**Ecological Networks - Mapping of Standardization Needs**

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1. ***Scope***

*This document assesses the current state and identifies terminologies, standardization needs and best - practices for the identification, planning, designation, management, monitoring and reporting of Ecological Networks which maintain, enhance, and restore the structural and functional connectivity of ecosystems and their biodiversity. This document includes benchmarking geared towards obtaining inputs and is expected to assess the standardization needs, inclusion of ecological networks in science, policy and practice around the world, integrating indigenous knowledge and best standardization practices for conserving biodiversity.*

1. ***What are ecological networks: Terms and Definitions***

*This section would focus on synthesizing the available and relevant terms and definitions on ecological networks and connectivity from published reports and other publications.*

1. ***Ecological networks across ecosystems: A review of literature***

*3.1 Terrestrial*

*3.2 Freshwater*

*3.3 Marine*

*3.4 Aerial*

*3.5 Freshwater-Marine Interface: While all ecosystem interfaces are important, this subsection would specifically focus on the freshwater-marine interface given the particular significance of this interface for biological communities and the society, especially the indigenous and local communities living within.*

*This section would focus on providing a short synthesis of the concepts and processes related to ecological networks and connectivity within each ecosystem/realm type.*

1. ***Role of ecological networks in socio-ecological systems***

*This section would focus on synthesizing the role and contribution of ecological networks in the functioning and maintenance of socio-ecological systems, namely ecological, sociological and economic benefits and reasons to conserve networks - flood erosion, soil erosion, pollination, rich fisheries, etc. (ecosystems services approach) and those that align with the blue economy, in addition to socio-cultural significance e.g. traditional practices.*

1. ***Threats to ecological networks***

*This section would include a discussion of the key current and emerging threats to structure and functioning of ecological networks across realms.*

1. ***Ecological networks in science, policy and practice: status, knowledge gaps and conservation/implementation needs with a focus on indigenous communities***

*This section would focus on synthesizing information generated through the help of the questionnaire survey (as mentioned in section 1) on the extent of inclusion of ecological network considerations across science, policy and conservation practice and gaps therein keeping perspectives of indigenous communities into relevant context (from the view of developing a standard).*

1. ***Interlinkages between conserving ecological networks and national/global conservation commitments***

*This section would focus on exploring how ecological networks considerations play a role in contribution to the goals of several relevant conservation conventions/entities (as opposed to focusing on a single most relevant convention/entity).*

1. ***Best Practices in maintaining ecological networks: Case studies*** *(3-5 covering all/diff realms; 1-2 pages each) This section would focus on compiling relevant case studies (from literature and the questionnaire survey) demonstrating best practices around the globe on conservation and monitoring of ecological networks that can provide better insights into the standardization needs.*
2. ***First step towards standardization: enabling conditions, priority areas and implications***

*This section would include a discussion on the relevant parameters required for developing a standard for ecological networks. These include the presence of enabling conditions such as existing indicators/tools/methods, data protocols, policy levers, defining priority areas for implementation of a standard and clarifying implications of standardization for relevant sectors.*

1. ***Key takeaways and the way forward***

*This section would focus on drawing conclusions and carving a way forward based on the information provided in the preceding sections.*

***Appendices*** *(questionnaire survey [under development])*

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**1 Scope**

This document assesses the current state and identifies terminologies, standardization needs and best - practices for the identification, planning, designation, management, monitoring, and reporting of Ecological Networks which maintain, enhance, and restore the structural and functional connectivity of ecosystems and their biodiversity. This document includes benchmarking geared towards obtaining inputs and is expected to assess the standardization needs, inclusion of ecological networks in science, policy and practice around the world, integrating indigenous knowledge and best standardization practices for conserving biodiversity.

**2. What are ecological networks: Terms and Definitions**

**3. Ecological networks across ecosystems: A review of literature**

3.1 Terrestrial

**3.2 Freshwater**

Inland waters (which include freshwater ecosystems) include lakes and lagoons, rivers and their estuaries, ponds, streams, groundwater, springs, cave waters, floodplains, as well as peatland bogs, marshes and swamps (CBD, 2008). They are interactive systems within which biotic species and their growth and adaptation, and associated biological productivity, nutrient cycling, and energy flows among inland aquatic microbial, plant, and animal communities, are integrated with their environment (Wetzel, 2013).

