A Framework for Developing Connectivity Targets and Indicators to Guide Global Conservation Efforts

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Humans eliminate habitats and fragment ecosystems around the globe (Haddad et al. 2015), disrupting ecological flows, movement of species, and exchange of genes between populations. In response, conservationists strive to maintain and restore connectivity among core habitats (e.g., Peck et al. 2017), patches of relatively natural lands (Theobald et al. 2012), protected areas (Belote et al. 2016), or current and future climate niches (Carroll et al. 2018).

The Strategic Plan for Biodiversity 2011–2020 (CBD 2014) includes 20 targets (i.e., Aichi Biodiversity Targets) embedded under five goals. Target 11 calls for "17 per cent of terrestrial and inland water areas… [to be] conserved through… *well-connected* systems of protected areas" (emphasis added). We appreciate the Convention on Biological Diversity's (CBD) acknowledgement of a well-connected system of protected areas and recommend elevating the importance of connectivity in the CBD's 2021–2030 strategic plan. We believe connectivity should be represented by its own target with accompanying indicators. In the present article, we propose a framework for doing so, which involves developing condition-specific targets and indicators and establishing a monitoring program to evaluate the effectiveness of conservation action (figure 1).

Visconti and colleagues (2019) recognized that connectivity conservation strategies should be condition dependent. We offer a condition-dependent framework for establishing connectivity targets and indicators. We borrow from Locke and colleagues' (2019) proposal and recommend stratifying terrestrial land (including freshwater) into three conditions with different targets for each condition (figure 1). The three conditions proposed by Locke and colleagues (2019) include large wild areas, shared landscapes, and cities and farms.

Condition-specific targets

Large wild areas are lands relatively free of significant human modification with large patches of wildlands not fragmented by cities, farms, or major linear infrastructure. Such areas occur in Amazonia, Saharan Africa, the Congo Basin, and boreal Canada, Alaska, and Siberia, and they represent the wildest remaining lands where ecological processes are largely intact (Watson et al. 2016). We recommend targets for this condition include no loss of natural lands and no new fragmentation. Focusing on narrow corridors connecting protected areas (sensu Belote et al. 2016, Beier 2019) would be less useful in the large wild areas condition than maintaining large expanses of undeveloped land that already support long-distance migration and dispersal. Instead, progress in this condition could be assessed using indicators such as patch size distribution of lands free of human modification, edge-to-area ratio, and other landscape metrics that characterize the presence and configuration of large blocks of wildlands free of fragmenting features (Jacobson et al. 2020).

Shared lands consist of expanses of low human modification within a mix of agricultural lands, urban and suburban development, and linear infrastructure. Shared lands occur in the intermountain western United States, southern South America, parts of southern Africa, and central Eurasia. In the shared lands condition, landscape conservation plans—adopted by transportation and land planning agencies—will be needed to conserve and restore connections between the large wildlands or core protected areas. Protecting core habitats remains critical, and conservation planners should consider the costs and benefits of protecting additional core habitat versus investing in corridors (Simberloff et al. 1992). However, identifying and protecting corridors, migration routes, and other areas needed to support species dispersal is essential. We encourage CBD parties to set an intermediate target of 40% of the landscape consisting of well-connected protected areas by 2030, using a connectivity indicator such as those described in Saura and colleagues (2017) and Navarro and Fernández (2015).

The *cities and farms* condition represents lands dominated by intense human land use that host many small, isolated patches of natural habitat. In these areas, we recommend targets of conserving 90% of remaining natural areas (patches of relatively low human modification) and 100% of Key Biodiversity Areas and no degradation of connectivity to nearby larger protected areas. These human-dominated landscapes may benefit from corridors along riparian zones or hedgerows, green infrastructure initiatives that link networks of natural areas, and restoration activities that increase the size and connectedness of patches of natural habitat (Newmark et al. 2017). The number of protected riparian areas that connect natural areas could serve as an

