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Guidelines for conserving connectivity through ecological networks and corridors

Jodi Hilty, Graeme L. Worboys, Annika Keeley, Stephen Woodley, Barbara Lausche, Harvey Locke, Mark Carr, Ian Pulsford, James Pittock, J. Wilson White, David M. Theobald, Jessica Levine, Melly Reuling, James E.M. Watson, Rob Ament and Gary M. Tabor

Craig Groves, Series Editor

Developing capacity for a protected planet

Best Practice Protected Area Guidelines Series No. 30

WCPA World Commission on Protected Areas · Convention on Biological Diversity · Connectivity Conservation Specialist Group · Center for Large Landscape Conservation · Yellowstone to Yukon Conservation Initiative

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IUCN PROTECTED AREA DEFINITION, MANAGEMENT CATEGORIES AND GOVERNANCE TYPES

IUCN defines a protected area as:
A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

The definition is expanded by six management categories (one with a sub-division), summarized below.
Ia Strict nature reserve: Strictly protected for biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impacts are controlled and limited to ensure protection of the conservation values.
Ib Wilderness area: Usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, protected and managed to preserve their natural condition.
II National park: Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems, which also have environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.
III Natural monument or feature: Areas set aside to protect a specific natural monument, which can be a landform, sea mount, marine cavern, geological feature such as a cave, or a living feature such as an ancient grove.
IV Habitat/species management area: Areas to protect particular species or habitats, where management reflects this priority. Many will need regular, active interventions to meet the needs of particular species or habitats, but this is not a requirement of the category.
V Protected landscape or seascape: Where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.
VI Protected areas with sustainable use of natural resources: Areas which conserve ecosystems, together with associated cultural values and traditional natural resource management systems. Generally large, mainly in a natural condition, with a proportion under sustainable natural resource management and where low-level non-industrial natural resource use compatible with nature conservation is seen as one of the main aims.

The category should be based around the primary management objective(s), which should apply to at least three-quarters of the protected area – the 75 per cent rule.

The management categories are applied with a typology of governance types – a description of who holds authority and responsibility for the protected area. IUCN defines four governance types.
Type A. Governance by government: Federal or national ministry/agency in charge; sub-national ministry or agency in charge (e.g. at regional, provincial, municipal level); government-delegated management (e.g. to NGO).
Type B. Shared governance: Trans-boundary governance (formal and informal arrangements between two or more countries); collaborative governance (through various ways in which diverse actors and institutions work together); joint governance (pluralist board or other multi-party governing body).
Type C. Private governance: Conserved areas established and run by individual landowners; non-profit organisations (e.g. NGOs, universities) and for-profit organisations (e.g. corporate landowners).
Type D. Governance by Indigenous peoples and local communities: Indigenous peoples' conserved areas and territories - established and run by Indigenous peoples; community conserved areas – established and run by local communities.

For more information on the IUCN definition, categories and governance types see Dudley (2008). *Guidelines for applyingprotected area management categories*, which can be downloaded at: www.iucn.org/pa_categories

For more on governance types, see Borrini-Feyerabend, et al., (2013). *Governance of Protected Areas: From understanding to action*, which can be downloaded at https://portals.iucn.org/library/node/29138

Guidelines for conserving connectivity through ecological networks and corridors

International Union for Conservation of Nature (IUCN)

IUCN is a membership Union uniquely composed of both government and civil society organisations. It provides public, private and non-governmental organisations with the knowledge and tools that enable human progress, economic development and nature conservation to take place together.

Created in 1948, IUCN is now the world's largest and most diverse environmental network, harnessing the knowledge, resources and reach of more than 1,400 Member organisations and some 15,000 experts. It is a leading provider of conservation data, assessments and analysis. Its broad membership enables IUCN to fill the role of incubator and trusted repository of best practices, tools and international standards.

IUCN provides a neutral space in which diverse stakeholders including governments, NGOs, scientists, businesses, local communities, indigenous peoples organisations and others can work together to forge and implement solutions to environmental challenges and achieve sustainable development.

Working with many partners and supporters, IUCN implements a large and diverse portfolio of conservation projects worldwide. Combining the latest science with the traditional knowledge of local communities, these projects work to reverse habitat loss, restore ecosystems and improve people's well-being.

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IUCN World Commission on Protected Areas (WCPA)

IUCN's World Commission on Protected Areas (WCPA) is the world's premier network of protected area expertise. It is administered by IUCN Programme on Protected Areas and has more than 2,500 members, spanning 140 countries. WCPA is one of IUCN's six voluntary Commissions and its mission is to promote the establishment and effective management of a worldwide representative network of terrestrial and marine protected areas, as an integral contribution to the IUCN mission. WCPA works by helping governments and others plan protected areas and integrate them into all sectors, providing strategic advice to policy makers and practitioners to help strengthen capacity and investment in protected areas, and convening the diverse constituency of protected area stakeholders to address challenging issues. For more than 60 years, IUCN and WCPA have been at the forefront of global action on protected areas.

www.iucn.org/wcpa

Convention on Biological Diversity (CBD)

Opened for signature at the Earth Summit in Rio de Janeiro in 1992, and entered into force in December 1993, the Convention on Biological Diversity is an international treaty for the conservation of biodiversity, the sustainable use of the components of biodiversity and the equitable sharing of the benefits derived from the use of genetic resources. With 196 Parties so far, the Convention has near universal participation among countries.

www.cbd.int

WCPA Connectivity Conservation Specialist Group (CCSG)

CCSG was established in 2016 under the IUCN World Commission on Protected Areas (WCPA) to support information sharing, active participation, global awareness, and action to maintain, enhance, and restore ecological connectivity conservation around the world. Its objective is to advance the science, policy, and practice at international, national, and subnational levels to meet the growing demand for solutions that advance the identification, recognition, and implementation of consistent connectivity conservation measures.

www.iucn.org/wcpa-connectivity
www.conservationcorridor.org/ccsg

Yellowstone to Yukon Conservation Initiative (Y2Y)

Y2Y connects and protects habitat in North America spanning the Yellowstone to Yukon ecosystems so people and nature can thrive. It highlights and focuses on local issues that have implications for the region as a whole, and works to set the context for regional conservation work by providing the vision for a healthy Yellowstone to Yukon. Working across an area covering over 3,200 square kilometres, Y2Y engages partners across jurisdictions to knit together an interconnected system of wild lands and waters that harmonizes the needs of people and nature.

www.y2y.net

Center for Large Landscape Conservation (CLLC)

CLLC develops solutions, implements projects and contributes to global efforts that connect and protect crucial habitat across terrestrial, marine and freshwater ecosystems. It provides expertise through four key focus areas: science and research, mentorship and networking, community resilience and policy. By bringing knowledge and experience to bear on connectivity conservation issues worldwide, the Center works with communities, governments and other stakeholders to stop fragmentation and safeguard the legacy of protected and conserved areas by making them part of larger ecological networks for conservation.

www.largelandscapes.org

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Back cover photo: Connectivity is important for all species, but especially so for large-ranging carnivores such as the leopard (*Panthera pardus*). © Alison Woodley

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Foreword

Life on Earth thrives when ecosystems are healthy and ecologically connected. With the vast majority of the world experiencing increasing human impacts, natural ecosystems have been diminished and fragmented into smaller and smaller pieces. The destruction and fragmentation of natural ecosystems are a key cause of the global biodiversity crisis.

The need to both maintain and restore ecological connectivity is critical to the conservation of biological diversity, which provides irreplaceable functions and services, such as the provision of freshwater, food, climate regulation and pollination, just to name a few.

Ensuring that protected and other conserved areas are well-connected across landscapes and seascapes, as part of ecological networks, will both maintain biodiversity and provide an opportunity for species to adapt to climate change as local conditions change. Given the importance of healthy ecosystems to our own health and well-being, we need to urgently address and reverse the current trends of biodiversity loss and fragmentation.

The need for ecological connectivity is essential for the survival of wild species. Internationally, the Convention on the Conservation of Migratory Species of Wild Animals (CMS), a multilateral environment agreement under the United Nations, provides a global platform for States to take necessary collaborative actions to address the conservation and sustainable use of migratory animals and their habitats. At the national level, many countries have passed legislation to foster ecological connectivity, and this number is growing. The thirteenth meeting of the CMS Conference of the Parties (February 2020) affirmed that a commitment to maintaining and restoring ecological connectivity is one of the top priorities for CMS, and invited Parties to make use of these IUCN guidelines.

The World Business Council on Sustainable Development has come out with a call to action stating: “Creating landscapes with healthy, functioning ecosystems is not only key to making progress toward the environmental targets embedded in the Sustainable Development Goals, but also to addressing multiple social and economic targets that depend partly or wholly on the benefits that ecosystems provide to people.”