Multi-directional spatial connectivity is an inherent property of freshwater ecosystems which plays a crucial role in maintaining natural ecological processes and biodiversity. Freshwater connectivity can be defined as the degree to which matter (water, solutes, sediment, organic matter) and organisms can move among landscape or ecosystem components (Wohl et al., 2017; Ward et al., 2002). There are two elements in connectivity: structural connectivity and functional connectivity (Bracken and Croke 2007; Hilty et al., 2020; Zhang et al., 2021). Structural (static) connectivity refers to the spatial patterns of elements in the landscapes, such as spatial distribution of physical characteristics of catchments, while functional (dynamic) connectivity determines how structural connectivity enables different functions (e.g. ecological, hydrological processes) in the watershed. Within freshwater ecosystems, connectivity is typically present in four dimensions, where **longitudinal** (flow along the river), **lateral** (between the river and riparian and upland areas), and **vertical** (between the channel and the hyporheic zone) comprise three spatial dimensions, and variation over time is the fourth (Ward, 1989). The primary mechanism physically connecting different freshwater elements is water movement or hydrological connectivity, which provides a “hydraulic highway” (Fausch et al., 2002) through which matter, sediment, energy, biota get exchanged (Leibowitz et al., 2018). Freshwater structure and function also depends on biological connectivity across the watershed (Meyer et al., 2007) where active/passive movement of organisms or their reproductive materials (e.g., seeds, eggs, pollen) through space and time via multiple pathways (e.g., water, wind, other organisms) and multiple mechanisms (e.g., swimming, flying, walking) within and across freshwater ecosystems (Leibowitz et al., 2018).

These forms and dimensions of connectivity are variable over space and time and play a crucial role in governing key ecohydrological processes, maintaining populations, delivery of ecosystem services, thereby influencing resistance and resilience of freshwaters to natural and human-induced disturbances. For instance, longitudinal connectivity along rivers allows species migrations and, therefore, important for dispersal, reproduction and long-term population dynamics of many fish and other aquatic species. Inundation of river channels during wet season allows for movement of organism and nutrients between the river, riparian zones and floodplain (lateral connectivity) which is essential for maintaining viable populations of several aquatic and semi-aquatic flora and fauna (e.g. amphibians, turtles). Vertical connectivity is also crucial given the dependence of some surface ecosystems on groundwater or the exchange of biota (Hermoso et al., 2012). The hyporheic zone itself provides habitat for a range of microbes and invertebrates, sometimes several kilometers away from the channel, which contribute to secondary production among other functions.

Several factors influence freshwater connectivity such as climate, soil type, topography and vegetation. In most watersheds, one of major factors influencing or rather altering connectivity is anthropogenic influence. Human activities frequently alter connectivity – structures such as dams, levees, water abstraction, piping, groundwater extraction reduce connectivity while activities such as wetland drainage, irrigation, impervious surfaces, and inter-basin transfers increase connectivity. Landscape alterations or land use change such as conversion of forests to agriculture, linear infrastructure development, also alter hydrologic and biological connectivity (Wohl 2017; Leibowitz et al 2018; Zhang et al., 2021). The consequences of fragmented longitudinal connectivity are well studied and documented, especially for strictly aquatic taxa (e.g. fish) where barriers can impact upstream-downstream migrations, alter seasonal breeding/movement cues, alter habitats via regime changes in flow, sediment and organic matter resulting in disruption of exchange in individuals and gene flow. Altered lateral connectivity (such as due to dams, habitat conversion) can drastically decrease species biodiversity and abundance due to disconnection of critical habitats (river-wetland-floodplain connectivity). The importance of vertical connectivity in sustaining freshwater biodiversity is frequently overlooked and not well understood owing to difficulty in invisible (below ground) and complex nature. Disruption to vertical connectivity such as infilling and blockage of the hyporheic zones due to changes in flow regime caused by increased impervious surfaces, deforestation/afforestation, can have significant impacts on freshwater biodiversity (e.g. reduced survival of salmonid eggs), although these impacts across trophic levels need to be investigated further (Thieme et al., 2024).

