Monitoring Ecological Corridors for Nature and People

Annika T.H. Keeley[1], Jamie Faselt[1], Gabriel Oppler[1], Kristeen Penrod[2], Paul Beier[1], Diego Juffe Bignoli[3], Melissa Butynski[4], Andrew Gregory[5], Megan Parker[6], and Seth P.D. Riley[7]

[1]Center for Large Landscape Conservation
[2]SCWildlands
[3]University of Kent DICE
[4]Center for Large Landscape Conservation while the work was done, now University of British Columbia
[5]University of North Texas
[6]Center for Large Landscape Conservation while the work was done, now independent researcher
[7]National Park Service

Corresponding author: Annika Keeley, annika@largelandscapes.org

Abstract

Ecological corridors designed to maintain ecological connectivity between protected and conserved areas is a conservation strategy that is increasingly embraced around the world. Monitoring corridor effectiveness is essential to gauge progress toward connectivity conservation objectives; it also fosters learning among diverse rightsholders and interested parties. In particular, monitoring how social dynamics contribute to successful corridor conservation can enhance benefits to conservation and to local communities. By adapting to people's needs, corridor initiatives become socially acceptable and resilient to changing environmental and socio-economic conditions. Moreover, tracking public perceptions of corridors can inform adjustments in planning, management, governance, and outreach strategies. To prescribe comprehensive corridor monitoring, we follow the Open Standards for the Practice of Conservation to set goals, establish objectives, select indicators, design monitoring activities, and set thresholds for triggering adaptive management. To illustrate the application of this framework, we present a case study from an ecological corridor in California. Finally, we propose various options for

monitoring ecological outcomes, enabling conditions, and human well-being to ensure the effectiveness and sustainability of corridor conservation initiatives. We emphasize that creating a team environment among corridor players and holding regular meetings is vital for maintaining enthusiasm, participation, and funding over the long term.

Introduction

Ecological connectivity is the unimpeded movement of species, connection of habitats without hindrance and the flow of natural processes that sustain life on Earth (CMS 2024). It is critical to allow recolonization of locally extirpated populations, maintain genetic diversity, allow species to adapt by shifting their ranges in response to changing climate conditions, and support ecological processes such as pollination and hydrological connectivity (Hilty et al., 2019). In contrast, fragmentation disrupts ecosystems, isolates populations, and erodes biodiversity over time (Ewers et al., 2005).

The United Nations has highlighted the importance of connectivity through several initiatives and agreements, including the UN Decade on Ecosystem Restoration, the UN Convention to Combat Desertification (UNCCD), the Convention on Migratory Species (CMS), and the Convention on Biological Diversity (CBD). In the 2022 Kunming-Montreal Global Biodiversity Framework, 196 parties to the CBD committed to "ensure and enable that by 2030 at least 30 per cent of terrestrial, inland water, and of coastal and marine areas... are effectively conserved and managed through ecologically representative, *well-connected* and equitably governed systems of protected areas and other effective area-based conservation measures." Many nations are already working towards this goal. In the United States, the Biden-Harris administration has launched the ten-year America the Beautiful initiative to pursue locally led efforts to conserve, *connect*, and restore at least 30 percent of lands and waters of lands and waters by 2030.

Ecological corridors are one strategy to maintain or restore effective ecological connectivity in landscapes where natural areas are fragmented by roads, urbanization, and agriculture. Ecological corridors, defined as clearly defined geographical spaces that are governed and managed over the long term to maintain or restore effective ecological connectivity, can connect protected areas (PAs) and Other Area-based Effective Conservation Measures (OECMs) to form an ecological network for conservation (Hilty et al., 2000). They can take various forms, such as riparian corridors, stepping stone corridors, or landscape corridors designed to support area-sensitive focal species.

Monitoring is essential for measuring progress towards meeting connectivity and restoration goals. Monitoring, together with evaluation, is also a key component of adaptive management, supporting iterative learning to enhance conservation effectiveness (Salafsky et al., 2002). Ecological corridors have varying levels of protection, often include areas of the matrix outside of protected or conserved areas, and may span complex jurisdictional boundaries and institutional contexts (Keeley et al., 2019; Niemiec et al., 2021). Therefore, efforts to conserve connectivity in shared landscapes should be grounded in community action (Kremen and Merenlender 2018).

Comprehensive corridor monitoring plans should account for the complex context in which corridor conservation takes place. Monitoring ecological targets allows project managers to assess whether the intended conservation goals and outcomes are being achieved (Stephenson 2019, Sutherland et al., 2018), and may include monitoring gene flow as the ultimate goal of ecological corridors, or proxies such as habitat condition in the corridor, wildlife movement through the corridor, or whether the impact of barriers on movement have been mitigated (Gregory and Beier 2014). Monitoring of social factors is a critical, yet sometimes overlooked aspect of conservation monitoring (Mangun, 1992; Ghoddousi et al., 2021; Niemiec et al., 2021). Monitoring people's attitudes and beliefs about corridors can help adjust planning, management, governance, education, and outreach strategies (Herrara et al., 2016). Monitoring how ecological corridors improve local livelihoods, sustain cultural practices, and reduce human-wildlife conflict (Kiria, 2014) may increase support for corridor conservation (Obeng et al., 2019). Thus, monitoring human well-being and the social conditions that enable successful corridor conservation can help corridor projects be effective, socially acceptable, adaptable, resilient to changing environmental and socio-economic circumstances, and bring benefits to local communities. Although many corridors have been planned and established (Keeley et al., 2018), monitoring protocols have been created (e.g., SINAC 2018), and a monitoring framework has been conceptualized (Watson et al., 2017), our extensive search has not uncovered a single comprehensive terrestrial corridor monitoring plan that has been implemented, or is in the process of being fully implemented.

Here, we provide guidance for developing comprehensive monitoring plans to determine whether targets are being achieved and to improve the effectiveness of corridors. Specifically we (1) briefly outline the Open Standards for the Practice of Conservation developed and commonly used by non-governmental organizations such as The Nature Conservancy, Wildlife Conservation Society, and World Wildlife Fund, as a comprehensive framework for designing conservation projects (Conservation Measures Partnership 2020); (2) apply the framework to an ecological corridor case study; (3) lay out options for monitoring: enabling conditions, ecological outcomes, and human well-being in corridors; (4) argue for collaborative, consistent approaches to monitoring, (5) provide guidance on data management plans, and (6) review funding mechanisms to support monitoring (Figure 1).

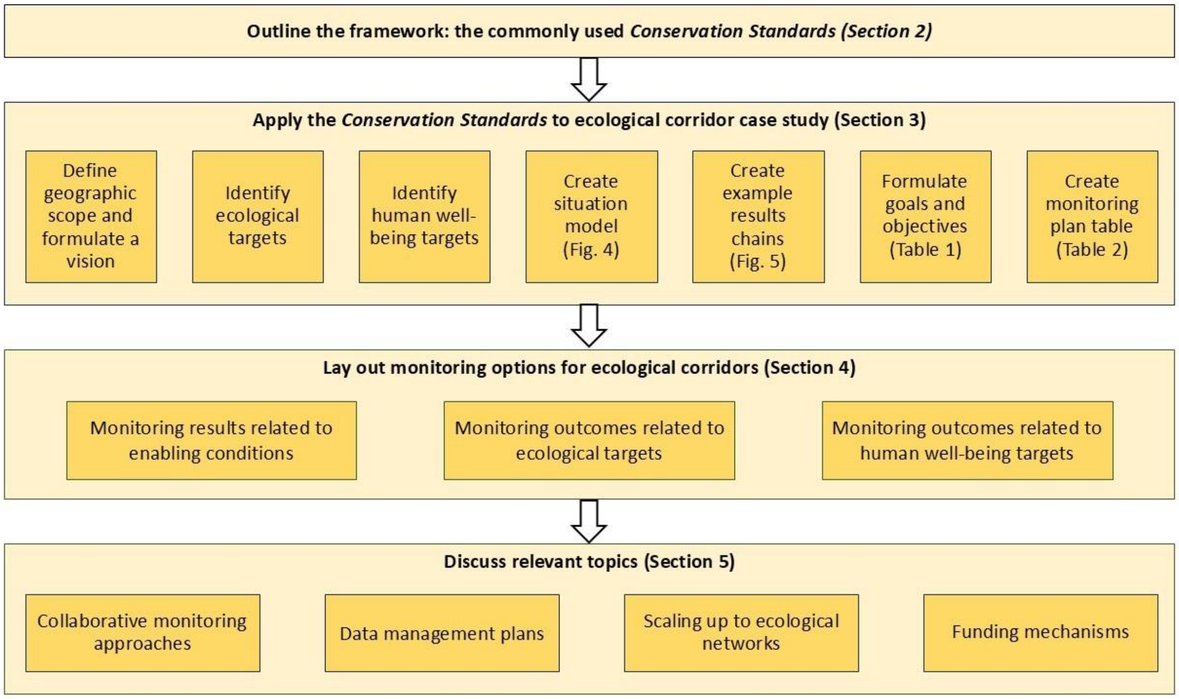

Figure 1. This paper lays out in four sections how to arrive at a comprehensive monitoring plan using a proven framework, provides details on monitoring options, and discusses relevant topics including funding mechanisms.