One of the key roles of the International Union for Conservation of Nature is to develop global guidance toward its vision of “a just world that values and conserves nature.” These guidelines, developed by the Connectivity Conservation Specialist Group of IUCN’s World Commission on Protected Areas, build on this tradition. They bring together the science of connectivity, and a range of case studies from terrestrial, freshwater and marine ecosystems, to provide practical solutions for meeting connectivity challenges. Moreover, they stress the need to connect protected areas and other effective area-based conservation measures into large-scale ecological networks, and are extremely timely, as we embark on a new decade in which better protecting our planet’s biodiversity must be a priority.

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Executive summary

Ecological connectivity is the unimpeded movement of species and the flow of natural processes that sustain life on Earth. This definition has been endorsed by the Convention on Migratory Species (CMS, 2020) and underlines the urgency of protecting connectivity and its various elements, including dispersal, seasonal migration, fluvial processes and the connectivity that is inherently present in large wild areas. Fragmentation caused by human activities continues to disrupt habitats, threatening biodiversity and impeding climate change adaptation. A large body of science and theory has been developing to address this problem in the context of protected areas.

The purpose of these Guidelines for Conserving Connectivity through Ecological Networks and Corridors is to consolidate this wealth of knowledge and best-available practices to support efforts to combat fragmentation. These Guidelines provide tools and examples (1) for applying ecological connectivity between protected areas and other effective area-based conservation measures, and (2) for developing ecological networks for conservation. In doing so, these Guidelines advance best practices for protecting ecological networks that maintain, enhance and restore connectivity across both intact and human-dominated systems. As demand grows for innovative solutions at international, national and subnational levels, these Guidelines recommend formal recognition of ecological corridors to develop conservation networks and thus ensure effective conservation of biological diversity.

Key messages

- Science overwhelmingly shows that interconnected protected areas and other areas for biological diversity conservation are much more effective than disconnected areas in human-dominated systems, especially in the face of climate change.
- Although it is well understood that ecological connectivity is critical to the conservation of biodiversity, approaches to identify, retain and enhance ecological connectivity have been scattered and inconsistent. At the same time, countries on every continent, along with regional and local governments, have advanced various forms of corridor legislation and policy to enhance connectivity.
- It is imperative that the world moves toward a coherent global approach for ecological connectivity conservation, and begins to measure and monitor the effectiveness of efforts to protect connectivity and thereby achieve functional ecological networks. To promote these goals, these Guidelines define ecological corridors as ways to identify, maintain, enhance and restore connectivity; summarise a large body of related science; and recommend means to formalise ecological corridors and networks.

Acronyms

ABNJ	Areas Beyond National Jurisdictions
CBD	Convention on Biological Diversity
CCSG	Connectivity Conservation Specialist Group of WCPA
CMS	Convention on Migratory Species of Wild Animals
COP	Conference of the Parties
EEZ	Exclusive Economic Zone
EU	European Union
IUCN	International Union for Conservation of Nature
OECM	Other Effective Area-based Conservation Measure
SSC	IUCN Species Survival Commission
UN	United Nations
UNEP	United Nations Environment Programme
WCPA	IUCN World Commission on Protected Areas

Migratory species such as the humpback whale (*Megaptera novaeangliae*) demonstrate the need for connectivity conservation. © Adobe Stock

Introduction: The need for connectivity

1

The annual wildebeest (*Connochaetes* spp.) migration between Tanzania and Kenya is one of the world's great wildlife movement spectacles. © Gary Tabor

The 21st century is a time of crisis in the human relationship with the rest of nature. The climate is changing in dangerous ways, and up to one million species are currently at risk of extinction (IPBES, 2019).

Our planet is not in a uniform condition. For example, about 17% of land has been heavily transformed by cities and agriculture; 56% is characterised by less intense modifications such as mixed rural, urban and suburban development where half or less has been transformed; and about 26% is large wild areas that are largely intact (Locke et al., 2019). Different conservation strategies are needed for these three conditions, but all share the need for ecological connectivity within and across them.

'Ecological connectivity' is the unimpeded movement of species and the flow of natural processes that sustain life on Earth (CMS, 2020). This is not an overstatement. Without connectivity, ecosystems cannot function properly, and without well-functioning ecosystems, biodiversity and other fundamentals of life are at risk. The disruption or absence of ecological connectivity occurs because of human-induced 'fragmentation', the breaking up of a habitat, ecosystem or land-use type into smaller and smaller parcels.

The fundamental problem is that much of the world has been degraded and fragmented already by human activity (Venter et al., 2016). Over 75% of terrestrial ecosystems (excluding Antarctica) have been directly modified by anthropogenic activities (Ellis et al., 2010), and 70% of the world's remaining wilderness is now restricted to just five countries (Watson et al., 2018). The human footprint also extends into the oceans, with 87% of marine biomes impacted by overfishing, nutrient run-off and climate change (Jones et al., 2018).

The goal of conservation must be to retain intact ecosystems, as they provide the best chance to conserve biodiversity in a fast-changing world (Scheffers et al., 2016). Protected areas therefore are the foundation of nature conservation, even in fragmented areas of land, sea or freshwater. However, while protected areas and other effective area-based conservation measures (OECMs) are essential, they are no longer considered sufficient in many places (IUCN WCPA, 2019). It is now understood that active measures must also be taken to maintain, enhance or restore ecological connectivity among and between protected areas and OECMs (Tabor, 2019). Science has clearly demonstrated that in order to achieve long-term biodiversity outcomes, retaining ecological connectivity is essential in a time of climate change (Foden & Young, 2016; Gross et al., 2016). This new understanding is driving a fundamental shift in conservation practice in which actions and goals must vary according to land, freshwater and seascape context. With increasing human alteration of Earth, especially by rapid climate change, it is necessary to think and act at the larger spatial scales at which many species and processes actually operate.

Just one third of the world's rivers remain free-flowing. Dams are the primary barrier to freshwater connectivity. Here, a dam is under construction on the emblematic river Bâsca Mare, Romania, found in the heart of the Carpathian ecoregion of Europe. © Leeway Collective / Balkan River Defence, Courtesy Calin Dejeu

Wildlife crossing signage in Kananaskis Country in Alberta, Canada © Aerin Jacob/Yellowstone to Yukon Conservation Initiative

These Guidelines have been drafted to help clarify and standardise a shift in conservation practice from a narrow focus on individual protected areas to considering them as essential parts of large landscape conservation networks. This is done through creating 'ecological networks for conservation' that are specifically designed, implemented and managed to ensure that ecological connectivity is maintained and enhanced where it is present, or restored where it has been lost (see Bennett, 2003; Bennett & Mulongoy, 2006). Unless systems of protected areas and OECMs retain all essential ecosystem processes, they are not sufficient. A key component of this is ecological connectivity across land, freshwater and marine regions and among and between sites.

Chapter 2 of these Guidelines gives a brief, accessible explanation of the scientific basis for ecological connectivity. With ecological modelling playing an increasing role in connectivity conservation, this chapter also gives an overview of some of the most important methods to identify and model connectivity.

Because conservation at broader scales relies on a common understanding of the concepts involved, Chapter 3 sorts out the terminology that is emerging (both within IUCN and in the wider literature) to describe the ongoing shift in practice. The focus is on two key terms: 'ecological networks for conservation' and 'ecological corridors'. A clear grasp of these terms, and their relationship to established concepts, is essential to creating a common language that promotes better cooperation, sharing of experiences and, ultimately, more effective conservation.

With this foundation in place, Chapter 4 focuses on the concept of 'ecological networks for conservation', explaining what they are and why they are more effective in delivering conservation outcomes than a disconnected collection of individual protected areas.

To address the need for common guidelines regarding connected protected areas, Chapter 5 proposes 'ecological corridors' as a formal conservation designation, thereby recognising them as indispensable parts of ecological networks for conservation of biological diversity. This chapter offers detailed guidelines for establishing, planning, managing, monitoring and evaluating ecological corridors.

Chapter 6 reviews the applications and benefits of ecological corridors in terrestrial, freshwater, marine and mixed environments, as well as emerging considerations of connectivity in Earth's airspaces. Because climate change is affecting all of these environments, a short discussion of climate considerations for ecological corridor management is provided.

Chapter 7 discusses how the scientific understanding of connectivity conservation is increasingly being reflected in global conservation law and policy.

After a brief conclusion (Chapter 8, including a Glossary and References), an Annex provides numerous examples from around the world of efforts to create ecological corridors as part of ecological networks for conservation.