 Despite widespread recognition of the role that river systems play in providing ecological connectivity and functionality across landscapes and waterscapes, existing policy mechanisms and conservation area networks often fail to include connectivity measures. Assessments of the existing protected area network (except the Ramsar framework) largely show inefficiency in for freshwater biodiversity conservation primarily due to this reason as they have been designed or managed keeping terrestrial/marine ecosystems in mind (Abell et al., 2007; Thieme et al., 2024). Designing efficient and effective conservation area networks in freshwaters, therefore, needs to account for the inherent connectivity across these dimensions (Fausch et al., 2002; Turak & Linke, 2011). This is important because disturbances due human interventions such as pollution, flow alteration and the spread of introduced species are easily propagated through freshwater networks and seriously affect the biodiversity apparently protected within the reserved area (Hermoso et al., 2012, 2016).



Figure x. Types of freshwater connectivity and its ecological significance (Source: Moberg et al., 2024)

**3.3 Marine**

Marine environment includes biotopes that span across land ocean boundaries such as estuaries, intertidal mudflats, lagoons, mangroves, seagrass habitats, salt marshes to biotopes that are part of continental systems such as coral reefs including deep water coral, continental shelves, continental slope and the wider deep-sea. Connectivity is one of the most important sub-thematic in the area of biological sciences and therefore the concept of ecological connectivity is now widely accepted (Sheaves, 2009). Ecological connectivity in marine environment allows movement of populations, individuals, genes, gametes, and propagules between populations, communities, and ecosystem components as well as strongly influenced by prevailing physical and chemical gradients (NOAA). The ecological connectivity across marine realms ensures sustenance of rich biological diversity, linked blue economy and blue financing, key ecosystem processes such as cycling of nutrients, and overall importance of marine environment for carbon sequestration (IPCC SRCCS 2018; WOAII 2021). The connectivity ensures the conservation of knowledge and cultural practices of indigenous and coastal communities living along coastlines globally (WOAII 2021).

In marine environment, the concept of ecological connectivity span across landscape, hydrologic, patch, structural and functional connectivity (Tischendorf and Fahrig 2000; Freeman et al 2007; Niculae et al 2006; Bishop et al 2017). The connectivity of ocean with land as part of land-ocean boundary drives productivity of marine environment along coastlines globally. In land-ocean boundary systems, estuarine connectivity along with other coastal biotopes drive the rich coastal fisheries. The complex interactions of physical, chemical and biological gradients as part of land-ocean ecological connectivity ensures migration as well as foraging of neritic biological communities. Moreover, hydrologic cycle change, saltwater intrusion, biogeochemical gradients, development of delta, among others that can vary spatially and temporally may lead to convenience or hindrance of ecological connectivity in marine environment, particularly for coastal biotopes.

In marine environment, ecological connectivity can be attained through passive connectivity, active connectivity, habitat connectivity and seascape connectivity (Fang et al 2017). Environmental changes can promote or impede the flow of ecological resources with consequences for species and community as well as wider ecological connectivity regime in marine environment. However, ecological connectivity in marine environments across local, regional and global scales are facing unprecedented challenges from anthropogenically driven climate change. The shifts in sea surface temperature, sea level rise, ocean acidification, loss of coastal and shelf biotopes, geographical expanse of invasive species and from various types of pollutants including microplastic and persistent organic pollutants are creating multiple stressors on the marine environment with negative consequences for ecological connectivity (CBD 2008; Boyd and Hutchins 2012; Bruno et al 2018). Given the dependence of many biotopes representing marine environment with land attributes, effects of climate change altering the flow of freshwater, shifts in terrigenous carbon inputs, flow of untreated pollutants from urban and semi-urban settings are increasing the scale and level of multiple stressors with consequences for wider components of ecological connectivity (e.g. landscape, estuarine and patch connectivity). Moreover, fluxes of energy, movement of materials such as pollen, biomass, sediment and nutrients, can be impeded or affected in marine environment as a result of climate change. Globally developmental activities inland and along the coastlines such as creation of ports, cargo terminals and development of tourism infrastructures are also impeding ecological connectivity in marine environment and wider landscape connectivity components.