Monitoring and Adaptive Management

Adaptive management is a science-based, structured approach to iterative learning that aims to reduce the social and ecological costs of managing natural resources in the face of uncertainty (Holling 1978; Walters 1997). Because there are many uncertainties regarding the implementation of corridor conservation, such as the necessary corridor width, the threshold in intensity of land use in landscape corridors, the effect of human uses in a buffer around a corridor (Beier, 2019; Gregory et al., 2021), effective governance arrangements, and outreach strategies (Keeley et al., 2018), it will be vital for ecological corridor projects to practice adaptive management and for the conservation community to "learn by doing".

Many frameworks have been developed to guide adaptive management schemes. Because of its widespread use, here we follow the Conservation Standards (CS), which are a set of principles and practices that unify concepts, approaches, and terminology for conservation design, management, and monitoring (CMP 2020; Table 1). They were built on a foundation of best practices for conservation, adaptive management, and other decision-support approaches. The CS comprise five iterative steps: (1) assess, (2) plan, (3) implement, (4) analyze and adapt, and (5) share outcomes and lessons learned with project partners and the larger conservation community (CMP, 2020). While all steps are critical for the entire conservation project cycle (including design, implementation, monitoring, and adaptive management), the assessment and planning stages are key for developing a comprehensive monitoring plan. Therefore, here we focus on these two stages only, but we have learned that all stages must be iterated by the partners.

The assessment phase involves defining the geographic scope, formulating a shared vision, identifying threats and targets, and doing target viability assessments. Targets can be ecological (e.g., biodiversity features, particular wildlife species) and aspects of human well-being. A situation model is used to visually represent the relationships between these targets, direct threats, factors contributing to these threats, and strategies to address both the direct threats and the contributing factors.

Building upon the assessment phase, the planning phase involves formulating results chains, goals for the targets, objectives for results, indicators to measure change and intervention points. A key aspect of the monitoring plan is formulating SMART goals and objectives, which are specific, measurable, achievable, relevant, and time-limited (CMP, 2020). These components are vital in formulating a monitoring plan. We demonstrate the application of the assessment and planning phases of the CS to draft a monitoring plan for an ecological corridor with a case study from southern California.

Table 1. Terminology related to connectivity and the Open Standards for the Practice of Conservation

Connectivity	
Ecological corridor	A clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity (Hilty et al., 2020).
Linkage	Although 'linkage' and 'corridor' are frequently used synonymously, "linkage" technically refers to broader regions that maintain connectivity and may include multiple strands.
Ecological network (for conservation)	A system of core habitats (protected areas, OECMs and other intact natural areas), connected by ecological corridors, which is established, restored as needed and maintained to conserve biological diversity in systems that have been fragmented (Hilty et al., 2020).
Matrix	The land outside the protected or conserved areas that are connected by corridors.
OECM (Other Effective Area-Based Conservation Measure)	A geographically defined area, other than a protected area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in-situ conservation of biodiversity with associated ecosystem functions and services and, where applicable, cultural, spiritual, socio-economic and other locally relevant values are also conserved (IUCN WCPA, 2019).
Open Standards	
Scope	What the project intends to affect. In ecological corridor projects, the place-based scope usually encompasses the extent of the corridor.
Vision	A description of the desired state or ultimate condition that the project is designed to achieve. A general vision for ecological corridors is that they are functional landscape-level connections that contribute to a broader ecological network.
Situation model	A visual representation of a conservation project's context and observed and presumed causal relationships between targets, direct threats, contributing factors, and strategies. It provides the foundation for strategic planning and monitoring (e.g., Figure 4 below).
Targets	Specific, tangible entities that the project is designed to conserve that represent and encompass the ultimate aims of the project. In ecological corridor projects, ecological targets may be focal species that should be able to move through or live in the corridor. Human well-being targets may be ecosystem services that the corridor provides.
Results Chains	A visual representation of how actions lead to changes in conditions, and ultimately to the achievement of expected results. They facilitate identifying indicators and prioritizing monitoring actions in a logically informed and systematic way.

Theory of Change	A conceptual framework that describes the underlying assumptions and pathways of change that link conservation actions to desired outcomes. It outlines the sequence of events or interventions that are expected to lead to the desired changes and helps to guide the design and implementation of conservation strategies.
Strategy	A set of one or more activities with a common focus that work together to achieve specific goals and objectives by targeting key intervention points. Strategies should be linked, focused, feasible, and appropriate.
Activity	A specific action or set of tasks within an overall strategy.
Threat-reduction results	The measurable changes or achievements that occur as a result of conservation actions. They represent milestones along the results chain and serve as indicators of progress toward the ultimate conservation goals.
Intermediate results	Specific outcomes achieved through efforts to mitigate or eliminate the threats facing biodiversity or ecosystems. These outcomes may include reduced fragmentation, degradation, or disturbance of habitat, improved land-use practices, or enhanced enforcement of conservation regulations.
SMART goals and objectives	Formal statements detailing a project's desired status of a target. SMART stands for specific, measurable, achievable, relevant, and time-limited. SMART goals and objectives help ensure that conservation efforts are focused, realistic, and capable of being monitored and evaluated effectively.

Case study: The Santa Monica-Sierra Madre Linkage in Southern California

3.1 Background

The Santa Monica-Sierra Madre Linkage (Penrod et al., 2006), a landscape-scale ecological corridor, connects extensive protected lands in the South Coast Ecoregion of California. The Santa Monica-Sierra Madre Linkage stretches from the Santa Monica Mountains on the coast, north through the Simi Hills to the Santa Susana Mountains and ultimately to the Sierra Madre Ranges (Figure 2). The linkage contains a mosaic of oak woodland, chaparral, coastal sage scrub, grasslands, and riparian forests, and it includes several major branches to accommodate diverse species and ecosystem functions. About 43% of the linkage are designated protected areas, under conservation easement, or conserved as working rangelands. The Santa Monica-Sierra Madre Linkage has also been integrated into numerous local, regional, state, and federal plans. About 5% of the linkage has been lost to urbanization (Penrod and Smith, 2023). It is located in the largest urban region in the United States, the Los Angeles Metropolitan Area, and several major roads bisect the linkage (Figure 2). The National Park Service, together with many partners, has been studying connectivity in this region for more than 25 years. The freeways have been documented as significant barriers both to movement and to gene flow for multiple carnivore species including bobcats (*Lynx rufus*), coyotes (*Canis latrans*), and mountain lions (*Puma concolor*; Riley et al., 2006, 2014). For mountain lions, the population in the Santa Monica Mountains was found to have very low genetic diversity as a result of genetic drift, lack of immigration, and regular instances of inbreeding (Riley et al., 2014). Physical signs of potential inbreeding depression, such as kinked tails and high levels of abnormal sperm have been documented in mountain lions in the region (Huffmeyer et al., 2022). Population modeling has indicated that the population is at high risk of extinction if connectivity is not restored (Benson et al., 2016, 2019).

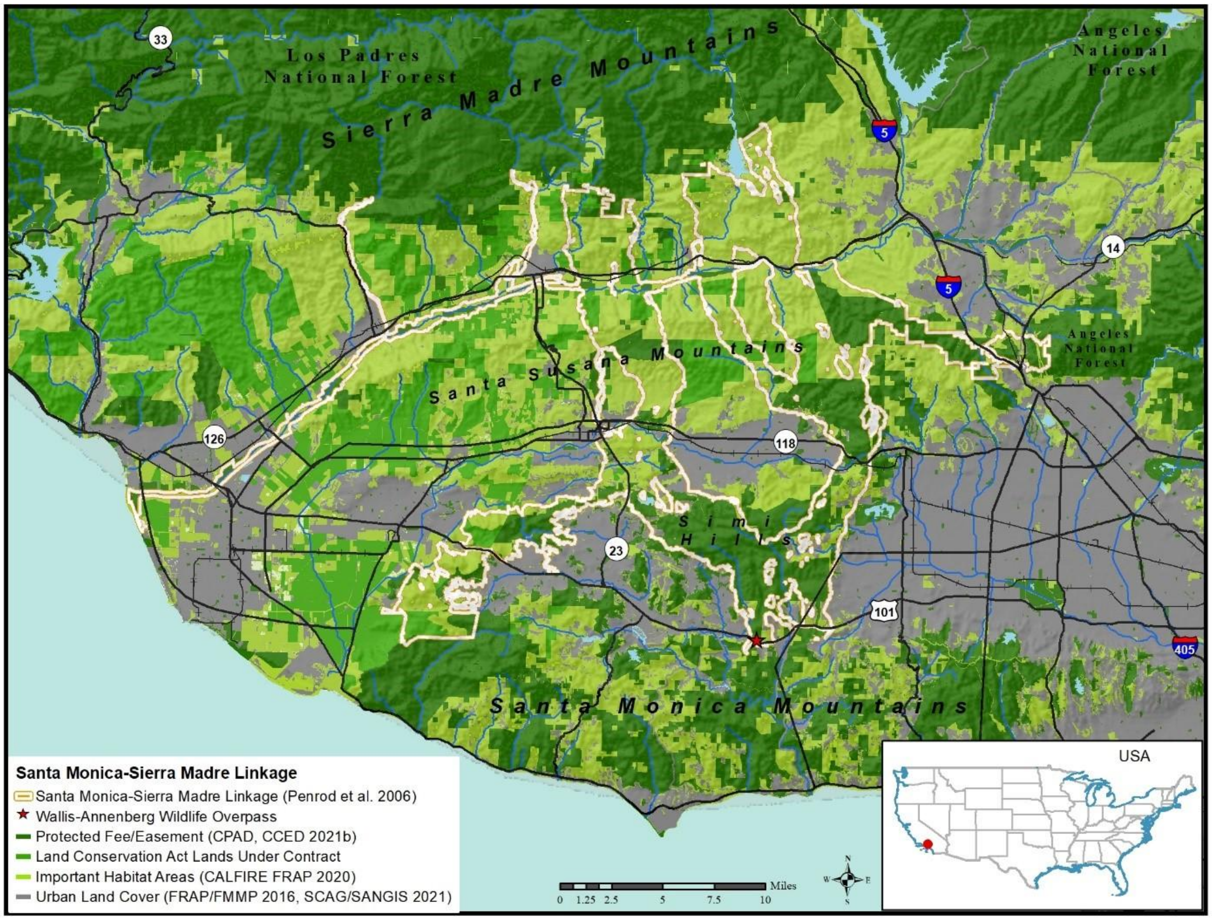

Figure 2. The multi-strand Santa Monica-Sierra Madre Linkage connects large, protected areas in the Los Angeles Metropolitan Area and includes riparian connections for species such as steelhead trout.