Box 1
Definition of key terms

Connectivity

- **Ecological connectivity:** The unimpeded movement of species and the flow of natural processes that sustain life on Earth (CMS, 2020). There are various sub-definitions of ecological connectivity that are useful in the context of these Guidelines:
    - **Ecological connectivity for species (scientific-detailed definition):** The movement of populations, individuals, genes, gametes and propagules between populations, communities and ecosystems, as well as that of non-living material from one location to another.
    - **Functional connectivity for species:** A description of how well genes, gametes, propagules or individuals move through land, freshwater and seascape (Rudnick et al., 2012; Weeks, 2017; see Chapter 2, section on 'Modelling Ecological Corridors').
    - **Structural connectivity for species:** A measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances and other land, freshwater or seascape elements presumed to be important for organisms to move through their environment. Structural connectivity is used in efforts to restore or estimate functional connectivity where measures of it are lacking (Hilty et al., 2019; see Chapter 2, section on 'Modelling Ecological Corridors').
- **Ecological corridor:** A clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity. The following terms are often used similarly: 'linkages', 'safe passages', 'ecological connectivity areas', 'ecological connectivity zones', and 'permeability areas'.
- **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. (See Chapter 3, Table 2, for related terms.)
- **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).
- **Protected area:** A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008; Stolton et al., 2013).]

More than half of the world's wild tigers (*Panthera tigris*) are found in India, and they depend on defined corridors within highly fragmented landscapes to survive. Here, a young tiger traverses Tadoba National Park, Central India. © Grégoire Dubois

The scientific basis for connectivity

2

Movement ecology is critical for many species. Invertebrates range widely to complete their life cycles. Painted lady butterflies (*Vanessa cardui*) migrate thousands of kilometers each year. © Adobe Stock

Habitat loss and fragmentation are a leading cause of biodiversity loss worldwide, and climate change is exacerbating this problem. Species loss, decreasing population sizes and significant range contractions are caused by human activities that have negative impacts on biodiversity as well as ecosystem functions and services. These changes are happening more rapidly than in previous extinctions (Ceballos et al., 2017).

Historically, establishing individual protected areas, such as national parks, has been the primary focus of *in situ* conservation. The area of land and sea included in protected areas has increased steadily (Figure 1). In addition, protected areas are now supplemented by a range of OECMs – territories currently delivering effective conservation under a range of governance and management regimes even though conservation may not be a primary management objective (IUCN WCPA, 2019). Nevertheless, on a global scale, biodiversity loss continues to accelerate.

The scientific foundations of connectivity conservation

Protected areas do not always adequately conserve biodiversity, either because they are not well placed or else need stronger management (Venter et al., 2017; Jones et al., 2018). Increasingly, many terrestrial protected areas within human-dominated systems are isolated from one another (Wittemyer et al., 2008). Isolation increases the risk of species extinctions within these areas (Newmark, 1987, 1995, 2008; Brashares et al., 2001; Parks & Harcourt, 2002; Prugh et al., 2008). The relationship between isolation and extinction is founded on island biogeography and metapopulation theory (MacArthur & Wilson, 1963, 1967; McCullough, 1996; Hanski, 1999). The theory of island biogeography states that, on an island, the rates of new species arrival and species extinctions depend on the size and shape of the island and its distance from the mainland. This concept has been transferred from islands to mainland ecosystems, where isolated protected areas are like islands in an ocean of human-dominated systems. In reality, human-dominated systems act as a filter, wherein individuals of some species can pass through freely while others cannot. Metapopulation theory states that many spatially distinct subpopulations can be reconnected by movement of individuals, leading to genetic exchange and the possibility of re-establishing formerly extirpated subpopulations. Together, these theories support the conclusion that larger and more well-connected areas are likely to maintain higher biodiversity over time. They support the need for ecological networks in large-scale land, freshwater and seascape conservation.

It is clear that sufficiently large, well-placed and well-managed protected areas and OECMs can provide connectivity among different habitat patches or resources within their boundaries.

Linear infrastructure development continues to rise unabated in large, previously intact landscapes and in high-biodiversity regions of the world. Deforestation and landscape fragmentation, Cameroon © Grégoire Dubois

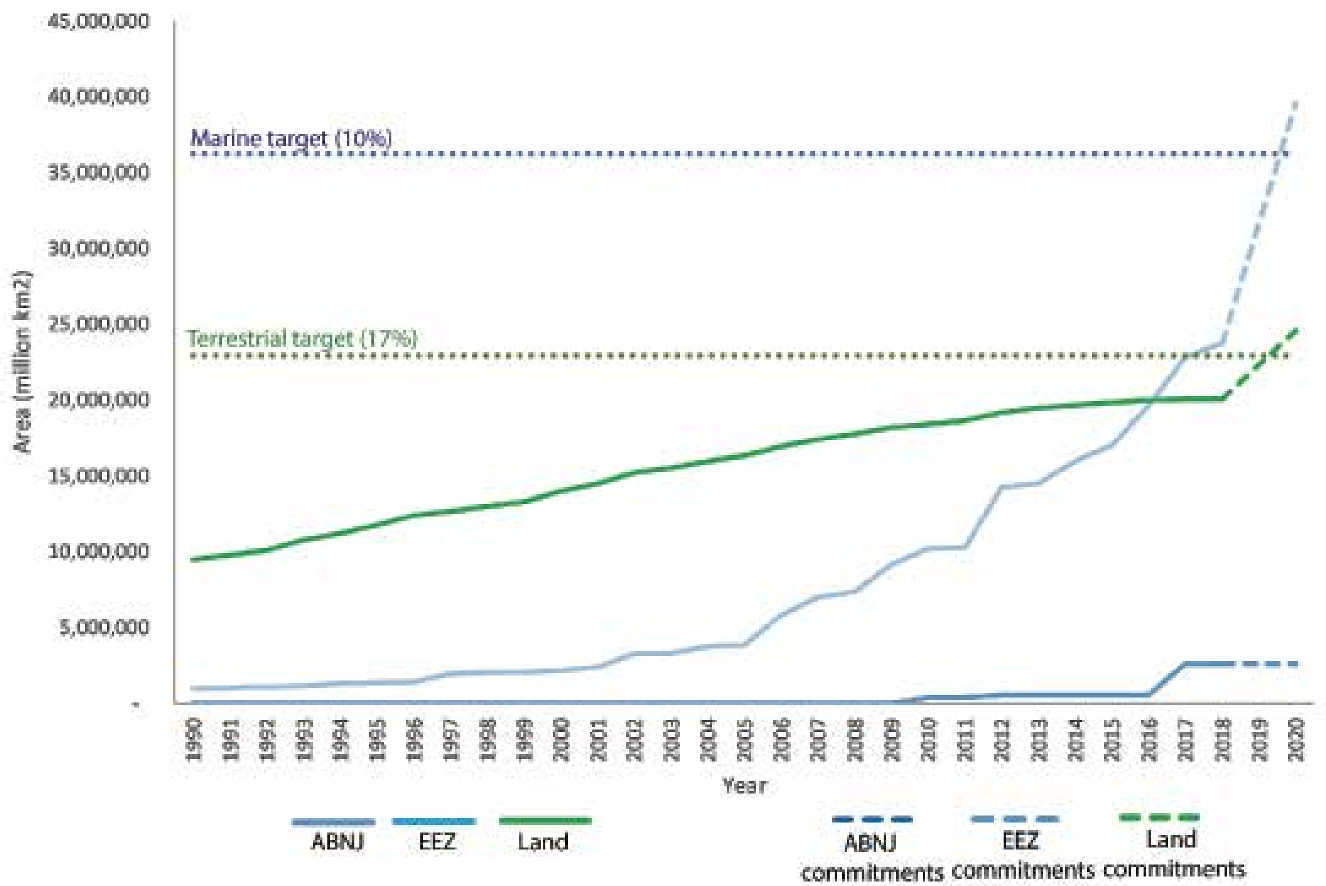


Figure 1. Growth in protected area coverage on land and in the ocean between 1990 and 2018, and projected growth to 2020, according to commitments from countries and territories. ABNJs: Areas Beyond National Jurisdiction (i.e. those more than 200 nautical miles from the coast); EEZs: Exclusive Economic Zones (i.e. marine areas under national jurisdiction that are less than 200 nautical miles from the coast). OECMs are new and therefore not incorporated into the figure. (From UNEP-WCMC, IUCN, and NGS, 2018. Reproduced with permission.)

However, because so much of Earth's terrestrial surface is fragmented, improving or sustaining connectivity among and between protected areas and OECMs is key for the effective conservation and management of biodiversity. Where it is not possible or appropriate to create additional protected areas or OECMs, connecting those already in place can serve to enhance biodiversity conservation. Managing for connectivity in ranching or forestry systems can enhance the conservation estate by increasing the total area within the landscape that is effectively connected, thereby reducing extinction risk (Newmark et al., 2017). In the face of climate change, connectivity becomes even more important, allowing some species to respond with range shifts and others to migrate into protected areas offering newly suitable habitat.