Overcoming the impediments of ecological connectivity require integration of regional and global factors keeping network within marine environments and network of marine environments with other connectivity components into context. Marine Protected Areas (MPAs) are widely implemented to conserve biodiversity and ecosystem services (Gaines et al 2010; Speed et al 2018). To create resilient MPAs adaptable to climate change, there is a need to adopt the principles of ecological connectivity. Ecological connectivity is a key ecological criterion to be considered during the design of a marine protected area (MPA) and network of marine protected areas (MPAn) in the marine environment (Botsford et al 2009; Cowen and Sponaugle 2009; Grorud-Colvert et al 2014). In reality, the use of ecological connectivity for designing of MPA is rather limited (Leslie 2005; Magris et al 2014). As benefits of ecological connectivity are becoming clearer at landscape levels, it has been found that only 11% of MPAs across six global regions explicitly considered connectivity during the process of site selection (Balbar and Metaxas 2019). Many of these are located in MPAs of North America or in Australia. Majority of the existing MPAs globally do not take into account ecological connectivity (Barr and Possingham 2013) but consider species or habitat into consideration as part of wider ecological selection criteria. Therefore, gap in terms of on-ground implementation of the concepts of ecological connectivity across marine environments are limited and require integration in terms of policy and decision centric processes. For effective MPAs, ecological networks as part of the wider ecological connectivity could be critical towards developing ecological corridors in marine environment for conservation of biological diversity, particularly for fragmented coastal biotopes such as estuaries and mangroves. Globally, conservation strategies that focus on landscape or on freshwater, may not take into account the wider ecological connectivity components such as land-sea ecological connectivity. As a result, ecological networks within marine environment driven by process connectivity, such as biogechemical or functional connectivity are being affected resulting in changes in downflow components that could affect the structure, functions and overall health of marine environment.

While studies on ecological connectivity in marine environment across geographical scales are not wide-spread, nevertheless there are existing challenges. In addressing ecological connectivity for marine environment, focus is laid towards economically important, charismatic, and/or highly mobile species. On the contrary, many of the biological groups such as microbiome components, which collectively shape key ecosystem processes in marine environments are overlooked and not considered as part of the ecological connectivity components. Ecological knowledge and collective memory for marine environment in coastal communities are resources that are yet to be considered or integrated in ecological connectivity (Jarrigeo and del Corral 2024). Network interventions are essential component of behavioral connectivity and the need to integrate existing knowledge of indigenous communities can effectively shape ecological connectivity. At present, many of the interventions in marine environment clearly sidelines the viewpoints of indigenous community which would have consequences for pan-generation knowledge, artisanal practices and socio-cultural practices of coastal communities.

Figure 1 [to be inserted; in progress]

3.4 Aerial

3.5 Freshwater-Marine Interface:

**4. Role of ecological networks in socio-ecological systems**

**5. Threats to ecological networks**

**6. Ecological networks in science, policy and practice: status, knowledge gaps and conservation/implementation needs with a focus on indigenous communities**

**7. Interlinkages between conserving ecological networks and national/global conservation commitments**

Conserving ecological networks is deeply intertwined with national and global conservation commitments. Ecological networks, comprising interconnected habitats and ecosystems, are vital for biodiversity conservation, ecosystem services, and resilience to climate change. These networks align with and support achieving broader conservation goals outlined in international agreements and national strategies. and are summarized below:

**7.1. Ecological Networks and International Commitments**

**7.1.1 Kunming-Montreal Global Biodiversity Framework (GBF)**:

**Target 2**: Restore 30% of degraded ecosystems by 2030 aligns with the need to maintain and expand ecological networks.