As a result of reduced connectivity in the region, the California Department of Transportation (Caltrans), working with the National Park Service and other partners, has implemented several wildlife crossing infrastructure improvements in this linkage, and more are being constructed. Most notably, the Wallis-Annenberg Wildlife Overpass is currently under construction and will be the largest wildlife overpass in the world spanning 61 m across 10 lanes of roadway that receives more than 300,000 vehicles per day. In 2011, diverse agencies and organizations – including county planning departments, Caltrans, and many local conservation agencies and organizations – joined together to form the Santa Monica-Sierra

Madre Linkage Implementation Alliance (LIA) to promote and maintain the linkage through land conservation, tracking threats and opportunities, research, and monitoring.

For this case study, coauthors KP, SR, & PB, all LIA members with deep knowledge of the linkage, used the road map outline in CMP (2020) to create a situation model and example results chains and to develop goals, objectives, and indicators. While monitoring is taking place in the corridor and the wider landscape (e.g., Stork et al., 2023), the LIA will consider developing a comprehensive monitoring plan.

3.2 The Conservation Standards Applied to a Monitoring Framework for the Santa Monica-Sierra Madre Linkage

Based on planning documents (Penrod et al., 2006) and our (KP, PB, SR, AK) knowledge of the linkage, we articulated the geographic scope, vision, and ecological and human well-being targets. The geographic scope encompasses the multiple strands of the corridor (Figure 2). The vision is a functional landscape-level connection that contributes to the broader ecological network in the South Coast Region (Beier et al., 2006; South Coast Wildlands, 2008). The ecological targets are large mobile mammals and migrating aquatic species that move through the corridor and flying, non-flying, resident aquatic corridor dwellers as well as plants. The focal species are sensitive to habitat loss and fragmentation and cover a broad range of habitat and movement requirements, making them representative of the ecosystems' connectivity needs (Table S1). Human well-being targets include different ecosystem services, cultural and spiritual values, human safety, and climate resilience. Targets need to go through a target viability assessment where the current health of the target is assessed and the desired state defined (Table S2). To do this, key attributes that define the target´s health and indicators to measure are selected. The aim of this stage is to have a good understanding of the current situation and the desired state of ecological targets.

As prescribed by the CS (CMP, 2020), we then created a situation model which is a visual representation of the observed and presumed causal relationships between targets, direct threats, and contributing factors. The situation model is the starting point to define the key interventions or strategies a plan needs to follow to achieve the desired result in the ecological targets (Figure 3). In monitoring plans, the situation model is accompanied by a detailed narrative. Together, the situation model and the narrative provide the foundation for a monitoring and adaptive management framework. The next step was crafting the results chains which illustrate the theory of change and show the chronological nature of expected results (Figure 4). Results chains facilitate identifying indicators and prioritizing monitoring actions in a logically informed and systematic way. They should be developed to address all direct threats included in the situation model. Here, we provide two example results chains, one focusing on the threat roads pose to wildlife movement and the other addressing habitat quality in the linkage.

We then formulated specific, measurable, achievable, relevant, and time-limited (SMART) goals and objectives to reach intermediate and threat reduction results and address the targets in the results chains (Table 2: column 1).

When creating the monitoring plan table (Table 2), we started with the goals and objectives and developed relevant indicators that are measurable, precise, consistent, and sensitive. Once the indicators were selected, we determined the monitoring activity, suggested the entities to carry out the monitoring activity, and specified a monitoring timeframe. When sensible, we related the thresholds that trigger action or adaptive management to a baseline condition and specified the timeframe when the thresholds should be evaluated.

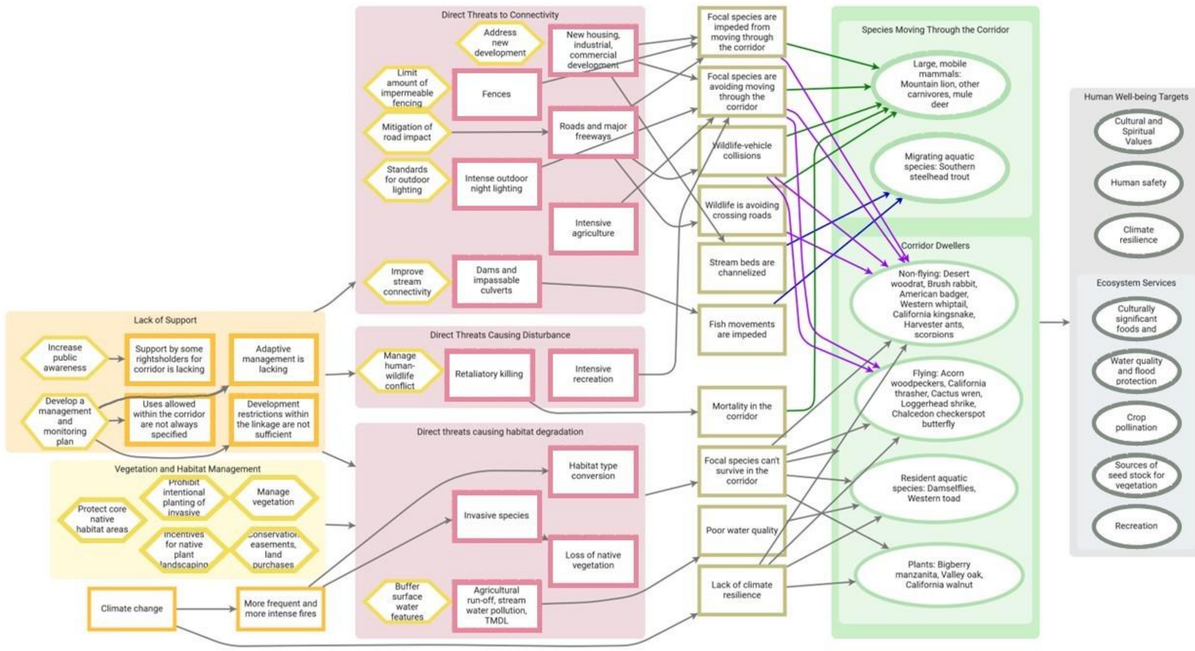

Figure 3. Situation model of the Santa Monica-Sierra Madre Linkage in southern California.