Conservation practitioners and scientists have demonstrated that conservation of species, ecosystems and habitats can only be achieved if protected areas are *functionally* connected (Trombulak & Baldwin, 2010; Resasco, 2019). In intact ecosystems, protected areas are *de facto* connected; in fragmented land, freshwater and seascapes, significant attention must be placed on achieving connectivity. Although connecting protected areas and OECMs has not been proven to strengthen conservation in every situation, connectivity has been demonstrated as an important component of many systems (Hilty et al., 2019).

There is some debate in the literature on negative impacts of corridors (Anderson & Jenkins, 2006; Hilty et al., 2019). Most negative effects appear to be related to increased predator activities, the movement of invasive species and diseases or micro-habitat changes (Weldon, 2006). These negative effects might be significant in individual situations. However, the reported benefits of corridors are far greater than any negative impacts (Hilty et al., 2019). Any potential drawbacks should be considered in corridor design, such as minimising potential edge impacts, exotic and invasive species and potential spread of infectious disease, as well as cost trade-offs of investing in corridors versus core habitat areas (Anderson & Jenkins, 2006; Weldon, 2006; Hilty et al., 2019).

Ensuring that protected areas and OECMs in fragmented systems are functionally connected across terrestrial, freshwater and marine realms and associated airspaces is critically important for many species (Marine Protected Areas Federal Advisory Committee, 2017; Hilty et al., 2019). Examples of organisms that move between these realms include anadromous fish that migrate from the sea to rivers to spawn, amphibians that inhabit multiple ecosystems during different life stages and butterflies (e.g. monarch butterflies, *Danaus plexippus*) that use numerous ecosystem types in their continental-scale, trans-generational migration.

Coral reefs need connectivity at a seascape scale to thrive. *Acropora* sp. shelters a *Linckia* starfish and many fish including *Chromis* sp., Piti Chanel, Guam. © Alisha Gill

Maintaining or restoring ecological connectivity may alsohave temporal aspects; migration can occur on a seasonal, annual or multi-year cycle, as evidenced by monarch butterflies (Runge et al., 2015). Usually, such connectivity movement occurs in all directions, but there are instances of unidirectional movement, such as during long-term climate change when species may shift their ranges poleward or upslope.

It is possible to manage for connectivity from small scales (e.g. streams, coral reefs and seagrass beds) to regional and even continental scales (e.g. chains of islands, mountains, major river systems and deep-sea hydrothermal vent ecosystems). Connectivity conservation is needed at local, regional and global levels and across various degrees of human modification. Many large-scale conservation visions seek to connect protected areas on land, in freshwater and in the ocean (Figure 2) (Worboys et al., 2015). Approaches for implementing these visions have been established in several human-dominated systems (Keeley et al., 2019). Notable examples include Baja to Bering (Mexico, US, Canada), Great Eastern Ranges Initiative (Australia), Amazon Freshwater Connectivity (Pan-Amazon, South America), Yellowstone to Yukon Conservation Initiative (US, Canada), and Vatu-i-Ra Seascape (Fiji).

For more information and examples, see the Annex, ‘Approaches to conserving ecological corridors in ecological networks’.

Modelling ecological corridors

The science of measuring, modelling, and mapping the connectivity of land, freshwater and seascapes has grown steadily over the past two decades. This section is a brief overview of key conceptual issues, available tools for modelling connectivity and useful resources to support the definition and delineation of ecological corridors. Many of the conceptual issues (e.g. Crooks & Sanjayan, 2006; Rudnick et al., 2012; Olds et al., 2016; Hilty et al., 2019) are increasingly well understood and practical implementation and management guidance are available (e.g. Beier et al., 2008, 2011; Hermoso et al., 2011; Olds et al., 2016).

There are a number of ways to categorise connectivity. At the highest level, a key distinction relevant to ecological corridors is that connectivity has both *structural* and *functional* components, which are described further below. Although not addressed in depth here, it is worth noting that connectivity

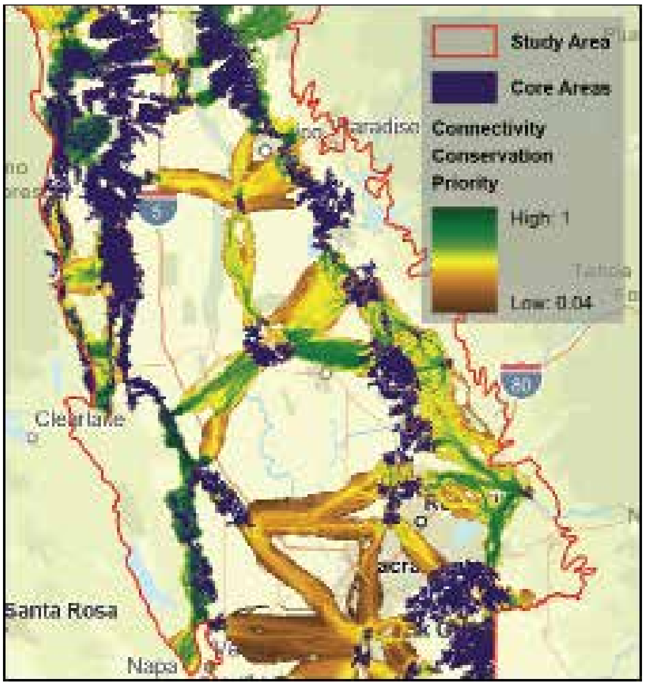
Figure 2. A conceptual representation of an ecological network for conservation. Terrestrial protected areas are in dark green and depicted as surrounded by human activities. Marine protected areas are in dark blue. OECMs are represented in orange. Ecological corridors, both those that are continuous and those that function as stepping stones, are outlined with dashed lines. The ecological network for conservation includes protected areas, OECMs and ecological corridors. © Kendra Hoff / CLLC

Experimental corridors provide a controlled environment to study ecological connectivity. The Savannah River Site Corridor Experiment (South Carolina, USA) is the largest corridor experiment in the world. © Ellen Damschen

Avoiding barriers to species movement is the necessary first step in maintaining connectivity; many barriers can be mitigated by, for instance, installing wildlife-permeable fencing. Whitetail deer (*Odocoileus virginianus*) jumping fence © BG Smith/Shutterstock

can be characterised based on the type of habitat (e.g. marine, freshwater and terrestrial, as described in Chapter 6, 'Applications and Benefits of Ecological Corridors'); the degree of human disturbance (e.g. hedgerows to remnant forest corridors; Theobald, 2013); the scale (local, regional, cross-oceanic, continental); or objectives (daily or seasonal movement, dispersal or habitat, long-term persistence, adaptation to climate change; Crooks & Sanjayan, 2006; Rudnick et al., 2012; Olds et al., 2016; Hilty et al., 2019).

'Functional connectivity' describes how well genes, gametes, propagules or individuals move through land- and seascapes (Rudnick et al., 2012; Weeks, 2017). Identifying areas that provide functional connectivity, either now or in the future, based on the known movements of individuals is an effective way to delineate movement corridors (e.g., Sawyer et al., 2009; Seidler et al., 2015; Hilty et al., 2019 (see Annex, Case Study 15 for details). Because it can be difficult to track a sufficient number of individuals over time, a suite of other approaches to define connectivity has been developed (Rudnick et al., 2012). In some cases, indicator or umbrella species are used to identify connectivity areas for a suite of species (e.g. Weeks, 2017). For long-lived species that are difficult to monitor, indirect approaches that can account for changes over time, such as in genetic make-up, can be effective (Proctor et al., 2012). However, genetic approaches



Modelling software, such as Linkage Mapper, is a tool conservation planners can use for decision-making. A synthesis of four Linkage Mapper outputs (Linkage Priority, Pinchpoint Mapper, Linkage Pathways and Centrality Mapper) provides an initial estimate of connectivity conservation priorities for American badger (*Taxidea taxus*), in the Sacramento Valley, California, USA (Gallo et al., 2019). © John Gallo are generally only a first step to identifying where once-continuous populations are fragmenting. The next step is to delineate potentially important connectivity areas (as per Proctor et al., 2015). Genetic tools can also potentially validate functionality and serve as monitoring tools (Proctor et al., 2018). This approach may be more difficult in marine systems because of data limitations (Balbar & Metaxas, 2019).

'Structural connectivity' is a measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances, and other land, freshwater or seascape elements presumed to be important for organisms to move through their environment (Hilty et al., 2019). Structural connectivity modelling aims to identify areas through which a variety of species may be able to move. Models often prioritise ecological corridors characterised by a low degree of human modification – areas which are assumed to be permeable to species sensitive to human disturbance (Dickson et al., 2017). In addition, linear areas that provide connectivity, such as river corridors, ocean currents or linear forest fragments, can be identified and prioritised for conservation (e.g. Rouget et al., 2006).

