a species can move through an environment, whether on land, in the air, or in water. For marine and avian migratory species, 'porosity' may relate to seascape or airspace connectivity, such as the availability of safe flyways, oceanic migration routes, or favourable environmental conditions. Therefore, this document treats porosity as a cross-system property, acknowledging that different species experience and respond to barriers in context-specific ways, and that functional connectivity may be achieved in diverse environments through suitable structural or ecological conditions.*

Examples of physical anthropogenic barriers

1. Fences and walls [16-19]

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 [20-27]

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 better consider migration patterns.

3. Bridges and tunnels [27, 28]

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 [29-33]

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. **Offshore wind turbines** and **underwater cables** can pose significant risks to **aquatic ecosystems**, through **physical disturbances** in marine habitats, such as changes in water flow or sediment patterns alongside noise pollution from the construction and operation of these installations. Furthermore, **underwater cables** and energy transmission systems can introduce **electromagnetic interference**, disrupting the navigation and migratory patterns of marine species, including fish and marine mammals that rely on the Earth's natural magnetic field.

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. For offshore wind farms (OWFs), time construction activities to avoid peak marine mammal seasons, and incorporate **quietening technologies** (e.g., bubble curtains or alternative pile-driving techniques) during installation to reduce noise disturbance. Design and route underwater cables to minimise electromagnetic interference and habitat disruption. Additionally, monitoring and evaluating **wildlife mortality hotspots**.

5. Dams and hydroelectric installations [32, 34, 35]

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 [36-40]

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. Aircraft may affect the migration paths of avian species, where collisions and localised disturbance are known, but wider impacts are not well understood.

Mitigation needs – Creation of marine protected areas (**MPAs**) or other area-based measures, such as Areas To Be Avoided (ABTAs), Particularly Sensitive Sea Areas (PSSAs), or traffic re-routing schemes under the auspices of the IMO 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 [41-43]

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 [44-45]

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 [46-48]

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**. Additionally, these hard structures contribute to coastal squeeze, where rising sea levels eliminate the landward migration of habitats, leading to habitat loss and further reducing the available space for species. **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 [49-53]

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 [54-56]

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**. Monocropping systems often reduce plant diversity and limit available foraging resources, further **reducing 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, wildlife friendly fencing**, and **regenerative** or **nature-friendly farming techniques** that diversify crop cover and enhance food availability, increasing permeability and enhancing connectivity both within and around cropped areas.

12. Mining and quarrying operations [57-60]

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**. This extends to trace element exposure in birds from metal mining areas. Additionally, **noise** and **light** from mining operations can discourage animals from passing through affected areas. This also applies to **underwater mining** and associated disturbance, which can affect both lateral and vertical movements through the water column.

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 exploration, production, and transportation [55, 61, 62]

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**. For example, the Trans-Alaska Pipeline, including its continued maintenance, in the US, impacts caribou migration. **Exploration, production, and infrastructure construction** and operation for **oil** and **gas** in marine environments can disrupt the migration of **marine species** due to noise, construction disturbances and habitat alterations.

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. Noise reducing technology and temporal and/or spatial restrictions for operations in the marine environment.

14. Conflict zones and military areas [63-66]

Active conflict zones may be large-scale areas, which destroy vast habitats, with ongoing conflicts removing migration pathways (e.g. **migratory birds** in the Russia/Ukraine conflict zone 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. This additionally extends to the seismic and sonar activity, and military controlled explosions of large or novel weapons, often in deserts, underground, or in marine spaces.

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) [67-70]

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**.

16. Traps [55]

Animal traps, whether designed for hunting, research, or pest control, can act as significant physical barriers to migratory species. These traps can include snares, cage traps, leg-hold traps, and live-capture devices (e.g. mist nets). Traps pose direct threats to animals by causing **injury**, **stress**, or **mortality**, particularly when they are placed along migratory routes. For species that must travel through large areas, encountering traps can **disrupt their movement**, force them to **alter their path**, or prevent them from reaching critical habitats. Additionally, animals caught in traps often experience **heightened stress**, which can **reduce their fitness**, especially if they are left trapped for extended periods. Traps can also result in **unintended capture of non-target species**, including endangered species or juveniles, further complicating conservation efforts.

Mitigation needs – Regulations to **limit the use of certain types of traps**, particularly those that cause unnecessary suffering or mortality. Wildlife-friendly traps that allow for non-lethal capture and release should be encouraged, with efforts to reduce the number of traps in high-risk migration corridors. Additionally, the **placement of traps** in migratory routes can be minimised, and alternative pest control methods should be explored. Enhanced **monitoring and enforcement** of trapping regulations can also ensure that traps are being used responsibly and in a way that minimises harm.