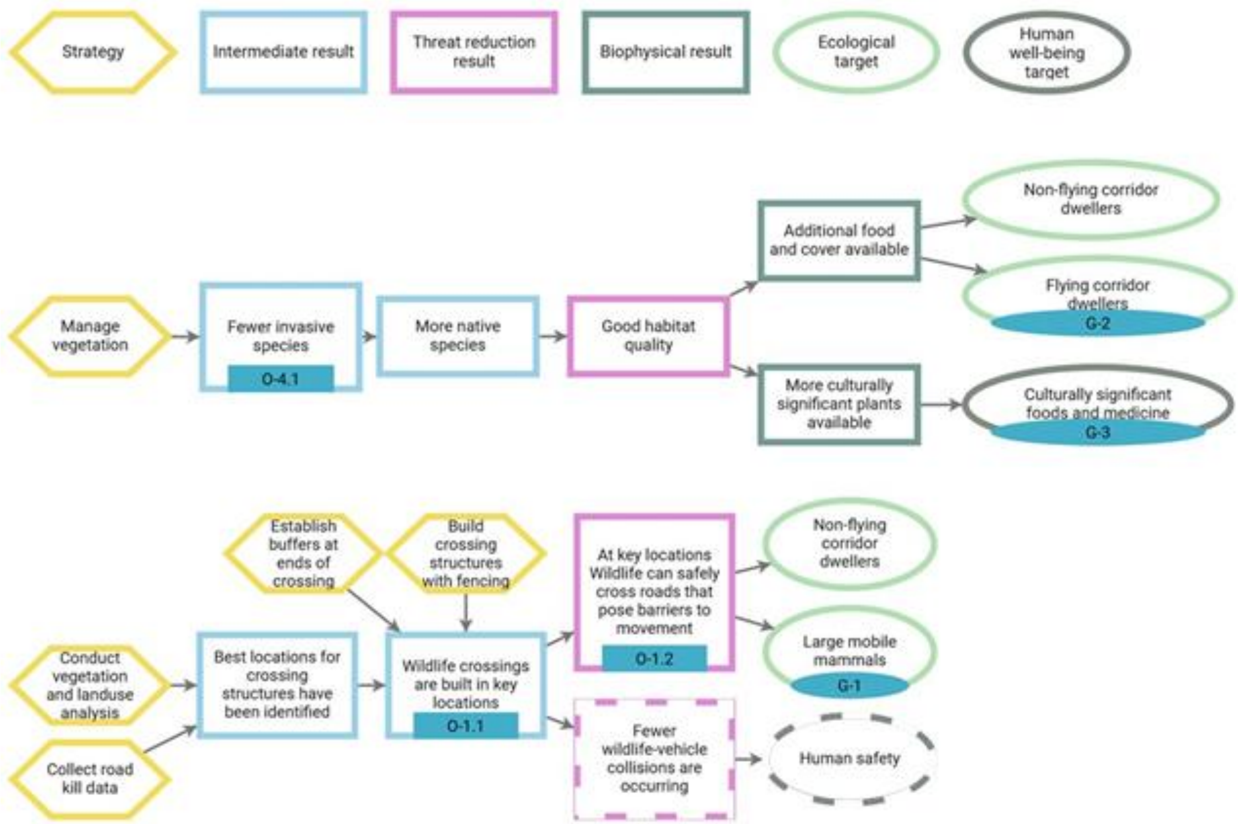

Figure 4. Two example results chains for the Santa Monica-Sierra Madre Linkage in southern California. The solid boxes and ovals refer to the SMART goals and objectives associated with the intermediate and threat reduction results and the targets (see Table 2). Dashed box lines indicate factors that are not 100% relevant to this linkage.

Table 2. Example excerpt of a monitoring table for the Santa Monica-Sierra Madre Linkage in southern California.

SMART Goals and Objectives	Indicators (one indicator per species is recommended)	Methods (build on ongoing monitoring activities)	Who	Timeframe	Threshold that triggers action or adaptive management
Goal 1. By 2030, geneflow between focal species populations in the Santa Monica Mountains and the Sierra Madre Mountains has increased.	Genetic distinctiveness of focal species populations in the Santa Monica Mountains compared to the Sierra Madre Mountains, based on population assignment tests and pop gen measures such as F_{ST}	Collect genetic samples, conduct genetic analyses	CDFW, UC, NPS, USGS	Baseline in 2024, then 2027 and 2030	If genetic distinctiveness was determined in baseline study: genetic distinctiveness increased or failed to decrease.
Objective 1.1: By 2030, relevant focal species are documented to use wildlife crossings.	# of relevant focal species documented to use wildlife crossing structures	GPS Collars, Camera traps, pitfall traps	NPS, Caltrans, CDFW, USGS	Annual status update	2027: 1 or more relevant focal species are not documented to use wildlife crossing structures despite occurring in the vicinity of the structures

Objective 1.2: By 2030, 7 of the 9 recommended crossing structures have been built.	# of recommended crossing structures built	Communication with LIA	Caltrans, NPS, Wildlife Crossings Fund	Annual status update	2027: <7 structures have been built or are in planning phase 2030: <7 structures have been built
Goal 2. Abundance of focal species in the corridor is stable or increasing over time.	Indicator of abundance	Transect counts of butterflies, western whiptails, birds, harvester ant nests, desert woodrat nests; cover board surveys of snakes	NPS, CDFW, others	Baseline in 2024, then every 3 years	A decrease in abundance by 50% compared to the baseline
Goal 3. Culturally significant food and medicine plants grow in parts of the linkage for the tribe to use.	% of survey respondents responding positively to a question about the presence and abundance of culturally significant food and medicine plants in the linkage	Survey	Tribal council, a university, a non-profit	Baseline in 2024, then every 3 years	A lack of increase in the % of positive responses
Objective 2.1. By 2030, the percentage of non-native cover has decreased in the Simi Hills and has not	percentage of non-native cover	line-point intercept surveys	NPS's Mediterranean Coast Network Vegetation	annual	Simi Hills: Using a 3-year average, <3% decrease in the percentage of non-

increased in the rest of the linkage.		Inventory and Monitoring program, additional monitoring by NPS, others	native cover over baseline conditions Rest of the linkage: Using a 3-year average, 5% increase of the percentage of non-native cover over baseline conditions

Monitoring ecological corridors

Monitoring ecological corridors, which often occur in a complex social-ecological context across multiple jurisdictional boundaries, requires a holistic approach (Niemiec et al., 2021). This necessitates a nuanced understanding of enabling conditions that promote the conservation and management of the corridor, and progress towards ecological outcomes and human well-being targets. Enabling conditions include functioning governance structures and community buy-in which are key due to their role in shaping corridor planning and management and ensuring effective implementation. Monitoring ecological outcomes is essential to verify that conservation goals are being achieved. Finally, monitoring human well-being ensures that ecological corridors not only fulfill conservation objectives, but also deliver tangible benefits to local communities such as ecosystem services, human safety, and the opportunity to carry out cultural practices. Below we provide further details on how to consider enabling conditions, ecological outcomes, and human well-being when developing monitoring plans for ecological corridors.

4.1 Enabling conditions

Enabling conditions for effective connectivity conservation are numerous (Beazley et al., 2023). For example, financial resources that are secure, adequate, and flexible are required for adaptive management and governance and linking knowledge to action (Folke et al., 2005; Reid et al., 2016; Wyborn, 2015). Similarly, legislation and policies can also provide important enabling conditions for successful corridor implementation. Local land management agencies and political offices should be able to contribute context-specific knowledge on laws and policies relevant to corridor activities and alert implementers when any changes at the local, regional, and national level occur. While both funding and knowledge of corridor-relevant laws and policies are essential for successful corridor implementation, here we focus on monitoring two enabling conditions that can be influenced, namely effective and equitable governance, and community buy-in.

4.1.1 Effective and equitable Governance

Corridor governance involves the decision-making process for identifying, planning, and managing for connectivity (Lausche et al., 2013; Hilty et al., 2020). According to the International Union for the Conservation of Nature (IUCN) guidelines on ecological corridors (Hilty et al., 2020), corridor governance has three components: "how and by whom decisions are made, and who should be held accountable". The guidelines outline a range of governance types that may apply to ecological corridors, including (1) governance by Indigenous Peoples or local communities, (2) governance by government agencies, (3) governance by private individuals, organizations, or companies, or (4) shared governance where various actors work together -- a wide diversity of options which can be combined and tailored to a corridor's specific context.

Several resources have been developed for monitoring governance of PAs and OECMs, including several by IUCN: WCPA Guidelines on Governance of Protected Areas (Borrini-Feyerabend et al., 2013), the IUCN Natural Resource Governance Framework (Springer et al., 2021), and the IUCN Green List (IUCN and WCPA, 2017). Given the broad similarities in PA and corridor governance, the principles established in these seminal publications should support assessments of corridor governance (WWF and IUCN

WCPA, 2023). In particular, it is important to recognize that there is no ideal governance setting for all corridors, and that governance is not static but can be adaptively improved (Borrini-Feyerabend et al., 2013). Several participatory approaches and tools have been established and tested for measuring the effectiveness of PA governance. Notable examples include the Green List and the Site-level Assessment of Governance and Equity (SAGE) frameworks (Franks, 2023). The IUCN Green List offers three components for assessing governance of protected and conserved areas: 1) guarantee legitimacy and voice, 2) achieve transparency and accountability, 3) enable governance vitality and capacity to respond adaptively. The SAGE framework, which consists of a set of questionnaires and stakeholder workshops, deserves particular attention due to its inclusion as a complementary indicator for Target 3 of the Global Biodiversity Framework ("The 30x30 Target"). It is based on principles of good governance, such as respect for all actors' knowledge and values, transparency and accountability in decision-making, access to justice and dispute resolution, and equitable sharing of benefits.

4.1.2 Buy-in and participation of rightsholders and interested parties

Monitoring people's attitudes and beliefs about a particular corridor may be critical for adjusting planning, management, and governance strategies. In addition, social capital, supported by trust, reciprocity, and common rules, is essential for effective conservation (Pretty and Smith 2004). Sustained engagement of actors (i.e., partnerships between land managers, scientists, and local actors) is important for successful connectivity conservation (Gray et al., 2020) and enduring partnerships have been reported as the best predictor of successful implementation of connectivity plans (Keeley et al., 2019). Establishing a baseline and monitoring change in engagement of rightsholders and interested parties and other underlying social factors can inform measures of success and direct efforts for adaptive management. Key aspects to monitor include the sense of belonging to groups and social networks, trust and solidarity, collective action and cooperation, social cohesion and inclusion, free flow of information and communication, and economic empowerment (Musavengane and Simatele, 2016).

Traditional social science methodologies, including surveys and interviews, can help assess these variables.

4.2 Ecological outcomes

Monitoring the ecological function of corridors can focus on the ultimate desired ecological outcomes, such as functional connectivity for species or processes, or on proximate outcomes, such as the level of fragmentation, disturbance, or degradation. Ideally, programs would focus on monitoring the ultimate outcomes, however, these approaches are often labor and resource intensive, and some genetic outcomes may not be evident for generations. In the short term, it may only be feasible to monitor proximate conservation outcomes such as the level of fragmentation, disturbance, or degradation. General options for monitoring include the monitoring activities and species selected for functional connectivity monitoring, taking a remote-sensing or field-work approach to monitoring fragmentation, and approaches to monitoring relevant occurrences of disturbance or degradation.