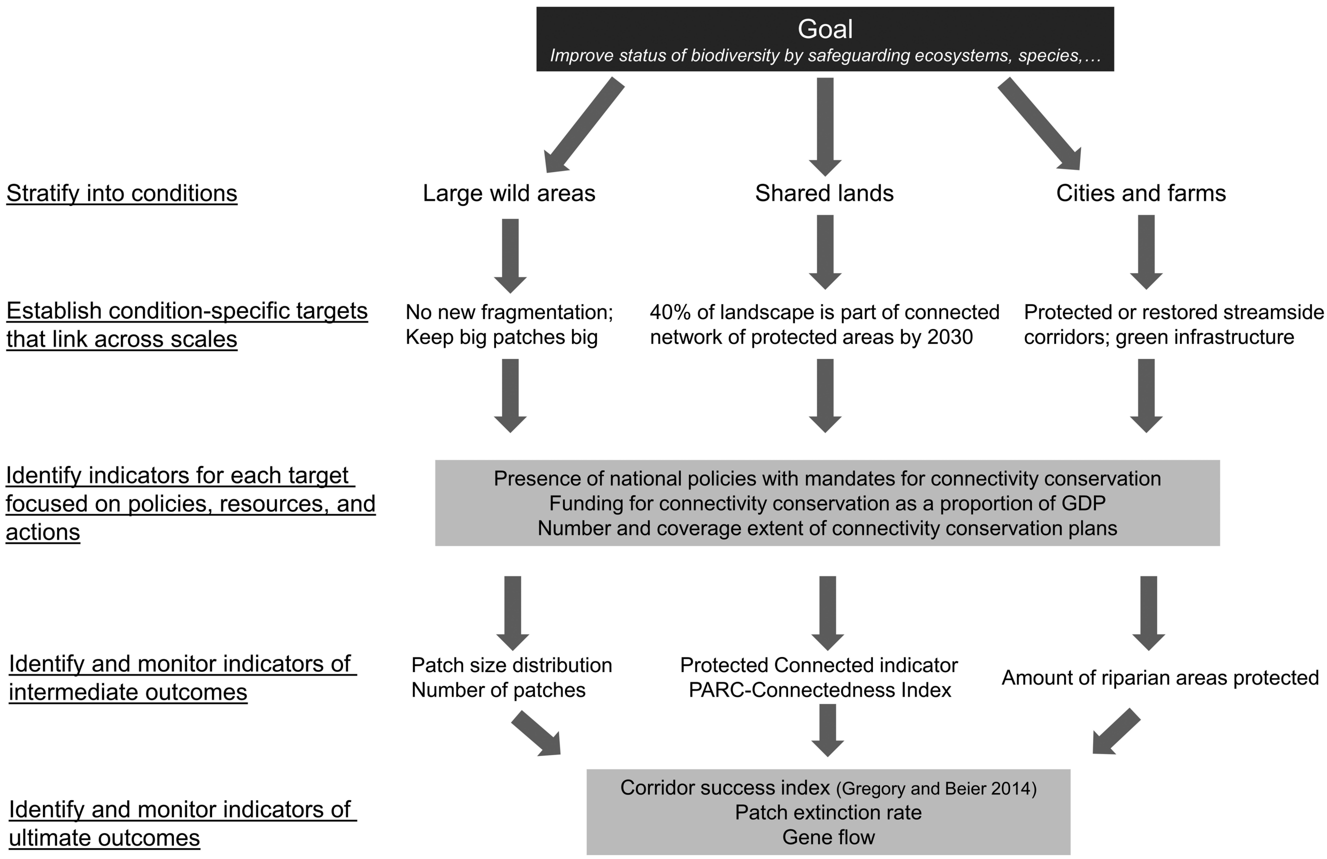

Figure 1. A framework for developing targets and indicators for revised and updated international conservation goals focused on connectivity. We recommend stratifying terrestrial land area into three broad conditions reflecting the degree of human modification and prevalence of fragmenting features and developing condition-specific connectivity targets and indicators. The indicators listed in the figure are illustrative examples and will vary by condition and local context. Targets and indicators should be considered the foundation of an adaptive program.

important indicator in this condition. Attention to fragmentation should not lead conservationists to overlook the importance of small, isolated patches of habitat (Fahrig 2019). Such patches may support endemic species, provide ecosystem services (e.g., water purification), and serve as stepping-stones for migratory species. By stratifying land into conditions, the value of small, isolated habitats may be appropriately assessed (i.e., small patches will not be compared on a global or national scale with vast patches of unfragmented wildlands).