Examples of physical natural barriers [71-73]

Natural physical barriers that can (species dependent) act as strict barriers to migration patterns. Often these barriers are static, such as large mountain ranges, or oceans, which have historically formed persistent obstacles for species. However, climate change and other anthropogenic activities may alter or enhance these barriers, causing them to shift or intensify. On the other hand, some natural barriers are dynamic, such as fluctuating weather patterns, and these barriers may shift, impacting different species or regions over time. Therefore, the mobility of these natural barriers, whether they are static or dynamic, play a critical role in migratory 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)
7. Atmosphere (e.g. Solar storms (e.g. Aurora Borealis), Earth’s magnetic field)

Examples of non-physical 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 more often 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.

Examples of non-physical natural barriers (but anthropogenic activities have accelerated their negative impacts)

1. Climate change [1, 74, 75]

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. The vulnerability of migratory species to climate change is closely linked to the permeability, and porosity, of landscapes and seascapes; more vulnerability where there is lower porosity and vice versa. Climate change links to many of the following non-physical barriers.

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

2. Changes in food availability [76]

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. In marine environments, **overfishing** and **unsustainable harvesting** of prey species can reduce the abundance of vital food resources for marine species. Additionally, **marine habitat degradation**, including coral reef destruction and the alteration of **seagrass meadows**, can further disrupt food chains, leaving species without essential feeding grounds. **Pollution**, particularly **nutrient run-off**, can also lead to harmful algal blooms, which can alter the availability of prey or create toxic conditions, making certain areas inhospitable. The combined pressures of **human**

offtake and **habitat loss** make it increasingly difficult for marine species to complete their migration and access necessary food resources.

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**.

Mitigation needs – Ensure the **availability of key food resources** along migratory routes through adaptive management, especially in stopover sites. **Restoration** and **conservation of habitats**, such as wetlands, grasslands, and forests, as well as encouraging **sustainable agricultural practices** that do not disrupt food cycles or habitats. In marine environments, implement and enforce regulated, **sustainable fisheries management** to prevent overfishing and overharvesting of prey species. Protect and restore critical marine habitats like coral reefs and seagrass meadows to support healthy food webs. **Raise awareness** about the **impacts of human-provided food**, especially during winter, and promote balanced approaches that avoid encouraging **dependency**, which can lead to vagrant individuals.

3. Pathogens and disease outbreaks [54, 77-82]

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.** Many pathogens arise in or spread rapidly through more intensively managed systems, which are often artefacts of industrial farming, forestry, and fishing techniques. These practices can disrupt natural pathogen dynamics. 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.

Mitigation needs – Strengthen **biosecurity measures** to reduce pathogen transmission through better **regulation of livestock and wildlife interactions**. Promote more **nature-friendly management practices** that work with natural systems rather than in competition. Implement disease management protocols for affected species, including controlled interventions where necessary. Increase **awareness** and **training** for **stakeholders** on the impact of pathogen dynamics and its potential to exacerbate risks.

4. Weather patterns and events [83-87]

With rising global temperatures, **suitable habitats for many species are shifting** towards the poles or higher altitudes, and their current suitable habitats are being lost or degraded, such that some migratory species are no longer able to persist in some parts of their range. The loss of keystone species can cause significant changes in habitat structure and ecosystem function, further degrading these areas and making it increasingly difficult for a species to return. This leads to a tipping point, whereby species cannot return, and those species already at peak altitudes or latitudes, no suitable habitats remain. 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 and the availability of habitat 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.

Mitigation needs – Implement climate adaptation strategies that include the **creation** and **management of flexible migration corridors** to accommodate shifting ranges, in conjunction with **regulatory frameworks**. Promote **habitat restoration** and **preservation** in areas predicted to be suitable as species shift their ranges. Encourage more **nature-friendly land management practices** that work with, rather than compete against, natural systems to support ecosystem resilience and species return. Enhance monitoring systems to track changes in migration timing and patterns, enabling conservation interventions without delay. Develop **climate-resilient infrastructure**, such as storm-proofing habitats and enhancing connectivity.

5. Natural hazards [88, 89]

Natural hazards, 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. While natural, many of these hazards have been **amplified by human actions** over time including the intensification of uses of the land and sea and burning fossil fuels that contribute to **climate change** and exposure to associated **risks**, including fires and floods.

Mitigation needs – **Reduce the vulnerability to risk** through land and sea use over time. Develop robust **disaster resilience measures** and **emergency response plans** that include wildlife. **Restoring damaged habitats** and creating emergency corridors to facilities species movement during such events, and in extreme cases consideration of temporary translocation of populations where movement to alternative sites is not possible, where their effects have been magnified through human activity. Improve **land-use planning** and **reduce habitat loss and fragmentation**, ensuring wildlife corridors remain intact post-disaster. Encourage **international cooperation** for disaster response, where habitats are transboundary.