4.2.1 Assessing functional connectivity

To assess whether corridors promote functional connectivity for focal species, monitoring activities can assess, for example, gene flow, species movement, re-colonization, and population health (Gregory and Beier, 2014; Van Der Ree et al., 2015). Monitoring activities will involve field data collection, such as genetic sampling (e.g., eDNA, scat, hair, tissue), camera trapping, occupancy surveys, or GPS telemetry (Dodd et al., 2007; Chakraborty et al., 2021; Kim et al., 2022; DeMatteo et al., 2023). While labor and resource-intensive, empirical data provide essential information on how species respond to landscape connectivity and the success of wildlife crossing structures built to remediate barriers to movement.

4.2.2 Focal species selection

Although corridors are intended to promote movement by all native species, it is impractical to monitor corridor effectiveness of every species in the landscape. When selecting a set of focal species, there are several species characteristics to consider. The set should include species that span the full spectrum of mobility and habitat specialization, and those that are highly sensitive to loss of connectivity (Beier et al., 2006; Belote et al., 2020). If the landscape includes linear infrastructure such as highways and railroads, focal species should also include those that have the greatest difficulty crossing these artificial features (Beier et al., 2008). Adding species to the list that exist in patchy distributions or small populations is important because these species may lose entire subpopulations if connectivity is lost. Focal species should include those that are culturally significant to indigenous communities and to other local people with ties to the natural landscape. These culturally significant species will often include charismatic large carnivores and ungulates, which have been prime drivers of funding and political support for corridor conservation (Penrod and Smith, 2023). Species crucial to ecosystem functions, such as pollinators of native or crop plants can also be selected as indicator species. In most landscapes there may be several barrier-sensitive species, species with limited mobility, habitat specialists, or another desired class of indicator species. In such cases, we suggest focusing on indicator species whose presence, gene flow, or other response variables can be monitored at relatively low cost, and species that may respond most rapidly to changes in connectivity (Tulloch et al., 2011). Finally, if the planning area is adjacent to the range of a species that is likely to shift into the planning area as the climate changes, we suggest considering some “climate refugees” as indicator species if they also meet the other selection criteria.

4.2.3 Monitoring fragmentation

Monitoring proximate outcomes of ecological corridors often focuses on structural connectivity, which refers to the permeability of habitat based on landscape characteristics (Hilty et al., 2019). In large corridors, changes in fragmentation can be monitored by assessing landscape composition and configuration over time. This can be achieved through satellite and aerial imagery, providing insights into land cover changes (Yadav et al., 2012). Various metrics have been developed to measure fragmentation such as the clumpy index, perimeter-area fractal dimension index, and the coefficient of variation of the proximity index (Wang et al., 2014). Other indicators reflecting permeability of a corridor are the area and proportion of natural land cover in the corridor, a human influence index, and linear infrastructure density (MNRT, 2022). Data layers derived from satellite images, such as land cover maps and the human modification index (Theobald et al., 2020) are currently updated much less frequently than satellite-based products, which limits their usefulness for monitoring over short time scales. New machine-learning based approaches for generating up-to-date high-resolution land cover maps (Brown et al., 2022) and estimating the human footprint using satellite imagery alone (e.g., Keys et al., 2021) are promising developments for rapid detection of landscape changes.

Field monitoring, though more expensive than monitoring through satellite images, offers more detailed information on structural connectivity, such as the quality and state of ecosystems. When actions are being taken to reduce the impacts of roads or other linear infrastructure, monitoring efforts should examine changes, for example, in wildlife-vehicle collisions or electrocutions at powerlines, or in animal movement or behavior, before and after measures have been taken. This approach is commonly referred to as a Before-After-Control-Impact (BACI) study design (see Rytwinski et al., 2015 for guidance on potential study designs). General guidance for monitoring wildlife crossing structures is also available (Clevenger and Huijser, 2011, chapter 5). Convening regular meetings with rightsholders and interested parties at which updates on activities in the corridor are shared can also be an effective monitoring strategy (KP, personal observation).

4.2.4 Monitoring disturbance

Examples of disturbance in ecological corridors are poaching, retaliatory killing of predatory and crop-raiding animals, and non-compatible recreation activities. Monitoring poaching and killing activities can be challenging, but engaging local communities in reporting suspicious activities has been successful in some cases (Bhatta et al., 2018). Approaches to monitoring the effects of recreational activities on the functionality of corridors may include camera trapping (Reilly et al., 2017; Naidoo and Burton 2020), acoustic monitoring (Gibb et al., 2018), measuring stress hormones in relation to recreational activities (Dantzer et al., 2014), and surveys or interviews with recreationists to understand their interactions with wildlife and their perceptions of the impact of recreational activities on wildlife (Levêque et al., 2015).

4.2.5 Monitoring habitat degradation

Anthropogenic disturbances, changing fire regimes, and extreme weather events can drive changes in the composition of the native vegetation in corridors, with non-native species invasions damaging ecosystem functioning (Stork et al., 2023). Monitoring habitat degradation and restoration may involve remote sensing, for example to analyze changes in vegetation indices like the Normalized Difference Vegetation Index (NDVI) as an indicator of vegetation density (Pettorelli, 2014), fire return interval departure (Safford et al., 2014), or changes in soil moisture as an indicator of land degradation (Vliet et al., 2021). Field surveys can give a more detailed picture of changes in plant biomass, species composition, richness, and ecosystem condition (e.g., Stork et al., 2023).

4.3 Human well-being

Monitoring the effectiveness of ecological corridors goes beyond assessing ecological outcomes and extends to the relationship between these corridors and human well-being, as successful corridor conservation requires a comprehensive understanding of the interactions between wildlife and human communities.

4.3.1 Human-wildlife interactions

Ecological corridors may require monitoring to effectively address human-wildlife conflicts (e.g., crop raiding, loss of livestock, human injuries) as part of the adaptive management cycle. IUCN's guidelines on human-wildlife conflict provide techniques and methodologies for understanding, monitoring, and reducing human-wildlife interactions (IUCN, 2023). Human-wildlife conflict indicators can be measured through interviews, surveys, and other monitoring schemes (Songhurst, 2017). For example, the number of depredation claims and payments made to a government can serve as an (imperfect) indicator of the frequency of human-wildlife incidents in a corridor.

Additionally, understanding the dynamics of human attitudes towards wildlife, which may be influenced by factors such as religion, ethnicity, and culture, but also by environmental education, can be helpful for effective conflict resolution (Dickman, 2010) and for understanding positive human-wildlife interactions, but requires time-consuming human-dimensions research. Monitoring change with thoughtfully designed indicators that consider underlying social factors can support the design of measures to improve human-wildlife coexistence and enhance education and awareness building activities (Letro and Fischer, 2020).

Wildlife-vehicle collisions (WVCs) are a unique type of human-wildlife interaction. To determine their impact on human well-being and monitor the effectiveness of road mitigation measures, approaches have been developed to monitor the number of WVCs as well as the effectiveness of mitigation measures in reducing human injuries and fatalities (Ament et al., 2023).

4.3.2 Ecosystem services

Ecological corridors may sustain provisioning services (e.g., drinking water), regulating services (e.g., carbon sequestration and pollination), supporting services (e.g., nutrient cycling), and cultural services (e.g., recreation; Millennium Ecosystem Assessment, 2005, Hilty et al., 2020). Indicators linking conservation action to tangible benefits for specific communities can document and convey how corridor conservation can translate into benefits for local communities (Olander et al., 2018). Provisioning ecosystem service indicators may include: crop production, fish or animal meat protein consumption, value of forest products, and water storage capacity (Layke et al., 2012). While cultural services may be more context-specific and qualitative in nature, indicators may include: value of real estate near nature or clear water, number of ecotourism visitors, and accessibility of culturally important resources. The integration of remote sensing indicators, like the Ecosystem Services Provision Index, can offer a valuable tool for monitoring ecological services in situations where specific indicators are lacking or have limited spatial and temporal coverage (Jullian et al., 2021).

4.3.3 Cultural, spiritual, biocultural values

To capture changes in a community's connection to an ecological corridor, monitoring biocultural perceptions can be enlightening (Goolmeer et al., 2022). Using biocultural indicators, such as the number of Indigenous groups engaged in sustainable stewardship, acknowledges and respects the intricate relationship between cultural values, ecological states, and Indigenous well-being (Sterling et al., 2017, Goolmeer et al., 2022). Applying such biocultural indicators in collaboration with Indigenous communities ensures a culturally sensitive, comprehensive, and robust monitoring strategy for human well-being targets of ecological corridors.

Discussion

The importance of connectivity conservation as a tool to respond to habitat degradation, fragmentation, and climate change is now being recognized at local and international levels. Monitoring is fundamental to assess and help improve the success of ecological corridors. Here we applied the CS framework to a case study which results in an example monitoring plan and laid out options for monitoring enabling conditions, ecological outcomes, and human well-being. There are four other important considerations for implementing comprehensive monitoring plans for ecological corridors: collaboration, scaling up to a regional monitoring program, data management, and funding mechanisms.

5.1 Monitoring should be a collaborative process

The best way to effectively address complex, large-scale, long-term conservation challenges such as conserving connectivity is to engage all rightsholders and interested parties (Indigenous and local communities, managers, policy makers, scientists, residents, and landowners) in co-producing actionable science and learning from the shared experience (Beier et al., 2017; Gray et al., 2020). Involving decision makers directly in indicator selection, monitoring, and analyses through a collaborative process encourages input from multiple knowledge systems (Cundill and Fabricius, 2009).