We recognize the importance of connectivity of terrestrial and freshwater realms that span our three conditions—namely, flyways for migratory birds and river systems for anadromous fish. Conserving biodiversity requires consideration of connections across continents and the globe. Maintaining such connectivity among seasonal habitats requires international efforts to ensure long-distance migrations are maintained or restored. Although our targets do not address connectivity in marine systems, we hope others will expand our framework to cover these important realms.

Indicators of inputs, outputs, and outcomes

In all three conditions, we recommend that connectivity indicators include multiscale assessments of inputs—namely, the existence of policies and the investment of resources to conserve or restore connectivity—and outputs—namely, the implementation of associated actions. Achieving targets for connectivity across scales requires policy frameworks that support coordination across levels of governance, sectors, and institutional actors (i.e., government agencies, nongovernmental organizations, and local communities). At national levels, mandates for connectivity in conservation and sectoral policies (e.g., wildlife and transportation policies) are fundamental. They provide authority for the development of connectivity conservation plans, which guide the implementation of local actions (Keeley et al. 2019). Achievement of policy targets requires adequate human, financial, and technological resources. Policies and resources can expand protected areas, construct wildlife crossing structures, designate special management areas, create financial incentives, and support community-based management, zoning regulations, easements and acquisitions, and ecological restoration. The importance of these actions will vary among the three conditions in service of condition-specific targets (figure 1), although some policies should be aimed at cross-condition targets.

Assessing inputs and outputs will help track progress toward connectivity targets but is insufficient without monitoring of outcomes. Metrics of landscape composition and configuration (i.e., structural connectivity) can serve as indictors of intermediate outcomes. However, the ultimate aim of these targets is functional connectivity (the movement of individuals, genes, and species in response to landscape elements). We propose that scientists monitor functional connectivity of focal species within key geographic areas (e.g., a jurisdiction or ecoregion). Monitored focal species should be chosen from those considered most sensitive to loss of connectivity; represent a range of habitat preferences, life history characteristics, and dispersal abilities; and occur in each of the three conditions described above guided by specialists using an adaptive monitoring approach (Lindenmayer and Likens 2009). When designing an adaptive monitoring program several key questions must be addressed:

How many and which focal species should be monitored? Highly mobile focal species sensitive to changes occurring across broad spatial scales may be more appropriate in large wild areas, whereas less mobile focal species sensitive to finer-scale changes may be preferred in developed landscapes.

How frequently should monitoring take place and with which structural and functional connectivity indicators? More frequent monitoring of connectivity outcomes may enable early detection of declining functional connectivity in rapidly changing landscapes. Structural connectivity can be monitored frequently by evaluating configuration of protected areas and land uses. Functional connectivity may require longer monitoring intervals, particularly if genetic or demographic indicators are applied to focal species with long generation times.

What resources are available for monitoring? Availability of human, financial, and technological resources may limit the number of focal species, monitoring interval, and type of data collected. The complexity of monitoring connectivity indicators warrants an adaptive approach (Lindenmayer and Likens 2009) in which experts regularly evaluate the monitoring strategy in light of new information, questions, and landscape conditions.

Conclusions

Protecting or restoring core habitat should form the foundation of international conservation goals and associated targets. However, connectivity-specific targets are also essential to achieve bold conservation goals (Dinerstein et al. 2019, Woodley et al. 2019). Our recommended framework provides a lens to assess connectivity in varying conditions of fragmentation, but local connectedness is fundamentally the scalable building block that links local to regional to global levels as well as linking conservation actions across all three conditions (Anderson et al. 2014). Our framework should be implemented as an adaptive program that embraces adjustments of targets and of indicators of structural and functional connectivity as our understanding of links between connectivity and the maintenance of biodiversity evolves.

Our proposal would require development of novel national policies, large investments of resources, and increased commitment to monitoring ecological responses to actions implemented to mitigate fragmentation. Growing evidence suggests that such efforts aimed at overcoming fragmentation will be essential to maintain biodiversity in our fragmented world.

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