6. Ocean currents and wind patterns [90-97]

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. It 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.

Mitigation needs – **Monitor** and **model changes** in ocean currents and atmospheric conditions to predict migration disruptions. Implement **marine protected areas** and **sustainable fisheries management** to help species **adapt** to shifting food availability. Encourage research to understand the impacts of climate change on oceanic ecosystems, and international cooperation to address large-scale changes in ocean currents and wind patterns.

Examples of non-physical anthropogenic barriers

7. Light pollution [49, 98-103]

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 **disorientate** 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. For marine species, artificial light may cause disorientation to sea turtle hatchling's natural instinct of positive phototaxis from the beach to the sea.

Mitigation needs – Implement **'Dark sky'** policies to **reduce light pollution** or promote **wildlife-friendly lighting designs** e.g. installing dimmers/shields to direct light away from wildlife and migratory routes. Artificial light use alters per season and may be impacting migration patterns as a result. Create wildlife corridors with **minimal artificial light** and promote research and monitoring of light pollution impacts on specific species to guide mitigation efforts. Consider the cumulative impacts of light pollution alongside other barriers, as multiple stressors can compound effects.

8. Chemical pollution [104-107]

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, and harms coral reefs where excess nutrients can cause **algal blooms** that **outcompete corals** and increase their susceptibility to **disease** and bleaching, with cascading effects on species dependent on these habitats. Pesticide use is recognised as a key factor in insect decline, which for insectivorous migratory bird can cause **food shortages.**

Mitigation needs – Strengthen chemical regulations, establishing **buffer zones** around critical habitats to prevent risks of negative anthropogenic impacts such as oil spills. Improved waste management, and the promotion of **non-toxic alternatives** in areas such as agriculture and industry. Develop robust **emergency response plans** and monitor contaminants to protect habitats. Consider the cumulative impacts of chemical pollution alongside other barriers, as multiple stressors can compound effects. Current regulatory thresholds may tend to be based on human health or economic perspectives, which may not adequately protect vulnerable species or ecosystem functions. A **multispecies approach** is needed to better capture these broader ecological risks.

9. Noise pollution [108-114]

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.

Mitigation needs – Implementing **noise-reducing technologies** on machinery and vehicles and restricting high-intensity sonar use during peak migration, through temporal or spatial management. Noise pollution's effects can be far-reaching, especially in marine environments where sound propagates over long distances and many organisms are highly sensitive to acoustic disturbances. Cumulative exposure to multiple noise sources can lead to chronic stress, behavioural changes, and habitat displacement. Current noise thresholds often reflect anthropocentric standards and may underestimate risks to diverse species, underscoring the need for more ecologically informed criteria and management.

10. Electromagnetic pollution [115-118]

Electromagnetic pollution, generated by **power lines**, **telecommunications**, and **satellite systems**, can interfere with the migratory behaviour of species that rely on **Earth's magnetic field** for navigation, such as sea turtles, birds, and some fish. The presence of artificial electromagnetic fields can disrupt their ability to detect natural geomagnetic cues, leading to **disorientation** or **deviation** from established migratory routes. This can result in individuals becoming lost or stranded. Additionally, this could interfere with species that rely on low-frequency electromagnetic signals for communication or environmental sensing, thus affecting their ability to interact with each other or respond to changes in their surroundings.

Mitigation needs – **Electromagnetic shielding** around key infrastructure, establishing **no-emission zones** along migratory routes, and **optimising frequency ranges** to reduce unnecessary disruption. Possibly implementing **temporal restrictions** during peak migration and monitoring emission levels to further minimise impacts.

11. Water quality changes [119, 120]

Changes in salinity, due to altered freshwater flows, ocean acidification, due to increasing anthropogenic CO_2, and ocean deoxygenation can act as barriers for aquatic migratory species. While direct evidence of impacts on migratory species remains limited, elevated **ocean CO_2 levels** are thought to have a number of short-term effects on **fish** physiology, such as **altered respiration and blood circulation**, and longer-term impacts including **reduced growth rate and reproduction**. There is greater certainty about the degradation of **marine habitats** such as coral reefs, which rely on carbonate ions to build their structure; such habitat loss will adversely affect migratory species reliant on these habitats. Adverse water quality effects are intensified by thermal stress, which increases aquatic systems' sensitivity to chemical and nutrient loading. This sensitivity is expected to worsen with ongoing climate warming, more frequent extreme events, and unusual weather patterns, exacerbating risks to aquatic species and habitats.