Engaging communities in collaborative monitoring of ecological corridors has the potential to cultivate a shared understanding of the ecology of a corridor, as well as the benefits of conserving connectivity for wildlife populations and human well-being. It can instill internal trust and external credibility, aid in conflict resolution, and promote social learning and community development (Fernández-Giménez et al., 2008). Sharing monitoring results can be dramatically effective in motivating all partners to sustain the effort of keeping corridors permeable.

Creating a team environment among all corridor actors is vital for maintaining enthusiasm, participation, and funding over the long term. Meeting as rarely as 1-3 times per year counteracts gloom by making participants aware of allies in other agencies and organizations and creates an environment that promotes innovation, collaboration and co-creation of strategies.

5.2 Consistency in monitoring can allow scaling up

For any corridor monitoring system to be effective, it must be scaled to measure ecological dynamics and responses across spatiotemporal scales of potential impact (Watson et al., 2017). Different species require different scales of connectivity. For example, native bees may require flowering plants to be spatiotemporally clustered within a few meters of both other flowering plants and bee nesting sites (Geslin et al., 2014; Lichtenberg et al., 2020), whereas other species such as brown bears (*Ursus arctos*) may utilize resources over more than 1000 km^2 (Cirovic et al., 2015). To scale monitoring beyond a single corridor it is advantageous to combine multiple corridors in a region into one monitoring plan. This will require (1) developing a shared vision of an ecological network for conservation that consists of PAs, OECMs, and ecological corridors, (2) agreeing on common indicators across multiple corridors in a region to allow the aggregation of results, (3) aligning monitoring protocols and data management to facilitate data sharing, (4) presenting results in a common format, and (5) using data from all monitoring efforts to evaluate change at the scale of the ecological network and make adaptive management decisions (Stephenson, 2019).

5.3 A data management plan is important

Effective data management is essential for monitoring ecological corridors, facilitating informed decision-making, and enacting adaptive management. Key to this process is the establishment of comprehensive data collection protocols, which incorporate rigorous quality assurance practices and integrate local and indigenous knowledge for a more holistic understanding (Buxton et al., 2021). Pre-collection planning should include developing quality assurance and quality control routines (Sutter et al., 2015). The adoption of electronic data capture methods is increasingly recognized for its efficiency in improving data entry and workflow, thereby aiding land managers in making evidence-based decisions (Kachergis et al., 2022). Ensuring the integrity and accessibility of data involves selecting appropriate custodians, such as universities, NGOs, or government agencies, and advocating for the data to be permanently archived and made open-access, complete with comprehensive metadata (Costello and Wieczorek, 2014). The roles and responsibilities of individuals involved in data management, including data collectors, analysts, and those responsible for data archiving and sharing, should be clearly defined. Security and privacy of the data, especially sensitive information, are paramount, as is the need for collaboration through clear data sharing mechanisms and policies, especially across transboundary corridors (Sandbrook et al., 2021; Buxton et al., 2021). To ensure that data will be used to inform adaptive management, data management plans should include a discussion of how and how frequently data will be analyzed and interpreted, including statistical methods, modeling approaches, or software tools that will be used. By developing, supporting, and following a data management plan, resulting data will be high-quality, reliable, and accessible.

5.4 Funding mechanisms to pay for monitoring

Dedicated funding and resources are vital for all aspects of data management in corridors, from collection to dissemination. Lack of funding for monitoring, especially long-term monitoring that goes beyond the funding cycle of specific projects, is one of the greatest challenges to implementing monitoring programs (Burns et al., 2014, Lindenmayer et al., 2022a), which also applies to monitoring of ecological corridors. However, there are opportunities, strategies, and mechanisms to consider when looking to fund a comprehensive long-term corridor monitoring program.

Funding may come from proponents, government programs, the non-profit sector, private foundations, or own-source revenues. While it is desirable that the entire monitoring cycle is funded, consecutive funding is also an option (Danielsen et al., 2009). Funders of corridor implementation should also fund monitoring because it provides them with information they need for regulatory processes and future project approvals. In some cases, agencies may be responsible for conducting or funding long-term connectivity monitoring, such as for threatened or endangered species (Lindenmayer et al., 2020). There are many diverse strategies for obtaining funding or increasing the chances of obtaining funding for corridor monitoring programs (Burns et al., 2014; Lindenmayer et al., 2011, 2022; Lindenmayer, 2020):

- Determine whether other monitoring programs are underway within the region where the ecological corridor is located that may contribute to a monitoring program and help leverage limited financial resources.
- Design a monitoring program that is sustainable and affordable from the beginning.
- Write monitoring costs (especially writing a monitoring plan and collecting data to establish knowledge of baseline conditions) into project grant proposals.
- If necessary, pool money from multiple sources.
- Create a community science program focused on monitoring the ecological corridor. Funding for monitoring may be more readily available if a main objective is public engagement.
- Collaborate with non-profit groups focusing on environmental education.
- Collaborate with high schools or colleges where leading or participating in monitoring activities could be a yearly activity for relevant courses.
- Report the ecological corridor to the World Database on Ecological Corridors administered by the World Conservation Monitoring Center (once it is up and running). Funding for monitoring programs may be more available if monitoring data are recognized as crucial to globally relevant initiatives.

- Demonstrate (e.g., with relevant references) to potential funders that long-term monitoring programs are cost-effective and deliver good returns on investment.
- Be aware that independent funding sources, such as endowment funding, may be ideal.

References

Ament, R., Clevenger, A., & van der Ree, R. (Eds.) (2023). Addressing ecological connectivity in the development of roads, railways and canals. IUCN WCPA Technical Report Series No. 5. Gland, Switzerland: IUCN.

Beazley, K. F., Hum, J. D., & Lemieux, C. J. (2023). Enabling a National Program for Ecological Corridors in Canada in support of biodiversity conservation, climate change adaptation, and Indigenous leadership. Biological Conservation, 286, 110286.

Beier, P. (2019). A rule of thumb for widths of conservation corridors. Conservation Biology, 33(4), 976-978.

Beier, P., Hansen, L. J., Helbrecht, L., & Behar, D. (2017). A how-to guide for coproduction of actionable science. Conservation Letters, 10(3), 288-296.

Beier, P., Majka, D. R., & Spencer, W. D. (2008). Forks in the road: choices in procedures for designing wildland linkages. Conservation Biology, 22(4), 836-851.

Beier, P., Penrod, K., Luke, C., Spencer, W., & Cabanero, C. (2006). South Coast Missing Linkages: restoring connectivity to wildlands in the largest metropolitan area in the United States. Connectivity Conservation, 555-586.

Belote, R. T., Beier, P., Creech, T., Wurtzebach, Z., & Tabor, G. (2020). A framework for developing connectivity targets and indicators to guide global conservation efforts. BioScience, 70(2), 122-125.

Bhatta, K. P., Bhattarai, S., & Aryal, A. (2018). Community based anti-poaching operation: Effective model for wildlife conservation in Nepal. Poult. Fish. Wildl. Sci, 6(2).

Borrini-Feyerabend, G., N. Dudley, T. Jaeger, B. Lassen, N. Pathak Broome, A. Phillips and T. Sandwith (2013). Governance of Protected Areas: From understanding to action. Best Practice Protected Area Guidelines Series No. 20, Gland, Switzerland: IUCN. xvi + 124pp.

Brown, C. F., Brumby, S. P., Guzder-Williams, B., Birch, T., Hyde, S. B., Mazzariello, J., ... & Tait, A. M. (2022). Dynamic World, Near real-time global 10 m land use land cover mapping. Scientific Data, 9(1), 251.

Burns E, Lindenmayer D, Tennant P, Dickman C, Green P, Hanigan I, Hoffmann A, Keith D, Metcalfe D, Nolan K, Russell-Smith J, Wardle G, Welsh A, Williams R, Yates C (2014). Making ecological monitoring successful: Insights and lessons from the Long Term Ecological Research Network, LTERN, Australia.

Buxton, R. T., Bennett, J. R., Reid, A. J., Shulman, C., Cooke, S. J., Francis, C. M., Nyboer, E. A., Pritchard, G., Binley, A. D., Avery-Gomm, S., Ban, N. C., Beazley, K. F., Bennett, E., Blight, L. K., Bortolotti, L. E.,

Chakraborty, P., Borah, J., Bora, P. J., Dey, S., Sharma, T., Lalthanpuia, & Rongphar, S. (2021). Camera trap based monitoring of a key wildlife corridor reveals opportunities and challenges for large mammal conservation in Assam, India. Tropical Ecology, 62(2), 186-196.

Cirovic, D., M. de. Gabriel Hernando, M. Paunovic, A.A. Karamanlidis. 2015. Home range, movements, and activity patterns of brown bear in Serbia. Ursus 26,2:79-85. doi: 10.2192/URSU S-D-15-00010

Clevenger, A. P., & Huijser, M. P. (2011). Wildlife crossing structure handbook: design and evaluation in North America (No. FHWA-CFL-TD-11-003). United States. Federal Highway Administration. Central Federal Lands Highway Division.

CMP (Conservation Measures Partnership). (2020). Open Standards for the Practice of Conservation. Version 4.0. Available online: https://conservationstandards.org/wp-content/uploads/sites/3/2020/10/CMP-Open-Standards-for-the-Practice-of-Conservation-v4.0.pdf (accessed on 19 April 2024).