Systematic conservation planning is increasingly incorporating connectivity as a component of planning (e.g., Hodgson et al., 2016; Rayfield et al., 2016; Albert et al., 2017). With a growing number of quantitative approaches, numerous tools are available to map and model connectivity (Table 1). Increasingly, efforts to model connectivity recognise the dynamics of ecological systems, including seasonal or annual dynamics and long-term climate-induced changes (Rouget et al., 2006; McGuire et al., 2016; Simpkins & Perry, 2017).

Table 1. Common approaches to connectivity modelling (Urban & Keitt, 2001; McRae, 2006; Theobald, 2006; Rudnick et al., 2012; http://conservationcorridor.org/corridor-toolbox/).

Model type	Brief explanation
Least-cost	Estimates the surface area of the least-cost movement path from one location (source patch) to another (destination patch) that an individual or process would likely take, assuming knowledge of the destination location, moving across a surface represented by 'costs' (https://corridordesign.org; McRae et al., 2014). Either the single shortest path from one location to another or the full surface area of least-cost distances can be used. Cost-distance surface areas that were created from single, pairwise, factorial or randomly placed locations can be combined.
Circuit theory	Adapted from electrical circuits, circuit theory identifies connectivity by modelling random walkers moving from sources across a surface of resistances to destinations (grounds), allowing multiple pathway options (McRae, 2006; https://circuitscape.org).
Graph theory	Graph theory is the study of graphs that formally represent a network of interconnected objects. Graph theory provides the basis for nearly all connectivity methods, including least-cost and circuit theory. In addition, to prioritise ecological corridors, graph-theoretic metrics can be applied across a 'land- or seascape graph' where patches are nodes and areas of connectivity are edges (Urban and Keitt, 2001; Theobald, 2006; University of Lleida, 2007).
Resistant kernel	Based on least-cost movement from all locations across a land or seascape, implemented using a kernel (moving window) approach (Compton et al., 2007). This approach calculates a relative density of dispersing individuals around source locations.
Reserve design	An approach to guide systematic multi-objective planning to support spatial decision-making about the design of terrestrial, freshwater and marine reserves and management areas (e.g. Moilanen et al., 2008; White et al., 2013).
Individual-based modelling	Simulates movement paths of individuals by following postulated rules. The estimated relative frequency of use is mapped (Horne et al., 2007; Ament et al., 2014; Allen et al., 2016).

Tracking tiger movement along the Nepal–India border in the Himalayan Terai Arc corridor © Gary Tabor

Connectivity conservation also supports human communities by supporting healthy landscapes. A “superbloom” event paints Carrizo Plain National Monument, California, USA. © Emily Pomeroy / Emily Rose Nature Photography

Towards a common language of connectivity conservation

3

Connectivity is important for all domains; terrestrial, freshwater, marine, coastal and aerial. Here, a great egret (*Ardea alba*) patiently hunts in Elkhorn Slough State Marine Reserve, California, USA. © Emily Pomeroy / Emily Rose Nature Photography

A high priority for connectivity conservation policy must be to establish a common set of clearly distinguished terms. A central aim of these Guidelines is to define and explain two such terms, both of which are critical to connectivity conservation: 'ecological network for conservation' and 'ecological corridor'. Providing a clear definition of ecological networks for conservation and guidance on how to identify, establish, measure and report on ecological corridors aids many countries in reaching the goal of identifying, establishing, managing and restoring 'well-connected systems', spelled out in Aichi Target 11 of the Convention on Biological Diversity (CBD), and to achieve other commitments (see Chapter 7 for other examples). It is also critical for the post-2020 global biodiversity framework established to advance progress towards achieving the CBD's 2050 Vision of 'Living in harmony with nature'.

Definition of 'ecological network for conservation'

The idea of an ecological network for conservation is represented by various terms, which are outlined in Table 2. An agreed definition of 'ecological network for conservation' reduces confusion, provides a common standard for global monitoring and database management, and generally improves communication and comparability.

For these purposes, the following definition is used:

> An ecological network for conservation is 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.

Ecological networks are composed of core conservation units – protected areas and OECMs – connected with ecological corridors. The definitions of these areas follow:

- 'Protected areas' are clearly defined geographical spaces, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008; Stolton et al., 2013).
- 'OECMs' ('other effective area-based conservation measures') are geographically defined areas other than protected areas, which are 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).

Landscapes are mosaics of interconnected ecological patches which function across spatial scales. The Chignecto Isthmus is the critical landscape gossamer that connects Peninsular Nova Scotia to mainland Canada. © Mike Dembeck

Table 2. Other terms (some of which have been translated into English) that have been applied in practice to describe what these Guidelines call 'ecological networks for conservation'. The presentation of terms in this table is meant to illustrate that the central ideas of 'ecological corridor' and 'ecological network' can be similar and expressed in many ways.

Term	Example
Area of connectivity conservation (ACC)	Used by the Great Eastern Ranges Initiative of Australia, which is an effort to establish connectivity across a large landscape that may encompass a range of land uses, such as agriculture, forestry and human settlements, in addition to protected areas.
Biological corridor	Used by the Mesoamerican Biological Corridor, which was initiated in the 1990s to maintain biological diversity, reduce fragmentation and improve the connectivity of the landscape and ecosystems in Central America and southern Mexico (Ankersen, 1994; Ramírez, 2003).
Conservation lands network	Used in the San Francisco Bay Area of California, USA, as part of a regional prioritisation of connected lands that are important for the protection of biodiversity (Bay Area Open Space Council, 2011).
Conservation management network	Commonly used in Australia in the context of land-based networks for conservation of threatened ecological communities and remnant vegetation. These networks are supported by landowners/land managers and communities (Context Pty Ltd., 2008).
Conservation mosaic of protected areas	Commonly used in South America to refer to a network of protected areas and complementary landscapes/seascapes, including combinations of formal protected areas (i.e. core conservation areas) and surrounding areas (e.g., production landscapes, privately owned areas, community areas), where the involved entities cooperatively plan and manage the various pieces (Caballero et al., 2015); similar to a biosphere reserve under the UNESCO Man and the Biosphere programme. A Conservation Mosaic of Protected Areas aims to improve ecological connectivity as well as the conservation and sustainable use of environmental goods and services; for an example, see the Brazil Southern Amazon Mosaic (www.wwf.org.br/?29690/Southern-Amazon-Mosaic-facilitates-Protected-Area-management).
Ecological framework	In Russia, commonly used to refer to an 'ecologically continuous system of natural communities', not affected by landscape fragmentation, whose natural communities are ensured legal protection due to their large size and high intensity of matter and energy exchange (Sobolev, 1999; 2003).
Ecological network	Used in nearly all European countries to describe an approach (national and regional) designed to link nature areas more effectively with each other, and with surrounding farmland (Jongman & Bogers, 2008; Miklos et al., 2019).
Flyway sites network	Used, for example, to describe the East Asia–Australasian Flyway; these networks provide various degrees of connectivity and protection for target bird species (Millington, 2018).
Freshwater systems network	Used in South America to refer to freshwater aquatic ecosystems that interact hydrologically, biologically and chemically, and in which a key determinant of these interactions is connectivity, requiring integrated management across ecosystems (e.g. streams, rivers, lakes and wetlands) (Abell et al., 2017; Leibowitz et al., 2018); an example is the Project for Sustainable Management of La Plata River Basin of Argentina, Bolivia, Brazil, Paraguay and Uruguay.
Green infrastructure	Used in the 28 EU Member States and in some regions of the USA. The EU definition: 'Green infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation. This network of green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life. It also supports a green economy, creates job opportunities and enhances biodiversity.' The Natura 2000 network constitutes the backbone of the EU green infrastructure.
Marine protected areas (MPAs) network	Used in Australia and the USA to refer to networks of formal MPAs that serve in turn as components of even larger ecological networks for conservation (e.g. the California Marine Protected Areas Network) (Almany et al., 2009; Carr et al., 2017).
Territorial system of ecological stability	In the Czech Republic and Slovakia, used to describe an interconnected complex of both natural and near-natural ecosystems that maintain natural balance (Jongepierová et al., 2012).
Transboundary conservation areas (TBCAs)	Used to define ecologically connected areas that cross international boundaries and contain protected areas. Research on TBCAs has been ongoing for more than 25 years, and the concept has been recognised by both IUCN and the CBD.

- An 'ecological corridor' is a clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity (see detailed explanation below).
- 'Ecological networks for conservation' are more effective in achieving biodiversity conservation objectives than a disconnected collection of individual protected areas and OECMs because they connect populations, maintain ecosystem functioning and are more resilient to climate change. In the context of ecological connectivity, 'connect' refers to the enabling of movement by individuals, genes, gametes and/or propagules.