Mitigation needs – Monitor and **regulate water quality** to prevent further degradation, **reducing CO_2 emissions** and **controlling nutrient runoff**. Promote nature-friendly management practices in agriculture, forestry, and wastewater treatment to reduce pollutant loads. Implement adaptive, dynamic management approaches using real-time monitoring to adjust thresholds and mitigate impacts effectively. **Protect** and **restore** coral reefs, mangroves, and seagrass beds. Implement strategies to manage freshwater flows and maintain natural salinity gradients in estuaries and coastal zones. Promote **sustainable fisheries management** to reduce anthropogenic pressure on aquatic ecosystems. Encourage further research on the effects of ocean acidification and deoxygenation on migratory species to inform mitigation efforts.

12. Invasive alien species [1, 55, 121-124]

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.** Creating fewer opportunities for invasives to establish is essential and includes maintaining the complexity and **connectivity** of land cover. The impact of connectivity depends on how ecological networks are managed to **promote resilience** rather than invasion pathways.

Marine and freshwater invasive species pose additional challenges due to the difficulty of control in aquatic environments. Measures such as ballast water management, regulation of aquarium and pond releases, and public awareness campaigns against releasing fish or vegetation into watercourses are critical to reduce the spread of aquatic invasives.

Mitigation needs – Implement **biosecurity measures** to prevent the introduction of invasive species, through regulatory frameworks. Promote **habitat restoration** to improve **resilience** against invasive species and support the control and management of invasive populations through **targeted eradication and containment strategies**. Enhance monitoring to assess the impacts of invasive species on native species and their habitats.

13. Hunting, overfishing and depletion of food resources [125-127]

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. This also extends to the impact of **bycatch**.

Mitigation needs – Encourage regulations and enforcement to prevent **overfishing**, **unsustainable hunting**, and the **depletion of prey/plant resources** in migratory routes and critical habitats. Promote **sustainable harvesting practices** that consider the needs of animal species and their reliance on these resources. Establish and enforce protected areas where hunting and fishing are restricted during critical migration periods. Enhance **bycatch reduction techniques**, such as modifications to fishing gear and practices, to minimise incidental capture of non-targeted species.

Note: This section expands on the anthropogenic factors that exacerbate natural challenges to food availability, including unsustainable hunting, fishing, and plant harvest, which can directly reduce critical food resources along migratory routes and at stopover sites.

14. Human disturbance [1, 128-129]

Human disturbance, caused by development, tourism, recreational activities, and **human migration** can act as a barrier for migration. Notably, human migration is likely to intensify because of climate change, especially in response to extreme weather. 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.

Mitigation needs – Implement protected areas to reduce human migration and settlement in critical migratory routes. **Urban planning** strategies should focus on **minimising encroachment**. Promoting **sustainable tourism practices** and regulating recreational activities during sensitive periods, such as breeding or migration seasons, can help reduce disturbances (e.g. turtle beaches). Additionally, designing **wildlife-friendly infrastructure** that accommodates both human and animal movement (e.g., eco-passages, tunnels) can allow species to safely navigate through human-dominated landscapes. **Public education** on the impacts of human migration and disturbance on wildlife, along with policies to manage and mitigate human population pressures, can further support species resilience.

15. Social barriers [130-136]

Social barriers can influence **human behaviours and attitudes** that affect species movement and habitat connectivity. These may include local **resistance** to wildlife corridors, **negative perceptions** of certain species (such as predators or perceived pests), cultural practices, economic concerns, and human-wildlife conflict. Negative attitudes towards large fauna can result in **persecution** or **retaliatory killings**. In some instances, **cultural traditions** are cited to justify practices that now differ substantially in scale, purpose, or context from their historical origins, creating complex and often contentious barriers. While some practices are rooted in subsistence needs, others are shaped by broader economic, recreational, or political drivers. For the **reintroduction or recolonisation** of some species, such as predators or ecosystem engineers, local opposition, often from farming communities, is common due to concerns over livestock predation or land-use impacts. This resistance can delay or block conservation initiatives, reduce the effectiveness of regulatory frameworks, and hinder the establishment of functional connectivity across landscapes.

It is important to note that declines in once-abundant species can lead to the loss of ecological functionality within ecosystems. This concept underscores the importance of addressing social barriers before species become rare or scarce, as their ecological roles may diminish or disappear entirely, leading to cascading effects throughout the ecosystem. The loss of key species can disrupt species assemblages and their interactions, further complicating conservation efforts.

The guiding principles of the CMS Community Participation and Livelihoods document can be used a reference point when addressing social barriers and feed into the approaches for mitigation needs.

Mitigation needs – Addressing social barriers requires **targeted community engagement, education**, and **awareness programmes** that promote understanding of species' ecological roles and foster coexistence. **Incentive-based approaches**, such as compensation schemes for crop or livestock losses, and benefit-sharing from eco-tourism or managed trophy hunting can present as actionable objectives. Integrating **social concerns** into **conservation planning** through participatory processes **increases community ownership**, **reduces conflict**, and improves the long-term success of barrier mitigation efforts.

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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