CMS (Convention on Migratory Species). (2024). Ecological Connectivity, Resolution 14.16 . Samarkand, Uzbekistan.

Costello, M. J., & Wieczorek, J. (2014). Best practice for biodiversity data management and publication. Biological Conservation, 173, 68–73. https://doi.org/10.1016/j.biocon.2013.10.018

Cundill, G., & Fabricius, C. (2009). Monitoring in adaptive co-management: toward a learning based approach. Journal of Environmental management, 90(11), 3205-3211.

Danielsen, F., Burgess, N. D., Balmford, A., Donald, P. F., Funder, M., Jones, J. P., ... & Yonten, D. (2009). Local participation in natural resource monitoring: a characterization of approaches. Conservation biology, 23(1), 31-42.

Dantzer, B., Fletcher, Q., Boonstra, R., & Sheriff, M. (2014). Measures of physiological stress: a transparent or opaque window into the status, management and conservation of species?. Conservation Physiology, 2. https://doi.org/10.1093/conphys/cou023.

DeMatteo, K. E., Escalante, O. M., Ibañez Alegre, D. M., Rinas, M. A., Sotorres, D., & Argüelles, C. F. (2023). A multispecies corridor in a fragmented landscape: Evaluating effectiveness and identifying high-priority target areas. Plos one, 18(4), e0283258.

Dickman, A. J. (2010). Complexities of conflict: the importance of considering social factors for effectively resolving human–wildlife conflict. Animal conservation, 13(5), 458-466.

Dodd, N. L., Gagnon, J. W., Boe, S., & Schweinsburg, R. E. (2007). Assessment of elk highway permeability by using global positioning system telemetry. The Journal of Wildlife Management, 71(4), 1107-1117.

Ernest, H. B., Vickers, T. W., Morrison, S. A., Buchalski, M. R., & Boyce, W. M. (2014). Fractured genetic connectivity threatens a southern California puma (Puma concolor) population. PloS one, 9(10), e107985.

Ewers, R. M., & Didham, R. K. (2006). Confounding factors in the detection of species responses to habitat fragmentation. Biological reviews, 81(1), 117-142.

Fernandez-Gimenez, M. E., Ballard, H. L., & Sturtevant, V. E. (2008). Adaptive management and social learning in collaborative and community-based monitoring: a study of five community-based forestry organizations in the western USA. Ecology and Society, 13(2).

Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. Annu. Rev. Environ. Resour., 30, 441-473.

Franks, P. (2023). *Site-level Assessment of Governance and Equity (SAGE) for protected and conserved areas: manual for SAGE facilitators.* IIED, London https://www.iied.org/21461iied

Geslin, B., M. Baude, F. Mallard. I. Dajoz. 2014. Effect of local spatial plant distribution and conspecific density on bumble bee foraging behavior. Ecological Entomology 39, 3:334-342. doi.org/10.1111/een.12106

Ghoddousi, A., Buchholtz, E. K., Dietsch, A. M., Williamson, M. A., Sharma, S., Balkenhol, N., ... & Dutta, T. (2021). Anthropogenic resistance: accounting for human behavior in wildlife connectivity planning. One Earth, 4(1), 39-48.

Gibb, R., Browning, E., Glover-Kapfer, P., & Jones, K. (2018). Emerging opportunities and challenges for passive acoustics in ecological assessment and monitoring. Methods in Ecology and Evolution, 10, 169 - 185. https://doi.org/10.1111/2041-210X.13101.

Goldman, M. (2009). Constructing connectivity: Conservation corridors and conservation politics in East African rangelands. Annals of the Association of American Geographers, 99(2), 335-359.

Goolmeer, T., Skroblin, A., Grant, C., van Leeuwen, S., Archer, R., Gore-Birch, C., & Wintle, B. A. (2022). Recognizing culturally significant species and Indigenous-led management is key to meeting international biodiversity obligations. Conservation Letters, 15(6), e12899.

Gray, M., Micheli, E., Comendant, T., & Merenlender, A. (2020). Climate-wise habitat connectivity takes sustained stakeholder engagement. Land, 9(11), 413.

Gregory, A., Spence, E., Beier, P., & Garding, E. (2021). Toward best management practices for ecological corridors. *Land*, 10(2), 140.

Gregory, A. J., & Beier, P. (2014). Response variables for evaluation of the effectiveness of conservation corridors. *Conservation Biology*, 28(3), 689-695.

Hardy, A., Clevenger, A. P., Huijser, M., & Neale, G. (2003). An overview of methods and approaches for evaluating the effectiveness of wildlife crossing structures: emphasizing the science in applied science. Making Connections.

Herrera, B., Chassot, O., Monge, G., & Canet, L. (2016). Technical guidelines for the design and management of participatory connectivity conservation and restoration projects at the landscape scale in Latin America. *Serie Técnica. Boletín Técnico,*. Section 4.2

Hilty, J. A., Keeley, A. T., Merenlender, A. M., & Lidicker Jr, W. Z. (2019). Corridor ecology: linking landscapes for biodiversity conservation and climate adaptation. Island Press.

Hilty, J., Worboys, G.L., Keeley, A., Woodley, S., Lausche, B., Locke, H., Carr, M., Pulsford I., Pittock, J., White, J.W., Theobald, D.M., Levine, J., Reuling, M., Watson, J.E.M., Ament, R., and Tabor, G.M. (2020). Guidelines for conserving connectivity through ecological networks and corridors. Best Practice Protected Area Guidelines Series No. 30. Gland, Switzerland: IUCN.

Holling, C. S. (ed.) 1978 Adaptive environmental assessment and management. International Series on Applied Systems Analysis. Toronto, Canada: John Wiley and Sons.

WCPA (IUCN World Commission on Protected Areas) (2019). Guidelines for Recognising and Reporting Other Effective Area-based Conservation Measures. Gland, Switzerland: IUCN.

IUCN (2023). IUCN SSC guidelines on human-wildlife conflict and coexistence. First edition. Gland, Switzerland: IUCN

IUCN and WCPA (World Commission on Protected Areas) (2017). IUCN Green List of Protected and Conserved Areas: Standard, Version 1.1. Gland, Switzerland: IUCN.

Jantz, P., Goetz, S., & Laporte, N. (2014). Carbon stock corridors to mitigate climate change and promote biodiversity in the tropics. Nature Climate Change, 4(2), 138-142.

Jullian, C., Nahuelhual, L., & Laterra, P. (2021). The Ecosystem Service Provision Index as a generic indicator of ecosystem service supply for monitoring conservation targets. Ecological Indicators, 129, 107855.

Kachergis, E., Miller, S. W., McCord, S. E., Dickard, M., Savage, S., Reynolds, L. V., Lepak, N., Dietrich, C., Green, A., Nafus, A., Prentice, K., & Davidson, Z. (2022). Adaptive monitoring for multiscale land management: Lessons learned from the Assessment, Inventory, and Monitoring (AIM) principles. Rangelands, 44(1), 50–63. https://doi.org/10.1016/j.rala.2021.08.006

Keeley, A. T., Basson, G., Cameron, D. R., Heller, N. E., Huber, P. R., Schloss, C. A., Thorne, J. H., & Merenlender, A. M. (2018). Making habitat connectivity a reality. Conservation Biology, 32(6), 1221-1232.

Keeley, A. T., Beier, P., Creech, T., Jones, K., Jongman, R. H., Stonecipher, G., & Tabor, G. M. (2019). Thirty years of connectivity conservation planning: An assessment of factors influencing plan implementation. Environmental Research Letters, 14(10), 103001.

Keys, P. W., Barnes, E. A., & Carter, N. H. (2021). A machine-learning approach to human footprint index estimation with applications to sustainable development. Environmental Research Letters, 16(4), 044061.

Kim, W. M., Lee, H. J., & Song, W. (2022). Environmental DNA metabarcoding effectively monitors terrestrial species by using urban green spaces. Urban Forestry & Urban Greening, 78, 127782.

Kremen, C., & Merenlender, A. M. (2018). Landscapes that work for biodiversity and people. Science, 362(6412), eaau6020.

Lausche, B., Farrier, D., Verschuuren, J. M., La Viña, A. G., Trouwborst, A., Born, C. H., & Aug, L. (2013). The legal aspects of connectivity conservation: A concept paper volume 1. IUCN.

Layke, C., Mapendembe, A., Brown, C., Walpole, M., & Winn, J. (2012). Indicators from the global and sub-global Millennium Ecosystem Assessments: An analysis and next steps. Ecological Indicators, 17, 77-87.

Letro, L., & Fischer, K. (2020). Livestock depredation by tigers and people's perception towards conservation in a biological corridor of Bhutan and its conservation implications. Wildlife Research, 47(4), 309-316.

Levêque, J., Marzano, M., Broome, A., Connolly, T., & Dandy, N. (2015). Forest visitor perceptions of recreational impacts on amphibian wildlife. European Journal of Wildlife Research, 61, 505-515. https://doi.org/10.1007/s10344-015-0920-x.

Lichtenberg, E., J.M. Heiling, J.L. Bronstein, J.L. Barker. 2020. Noisy communities and signal detection: why do foragers visit rewardless flowers. Philosophical Transactions of the Royal Society of London B. Biological Science. 375: doi: 10.1098/rstb.2019.0486

Lindenmayer, D. (2020). Improving restoration programs through greater connection with ecological theory and better monitoring. Frontiers in Ecology and Evolution, 8, 50.