Definition of 'ecological corridor'

These Guidelines recommend the adoption of a connectivity designation, termed 'ecological corridor', to denote areas within ecological networks that are explicitly devoted to ecological connectivity, and may incidentally also contribute directly to biodiversity conservation. We define the term as follows:

> An ecological corridor is a clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity.

It is worthwhile to elaborate some key phrases and concepts used in this definition to be clear about their intended scope and application in these Guidelines:

- 'Clearly defined geographic space' includes land, inland water, marine and coastal areas or a combination of two or more of these. 'Space' may include the subsurface, the land surface or ocean floor, and the water column and/or airspace including vertical, physical ecosystem structures in three dimensions (adapted from Lausche et al., 2013). 'Clearly defined' means a spatially defined area with agreed and demarcated borders.

Differences between protected areas, OECMs and ecological corridors

Referring back to the definition of 'ecological network for conservation,' note that it is defined as a system composed of two types of core conservation areas, protected areas and OECMs, with ecological corridors being the third element. They are the 'glue' of conservation networks.

Table 3 clarifies the key differences among the elements of an ecological network. Protected areas and OECMs are the fundamental core elements of conservation and of any ecological network. By definition, they *must* conserve *in situ* biodiversity and *may* also conserve ecological connectivity. On the other hand, ecological corridors *must* conserve connectivity. Depending on their condition and management, ecological corridors *may* also conserve *in situ* biodiversity, but this is not a requirement.

Focal species play a key role in determining connectivity conservation priorities, as the jaguar (*Panthera onca*) does across Central and South America.
© Grégoire Dubois

Seabirds play a critical role in marine, inter-island and coastal connectivity. © Dan Laffoley

Table 3. Differences in the role of protected areas, OECMs and ecological corridors. Note that all three terms refer to areas with conservation outcomes. Protected areas and OECMs protect nature as a primary consideration. Ecological corridors play a supporting role for protected areas and OECMs in building ecological networks.

	Protected areas	OECMs	Ecological corridors
MUST conserve *in situ* biodiversity	●	●	
MAY conserve *in situ* biodiversity			●
MUST conserve connectivity			●
MAY conserve connectivity	●	●	

In some cases, ecological corridors can be disjunct patches of habitat, often called 'stepping stones', particularly when supporting long-distance migration of wildlife such as marine mammals, sea turtles and birds. For example, for migratory birds, the distance between sites may not need to be minimised unless they are very far apart or the target species has metabolic constraints (Klaasen, 1996). Rather, the sites need to meet a particular species' natural history requirements (e.g. availability of food, low amounts of disturbance, presence of safe roost sites) at different stages of migration, particularly at staging and stopover sites within the corridors.

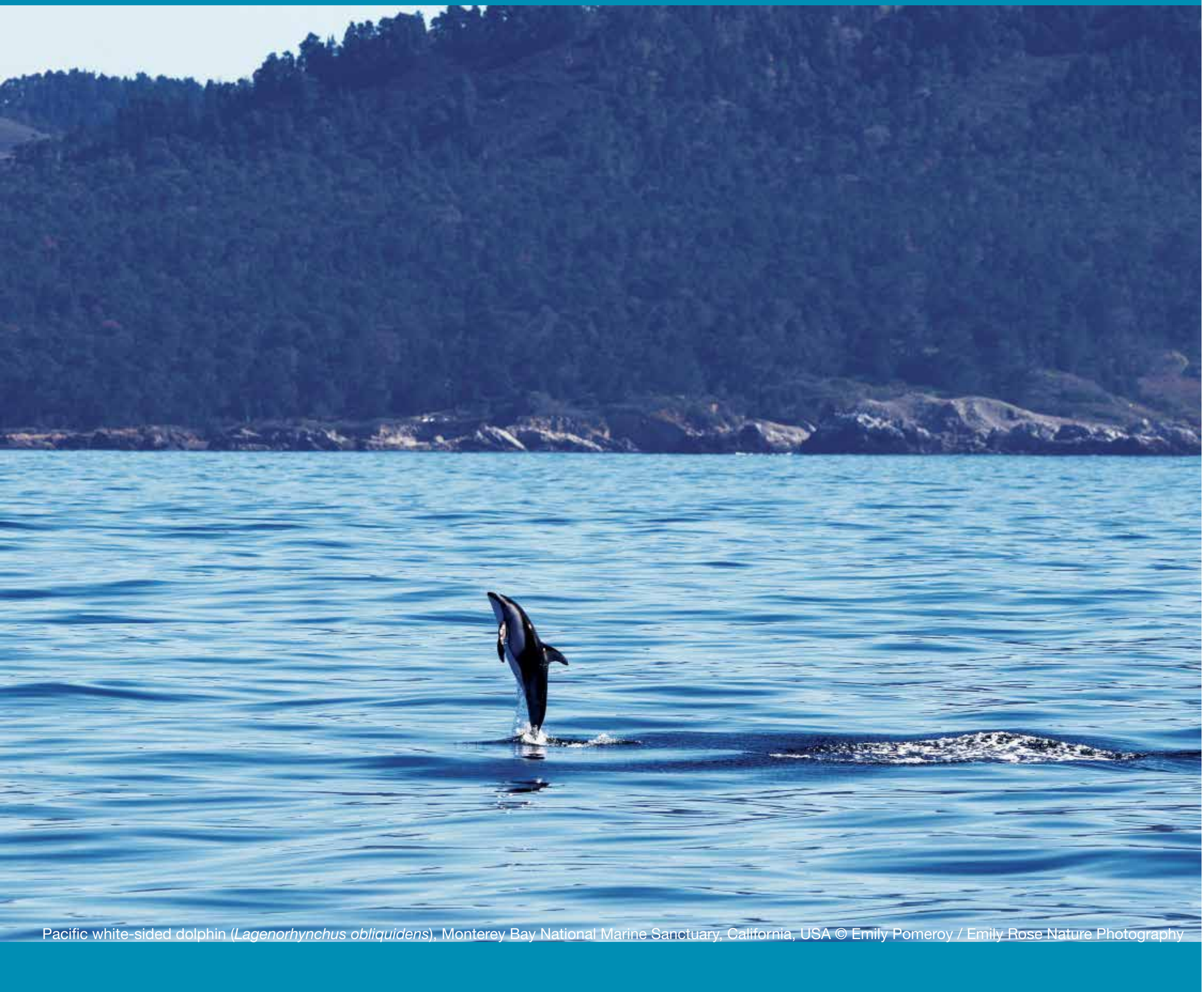
Next we turn to an in-depth discussion of ecological networks for conservation.

Tropical forest reserves require connectivity to function as ecological networks for conservation. Sunlight penetrates a shroud of moisture above the cloud forest, Panama. © Marie Read

Corridors can provide the architecture for large-scale conservation in fragmented landscapes. Landholders linking and restoring habitats on rural landscapes with Woomargama National Park, part of the Slopes to Summit alliance, an east–west section of the Great Eastern Ranges ecological corridor in southern New South Wales, Australia. © Ian Pulsford

Ecological networks for conservation

4



Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Monterey Bay National Marine Sanctuary, California, USA © Emily Pomeroy / Emily Rose Nature Photography

Effective ecological networks for conservation consist of two main elements: 1) areas that protect biodiversity (protected areas and OECMs), and 2) ecological corridors recognised for their contribution to connectivity (refer to Figure 2). Ideally, when designing ecological networks, systematic conservation planning is employed to identify the minimum set of sites needed to protect the most biological diversity in a given region (Margules & Pressey, 2000).

Targets for conservation, which may include focal species, key biodiversity areas, population sizes or habitat areas, are set and the ecological network for conservation is optimised to contain these targets, while also considering their spatial configuration. Socio-economic and political filters may also be considered in systematic conservation planning. Ecological networks are necessary to enhance the integrity, viability and stability of protected areas and OECMs in fragmented systems, making them less vulnerable to all threats, especially in the context of climate change.

In addition to isolation, it is important to consider the size of core habitats (protected areas and OECMs) when meeting the connectivity needs of some species in conservation networks. For large, wide-ranging species, individual protected areas are often not big enough to maintain minimum viable populations. The reality today in many land regions is that creation of new large reserves is not feasible because small habitat fragments are all that remain (Shafer, 1995). Creation of larger reserves is increasingly more common in the ocean. Small protected areas may not be big enough to support populations of even small animals over extended periods (e.g. Henderson et al., 1985; Green et al., 2014). Nevertheless, very small reserves (e.g. those less than 10 ha), even in the most highly fragmented regions, may have critical roles to play in advancing local conservation objectives and community involvement in conservation (Volenec et al., 2020). Moreover, in marine environments, small reserves may in some cases be adequate for specific species and their life-cycle needs. For example, in the sponge reefs off the east coast of Canada, sponge larvae are in the water for just a few days and disperse via currents; they may not go very far, so a marine protected area may readily encompass their dispersal distance. The same is true for invertebrates that are immobile and reproduce by brooding.