**Target 3**: Protect 30% of the planet's terrestrial and marine areas by 2030 emphasizes conserving connected habitats rather than isolated protected areas.

* + 1. **Paris Agreement**:

Ecosystem-based approaches within ecological networks enhance carbon sequestration and climate adaptation, directly contributing to national climate action plans (NDCs).

* + 1. **Ramsar Convention on Wetlands**:

Conservation of wetland networks supports global goals for water management and biodiversity protection.

* + 1. **Convention on Migratory Species (CMS)**:

Ecological networks facilitate species migration, a core principle of the CMS, especially for migratory birds, mammals, and marine species.

* + 1. **Sustainable Development Goals (SDGs)**:

Goals such as SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land) rely on conserving ecological networks to sustain biodiversity and ecosystem services.

**7.2. National Commitments and Conservation Strategies**

* + 1. **National Biodiversity Strategies and Action Plans (NBSAPs)**:

The Convention on Biological Diversity (CBD) has urged countries to incorporate ecological networks into their NBSAPs as a strategy to maintain genetic flow and ecosystem resilience. The European Union's **Natura 2000** network links habitats across member states, contributing to biodiversity targets. Several countries are aligning their existing NBSAPs with the KM-GBF

* + 1. **Protected Area Networks**:

National commitments to expand protected areas often focus on creating corridors and linkages between ecosystems, ensuring species can move and adapt to changing conditions. India's **Project Tiger** includes ecological corridors between tiger reserves to support genetic diversity.

* + 1. **Climate Adaptation and Mitigation Plans**:

Incorporating ecological networks into national climate plans ensures resilience against extreme weather and climate variability. Brazil’s efforts to conserve the Amazon rainforest contribute to biodiversity, climate mitigation, and global conservation goals.

**7.3. Interlinkages Between Ecological Networks and Conservation Commitments**

* + 1. **Biodiversity and Ecosystem Services**:

Ecological networks maintain ecosystem services (e.g., pollination, water filtration) essential for meeting global biodiversity targets and human well-being.

* + 1. **Species Migration and Adaptation**:

Climate change-induced shifts in species ranges require well-connected ecological networks to support migration and adaptation, aligning with global climate and biodiversity frameworks.

* + 1. **Preventing Habitat Fragmentation**:

Conservation commitments emphasize reducing habitat fragmentation, a key function of ecological networks. Wildlife corridors in Africa, such as the Kavango-Zambezi Transfrontier Conservation Area (KAZA), link ecosystems across borders.

 **7.3.4 Integrated Landscape and Seascape Approaches**:

National and global commitments increasingly call for managing landscapes and seascapes holistically to balance conservation and development, which ecological networks enable.

**7.4. Challenges and Opportunities**

**7.4.1 Challenges:**

1. **Policy Fragmentation**: Lack of alignment between biodiversity and climate policies at national and international levels.
2. **Funding Gaps**: Limited resources for creating and maintaining ecological networks.
3. **Cross-Border Management**: Coordinating conservation across political boundaries.
4. **Capacity Building**: Several countries lack the technical capacity to identify, delineate manage and monitor ecological networks.

**7.4.2 Opportunities:**

1. **Nature-Based Solutions**: Ecological networks serve as natural buffers against climate change, disasters, and biodiversity loss, supporting global and national commitments.
2. **Community Engagement**: Local communities can be empowered to manage ecological networks, ensuring alignment with both conservation goals and livelihoods.
	1. **Conclusion**

Conserving ecological networks is essential for achieving national and global conservation commitments. These networks act as the backbone for biodiversity protection, ecosystem resilience, and climate adaptation. Aligning efforts to conserve and expand ecological networks with international frameworks like the Kunming-Montreal GBF, Paris Agreement, and national strategies will ensure synergistic progress toward a sustainable future.

**8. Best Practices in maintaining ecological networks: Case studies**

**9. First step towards standardization: enabling conditions, priority areas and implications**

1. **Key takeaways and the way forward**
2. **Bibliography**

For Clause 3.2-

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