Lindenmayer, D. B., & Likens, G. E. (2010). The science and application of ecological monitoring. Biological Conservation, 143(6), 1317–1328. https://doi.org/10.1016/j.biocon.2010.02.013

Lindenmayer, D. B., Lavery, T., & Scheele, B. C. (2022a). Why we need to invest in large-scale, long-term monitoring programs in landscape ecology and conservation biology. Current Landscape Ecology Reports, 7(4), 137-146.

Lindenmayer, D. B., Likens, G. E., Haywood, A., & Miezis, L. (2011). Adaptive monitoring in the real world: proof of concept. Trends in Ecology & Evolution, 26(12), 641-646.

Lindenmayer, D. B., Woinarski, J., Legge, S., Maron, M., Garnett, S. T., Lavery, T., ... & Wintle, B. A. (2022b). Eight things you should never do in a monitoring program: an Australian perspective. Environmental Monitoring and Assessment, 194(10), 701.

Mangun, W. R. (1992). Fish and wildlife policy issues. American fish and wildlife policy: The human dimension, 3-32.

Millennium ecosystem assessment, M. E. A. (2005). Ecosystems and human well-being (Vol. 5, p. 563). Washington, DC: Island press.

MNRT (Ministry of Natural Resources and Tourism) 2022. Tanzania Wildlife Corridor Assessment, Prioritization, and Action Plan. Editors: Penrod, K., H. Kija, V. Kakengi, D.M. Evans, E. Pius, J. Olila and J. Keyyu. Unpublished report. Ministry of Natural Resources and Tourism (MNRT), Dodoma. 155 pp. + Appendices

Musavengane, R. and Simatele, D.M., 2016. Community-based natural resource management: The role of social capital in collaborative environmental management of tribal resources in KwaZulu-Natal, South Africa. Development Southern Africa, 33(6), pp.806-821.

Naidoo, R., & Burton, A. (2020). Relative effects of recreational activities on a temperate terrestrial wildlife assemblage. Conservation Science and Practice, 2. https://doi.org/10.1111/csp2.271.

Niemiec, R. M., Gruby, R., Quartuch, M., Cavaliere, C. T., Teel, T. L., Crooks, K., ... & Manfredo, M. (2021). Integrating social science into conservation planning. Biological Conservation, 262, 109298.

Obeng, E. A., Oduro, K. A., Obiri, B. D., Abukari, H., Guuroh, R. T., Djagbletey, G. D., ... & Appiah, M. (2019). Impact of illegal mining activities on forest ecosystem services: local communities' attitudes and willingness to participate in restoration activities in Ghana. Heliyon, 5(10).

Olander, L. P., Johnston, R. J., Tallis, H., Kagan, J., Maguire, L. A., Polasky, S., ... & Palmer, M. (2018). Benefit relevant indicators: Ecosystem services measures that link ecological and social outcomes. Ecological Indicators, 85, 1262-1272.

Penrod, K., Cabañero, C. R., Beier, P., Luke, C., Spencer, W., Rubin, E., Sauvajot, R., Riley, S. & Kamradt, D. (2006). South Coast Missing Linkages Project. A linkage design for the Santa Monica–Sierra Madre Connection. Produced by South Coast Wildlands, Idyllwild, CA. www.scwildlands.org , in cooperation with National Park Service, Sant Monica Mountains Conservancy, California State Parks, and The Nature Conservancy.

Penrod, K.L and T. Smith. 2023. At-Risk Habitat and Critical Linkages for Mountain Lions in Southern California. Prepared by Science and Collaboration for Connected Wildlands and Center for Large Landscape Conservation with assistance from The Nature Conservancy. 162pp.

Pettorelli, N. (2013). The normalized difference vegetation index. Oxford University Press, USA.

Pretty, J. and Smith, D., 2004. Social capital in biodiversity conservation and management. Conservation Biology, 18(3), pp.631-638.

Reid, R. S., Nkedianye, D., Said, M. Y., Kaelo, D., Neselle, M., Makui, O., ... & Clark, W. C. (2016). Evolution of models to support community and policy action with science: Balancing pastoral livelihoods and wildlife conservation in savannas of East Africa. Proceedings of the National Academy of Sciences, 113(17), 4579-4584.

Reilly, M. L., Tobler, M. W., Sonderegger, D. L., & Beier, P. (2017). Spatial and temporal response of wildlife to recreational activities in the San Francisco Bay ecoregion. Biological conservation, 207, 117-126.

Riley, S. P., Serieys, L. E., Pollinger, J. P., Sikich, J. A., Dalbeck, L., Wayne, R. K., & Ernest, H. B. (2014). Individual behaviors dominate the dynamics of an urban mountain lion population isolated by roads. Current Biology, 24(17), 1989-1994.

Rytwinski, T., Van Der Ree, R., Cunnington, G. M., Fahrig, L., Findlay, C. S., Houlahan, J., ... & van der Grift, E. A. (2015). Experimental study designs to improve the evaluation of road mitigation measures for wildlife. Journal of Environmental Management, 154, 48-64.

Safford, Hugh D.; Van de Water, Kip M. 2014. Using Fire Return Interval Departure (FRID) Analysis to Map Spatial and Temporal Changes in Fire Frequency on National Forest Lands in California. Res. Pap. PSW-RP-266. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 59 p.

Salafsky, N., Margoluis, R., Redford, K. H., & Robinson, J. G. (2002). Improving the practice of conservation: a conceptual framework and research agenda for conservation science. Conservation biology, 16(6), 1469-1479.

Sandbrook, C., Clark, D., Toivonen, T., Simlai, T., O'Donnell, S., Cobbe, J., & Adams, W. (2021). Principles for the socially responsible use of conservation monitoring technology and data. Conservation Science and Practice, 3(5), e374. https://doi.org/10.1111/csp2.374

SINAC (Sistema Nacional de Áreas de Conservación). 2018. Herramienta para medir la efectividad de gestión de Corredores Biológicos. Costa Rica. 90 pp.

Songhurst, A. (2017). Measuring human–wildlife conflicts: Comparing insights from different monitoring approaches. Wildlife Society Bulletin, 41(2), 351-361.

South Coast Wildlands. 2008. South Coast Missing Linkages: A Wildland Network for the South Coast Ecoregion. Produced in cooperation with partners in the South Coast Missing Linkages Initiative. Available online at http://www.scwildlands.org.

Springer, J., Campese, J. and Nakangu, B. (2021). The Natural Resource Governance Framework – Improving governance for equitable and effective conservation. Gland, Switzerland: IUCN.

Stephenson, P. J. (2019). The Holy Grail of biodiversity conservation management: monitoring impact in projects and project portfolios. Perspectives in Ecology and Conservation, 17(4), 182-192.

Sterling, E., Ticktin, T., Morgan, T. K. K., Cullman, G., Alvira, D., Andrade, P., ... & Wali, A. (2017). Culturally grounded indicators of resilience in social-ecological systems. Environment and Society, 8(1), 63-95.

Stork, N., Mainzer, A., & Martin, R. (2023). Native and non-native plant regrowth in the Santa Monica Mountains National Recreation Area after the 2018 Woolsey Fire. Ecosphere, 14(6), e4567.

Sutherland, C., Fuller, A. K., Royle, J. A., Hare, M. P., & Madden, S. (2018). Large-scale variation in density of an aquatic ecosystem indicator species. Scientific reports, 8(1), 8958.

Sutter, R. D., Wainscott, S. B., Boetsch, J. R., Palmer, C. J., & Rugg, D. J. (2015). Practical guidance for integrating data management into long-term ecological monitoring projects. Wildlife Society Bulletin, 39(3), 451–463. https://doi.org/10.1002/wsb.548

Theobald, D. M., Kennedy, C., Chen, B., Oakleaf, J., Baruch-Mordo, S., & Kiesecker, J. (2020). Earth transformed: detailed mapping of global human modification from 1990 to 2017. Earth System Science Data, 12(3), 1953-1972.

Tulloch, A., Possingham, H. P., & Wilson, K. (2011). Wise selection of an indicator for monitoring the success of management actions. Biological Conservation, 144(1), 141-154.

Van Der Ree, R., Smith, D. J., & Grilo, C. (2015). Handbook of road ecology. John Wiley & Sons.

Vliet, M., Jeu, R., Schellekens, J., & Schalie, R. (2021). A methodology to quantify and monitor the impact of environmental restoration using climate data records from satellite observations. . .

Walters, C. J. 1997. Challenges in adaptive management of riparian and coastal ecosystems. Conservation Ecology 1(2): 1. [online] URL: http://www.consecol.org/vol1/iss2/art1/

Wang, X., Blanchet, F. G., & Koper, N. (2014). Measuring habitat fragmentation: An evaluation of landscape pattern metrics. Methods in Ecology and Evolution, 5(7), 634-646.

Watson, D. M., Doerr, V. A., Banks, S. C., Driscoll, D. A., van der Ree, R., Doerr, E. D., & Sunnucks, P. (2017). Monitoring ecological consequences of efforts to restore landscape-scale connectivity. Biological Conservation, 206, 201-209.

WWF and IUCN WCPA. 2023. A Guide to Inclusive, Equitable and Effective Implementation of Target 3 of the Kunming-Montreal Global Biodiversity Framework: Version 1, August 2023

Wyborn, C. A. (2015). Connecting knowledge with action through co-productive capacities: adaptive governance and connectivity conservation. Ecology and Society, 20(1).