Further related to the issue of size, most protected areas and OECMs are not sufficiently large to survive larger-scale ecological disturbances to their biodiversity. For example, natural fires may form part of long-term ecosystem cycles of a protected area, but if it is not large enough the species within will need large tracts of adjacent unburnt habitat to which they can withdraw and recover.

Ideally, protected area and OECM sizes and locations are determined by ecological considerations, but design decisions are often constrained by existing ownership or resource use rights and human activities. To ensure that individuals of species can move between specific core habitats in an ecological network, calculations of appropriate distances between them should be made according to the species' characteristics, such as dispersal range and area required for a minimum viable population. Within these

In many parts of the world, such as East Africa, wildlife populations spend much of their time outside of protected areas, yet utilise protected areas on a seasonal basis. African elephants (*Loxodonta africana*) in Masai Mara, Kenya © Gary Tabor

Free-flowing rivers and their associated riparian corridors link terrestrial and freshwater systems. Aerial view of landscape during flight from Trinidad to Bellavista, Beni Department, Bolivia © World Wildlife Fund (WWF), Photographer Jaime Rojo

parameters, distances ideally should be minimised and the area between core habitats managed so as to maintain ecological connectivity.

Maintaining ecological connectivity, such as through corridors, is important to allow individuals to move among patchy resources and among populations/subpopulations and to facilitate seasonal or periodic migrations. Ecological corridors are also important to facilitate dispersal that ensures genetic diversity and permits recolonisation in areas where populations have gone extinct. These corridors can help increase populations' resilience to large-scale natural disturbances. Ecological corridors also may help extend specific ecosystem services for human use, while serving their main purpose of species movement. Corridors may help maintain ecological processes, such as nutrient cycling, pollination and seed dispersal, across landscapes and seascapes. Finally, even within ecosystems transformed by human activity, ecological corridors provide higher rates of ecosystem recovery in surrounding disturbed areas due to dispersal of seeds and animals from the remaining natural areas (e.g. M'Gonigle et al., 2015; but see also critique from Boitani et al., 2007).

Ecological networks and climate change

Ecological networks for conservation have been recognised as a means to help many species respond to climate change. When well designed, ecological networks, including corridors, can enable species to shift ranges and colonise newly suitable habitats and adapt to climatic conditions. Conservation strategies that make ecological networks more effective to facilitate adaptation to climate change include increasing the number and size of protected areas and OECMs, managing habitats to increase their resilience, establishing or widening connectivity areas, locating reserves in areas of high heterogeneity, and spanning elevational along with other critical gradients (Heller & Zavaleta, 2009; Anderson et al., 2014; Elsen et al., 2018). Of the different climate adaptation strategies, increasing the amount of conserved habitat is one of the most effective (Synes et al., 2015; Table 4). However, conserving a suitable network of habitats should be a priority, rather than increasing the size of a few isolated protected areas and OECMs (Hodgson et al., 2012).

Much of the world faces unprecedented levels of habitat fragmentation. Corridors of high-quality habitat provide the safety net to save biodiversity. Ranchlands near Punta Burica, Panama © Félix Zumbado Morales / ProDUS Universidad de Costa Rica

Table 4. Advantages and disadvantages of strategies to facilitate species range shifts through climate-wise connectivity (adapted from Keeley et al., 2018).

Strategy	Advantages	Disadvantages
Increasing the number of protected and conserved areas throughout the land- and seascape	If properly designed, may increase speed of range shifts in fragmented systems; benefits most species; increases persistence for some species	
Creating few, large protected or conserved areas		Slows speed of range shifts; may result in poor representation of the country/region's full ecosystem diversity
Adding connectivity areas (ecological corridors or additional protected or conserved areas) between existing protected or conserved areas	Increases speed of range shifts in fragmented systems; benefits most species	In rare cases, restoring connectivity could introduce invasive species and harmful alleles (variant forms of a given gene), particularly in freshwater and marine systems
Creating small stepping stones embedded in unsuitable habitat	Increases speed of range shifts in fragmented systems	Only benefits species capable of using stepping stones
Increasing the size of existing protected areas	Increases species persistence; improves temporal connectivity for some species; governance and management structure already exist	May not facilitate connectivity with respect to other resources that wildlife needs; may not provide adequate space for species to move in response to climate change

Ecological networks that collectively encompass temperature gradients can also effectively facilitate species range expansion. This might mean connecting lower- to higher-elevation sites, or inland to coastal areas; sites at different latitudes or ocean depths; or even sites that represent salinity gradients. The Appalachian Mountains in the eastern USA are an example of a mountain range critical for facilitating poleward species movements (Lawler et al., 2013). Likewise, corridor planning in the Albertine Rift region of Africa seeks to ensure elevational and latitudinal connectivity (Ayebare et al., 2013; Plumptre et al., 2016). It should be noted that, in addition to ecological corridors, ecological connectivity can be achieved by expanding existing protected areas and OECMs or adding more of them to a network.

Planning and implementing ecological corridors

5

Arabian oryx (*Oryx leucoryx*), Dubai, UAE © Peter J Hudson

This chapter provides detailed guidelines on how to plan and implement an ecological corridor, starting with fundamental principles that inform a corridor's ecological objectives. The chapter then describes how to document basic information, select objectives, choose a governance model, delineate boundaries and implement management and monitoring plans that reach the corridor's objectives.

Fundamental principles

Every ecological corridor should be founded on a set of objectives that concisely explains why the corridor is being designated and what the expected conservation outcomes are. Keeping a few fundamental principles in mind will be helpful.

1. *Ecological corridors are not a substitute for protected areas or OECMs.* They are meant to complement protected areas and OECMs. The purpose of ecological corridors is to maintain connectivity, especially in regions where additional protected areas and OECMs are not possible, and connectivity is required to retain their elements and processes. As noted earlier, ecological corridors provide specific connectivity value complementary to that of protected areas and OECMs (Table 3). Ecological networks for conservation, as understood in these Guidelines, may contain several corridors identified as part of a specific conservation network. The primary purpose of ecological corridors is to facilitate one or more defined types of ecological connectivity between and among protected areas, OECMS or other core habitats.
2. Ecological corridors should be identified and established in areas where connectivity is required with the aim of building ecological networks for conservation.
3. Each corridor should have specific ecological objectives and be governed and managed to achieve connectivity outcomes.
4. Ecological corridors may consist partly or entirely of natural areas managed primarily for connectivity. Corridors can also cross highly managed areas – such as ranches or commercial forests – provided the area within the corridor is explicitly managed for connectivity. In some cases, a corridor can combine a natural area and an area managed for extraction. *So long as their conservation objectives are supported, ecological corridors may include compatible human activities that practise sustainable resource use.* These might include some forms of human habitation, farming, forestry, grazing, hunting, fishing and ecotourism (see Annex, Case Studies 3 and 12).
5. *Ecological corridors should be differentiated from non-designated areas by the specific uses that are allowed or prohibited within them.* Whereas surrounding lands may look similar, and have similar uses, the uses allowed inside a designated ecological corridor cannot harm its specified connectivity purposes.

In many mountainous regions, valley bottoms contain the greatest biodiversity and provide necessary winter habitat. These are also the areas that people tend to inhabit. Connectivity conservation in these areas relies on coexistence strategies for people and wildlife and coherent multi-jurisdictional approaches to land and freshwater management. Pieniny National Park, Poland & Slovakia © Juraj Švajda

Box 2
Ecological corridor objectives — some examples

1. **Movement of individuals:** To allow for the movement of dispersing tigers (*Panthera tigris*) between India's Dudhwa and Jim Corbett national parks (Seidensticker et al., 2010); to allow wildebeest (*Connochaetes taurinus*) to move between the Serengeti Plains in the United Republic of Tanzania and the Masai Mara Reserve in Kenya in a clockwise manner (Serneels & Lambin, 2001); to aid in the recovery of biota after habitat destruction, e.g. due to mining in deep-sea hydrothermal vent ecosystems (Van Dover, 2014).
2. **Genetic exchange:** To allow for the movement of giant pandas (*Ailuropoda melanoleuca*) in China between population segments that have been separated by a highway and associated development (Zhang et al., 2007); to allow for the diadromous migrations of European eel (*Anguilla anguilla*) through rivers and the North Atlantic Ocean (Kettle & Haines, 2006).
3. **Migration:** To facilitate the annual June passage of wood turtles (*Glyptemys insculpta*) from habitat in Canada's La Maurice National Park to breeding beaches outside of the park (Bowen & Gillingham, 2004); to conserve the pathways of fish, such as the dorado catfish (*Brachyplatystoma rousseauxii*) to breeding sites in the Amazon or green sturgeon (*Acipenser medirostris*) in the Pacific Northwest of the USA (Benson et al., 2007); to conserve one or more of the stopover sites that maintain the migration of spoon-billed sandpipers (*Calidris pygmaea*) and other migratory sandpipers that breed in Russia's Siberia and Kamchatka and migrate along the Pacific coast of Asia, wintering from eastern India to southern China (Menxiu et al., 2012).
4. **Multi-generational movement:** To provide habitat for monarch butterflies migrating over several generations along a central flyway in the states of Minnesota, Iowa, Missouri, Kansas, Oklahoma, and Texas, USA (the 'Monarch Highway', www.monarchhighway.org).
5. **Maintenance/restoration processes:** To restore hydrologic function, such as sediment transport or nutrient cycling, by removing dams from small streams in Wisconsin, USA (Doyle et al,. 2000).
6. **Climate change adaptation:** To facilitate range shifts of species to adjacent mountain ranges through restoring riparian corridors in agricultural landscapes in California, USA (Keeley et al., 2018).
7. **Enhancement of recovery:** To serve as a source of conifer seeds for restoring native trees in logged areas of the mixed forest zone of European Russia (Degteva et al., 2015).
8. **Prevention of undesired flows:** To reduce erosion risk by stopping the increasing velocity of surface water flows downslope in rugged terrain of cultivated steppe landscapes in southern Russia, Ukraine, Moldova, Kazakhstan (Ladonina et al., 2001).

6. To achieve their connectivity objectives, *ecological corridors require their own management plans* (terrestrial, freshwater or marine as the case may be). These may be simple or complex depending on the human activities that are permitted and the tenure issues.

In most instances, ecological corridors will connect protected areas and OECMs, and perhaps other intact natural habitats. However, in some regions, an ecological corridor designation may be needed to funnel migrating species through bottleneck zones that do not necessarily connect to protected areas or OECMs. An ecological corridor could, for example, lead from a protected turtle nesting beach out through a set of islands to the open ocean.

It should be noted that protected areas and OECMs that are already effectively conserving connectivity do not need to be overlaid with an ecological corridor designation.

Objectives

The objectives of an ecological corridor should be clearly stated in its documentation. In addition, it may be useful to show any associated values of the corridor, such as contributions to ecosystem services.

Ecological connectivity objectives: The most critical step in documenting an ecological corridor is defining its objectives for ecological connectivity. Connectivity can be established or maintained for any one or a combination of the following purposes, all of which depend on movements between habitat patches: (1) genetic exchange; (2) movement of individuals to meet life-cycle needs, including migration; (3) provision of habitat for daily to multi-generational movement; (4) maintenance of ecological processes; (5) movement and adaptation responses to global change, including climate change; (6) recovery and recolonisation after disturbance; or (7) prevention of undesirable processes, such as the spread of fire. An ecological corridor should have clear and measurable ecological objectives meeting at least one of the above purposes. Examples of the seven ecological connectivity objectives are provided in Box 2.

Associated ecosystem service values (if applicable): Ecosystem service objectives can often be achieved along with connectivity conservation, and may also be documented. These can include maintaining or enhancing provisioning

Marine connectivity operates across all dimensions of space, within the water column and over the broad reaches of the seas. Scalloped hammerhead (*Sphyrna lewini*) © Adobe Stock

services such as of food and water; regulating services such as regulation of floods, drought, storm surge, land degradation, disease and carbon sequestration; and supporting services such as soil formation and nutrient cycling. While management for specific ecosystem services may be an important objective, so doing should support the ecological corridor's connectivity objectives. Detailed guidance for documenting ecosystem services can be found in the IUCN publication *Tools for Measuring, Modelling, and Valuing Ecosystem Services* (Neugarten et al., 2018).

Associated cultural and spiritual objectives (if applicable): Conservation of important cultural and spiritual values may be associated with an ecological corridor. These values should also be documented in order to maintain support for the corridor.

Contribution to an ecological network for conservation

The contribution of an ecological corridor to the ecological network for conservation in which it is located should be documented. Such documentation can consider multiple metrics (genetic, demographic, community and ecosystem consequences) depending on the conservation objectives of the network. A diversity of empirical and modelling approaches to measure ecological connectivity exist and are the subject of research to refine and expand them.

At minimum, documenting the existence of successful movement between protected areas is required. Quantitative estimates of the magnitude of connectivity should be provided. If possible, the contribution of connectivity to population and community metrics (e.g. genetic diversity, population size, species diversity) should be calculated. Evaluating the contribution of ecological corridors and connectivity to network performance should, when possible, include the performance of the network relative to a group of unconnected protected areas (Grorud-Colvert et al., 2011, 2014). Bennett & Mulongoy (2006) provide detailed guidance on how to incorporate many of the considerations of ecological networks.

Social and economic values

While these guidelines are primarily focused on the critical ecological role of ecological corridors, connectivity conservation can have a wide range of social and economic benefits (Hilty et al., 2019, pp. 112–115). Being aware of them can help in corridor design and increase social acceptance, while at the same time maximising their effectiveness. Below are examples of some of the more notable social and economic benefits.

- In some parts of the world, large ecological corridors might be managed for the benefit of mobile peoples, who need connected systems to maintain traditional livelihoods. This is particularly relevant for hunter/

gathering cultures and pastoralist peoples who depend on seasonal movements.

- Ecological corridors can provide a range of co-beneficial recreational values, such as pathways for walking trails (See Annex, Case Studies 10 and 20).
- Corridors established as setbacks, such as forestry or agricultural buffer strips, can protect riparian communities and water quality, and provide flood protection along watercourses.
- Ecological corridors can help define a community's sense of place or distinctiveness, and may help maintain a community's aesthetic preferences or historical grounding.
- Ecological corridors through agricultural areas may serve as a source of pollinators for crops.
- In forest management areas, ecological corridors can provide other benefits, such as acting as wind breaks and sources of seed stock for forest regeneration.

In establishing and managing ecological corridors, it is useful to consider a complete range of social and economic values. If they are to be part of the management plan, the interaction between them and the ecological objectives should be well understood. Any uses of a corridor that support social and economic values should not impair its connectivity (see Annex, Case Studies 16 and 17).

Delineation

An ecological corridor should be clearly delineated. It should have agreed boundaries demarcated by the entity or entities governing and managing it, whether on land, in inland waters, coastal or marine areas, or any combination of these. These boundaries may sometimes be defined by physical features that move over time, such as river banks, ocean currents or sea ice. Given how rapidly the world is changing, provisions for an ecological corridor to move in time and space may be articulated in its management approach. Although the size of an ecological corridor will vary, it should be large enough to achieve its specific ecological connectivity objectives over the long term.

An ecological corridor can be discontinuous (in which case it is often referred to as a 'stepping stone' corridor) provided that the objectives, governance and management are the same across its segments. In order to provide connectivity, stepping stones must be of an appropriate habitat type, align with mechanisms of dispersal (e.g. ocean currents, flyways), and be of a minimum threshold size (see Annex, Case Studies 24 and 25). In cases where there is more than one governance or management entity, management actions should be harmonised and coordinated.

Semi-domesticated reindeer herding is intertwined with the cultural identity and survival of Sami people of northern Scandinavia. Cultural aspects may be appropriate to consider in designing corridor objectives. Sami reindeer herding area, Finland © Juraj Švajda]

In some cases, the delineation of an ecological corridor may need to include a third, vertical dimension if biodiversity is to be effectively conserved. Some protected areas and OECMs already have vertical limits (e.g. they apply only to a certain depth underground or below the water surface). Vertical limits have become particularly controversial in marine protected areas, where vertical zoning for commercial purposes may undermine conservation objectives (e.g. by disrupting ecological connectivity), as it is extremely challenging to monitor or enforce. Examples of vertical-dimension considerations in terrestrial systems include the placement of wind turbines in flyways that intercept and kill migrating avifauna, and, in marine systems, the deployment of fishing gear (e.g. drift nets) at different levels of the water column that intercept and kill migrating pelagic species. Such considerations may also apply to surface freshwater systems, including deep-water lakes with faunal zonation, but also to subterranean freshwater systems, which require management strategies that recognise these systems might be affected by activities at the surface that are relatively remote from them. The height and depth dimensions of an ecological corridor need to allow for effective management to achieve its connectivity objectives.

Another aspect of vertical dimensionality is subsurface use rights given that accessing underground resources can harm conservation values. For example, subsurface rights to the seafloor vary greatly based on political jurisdictions and types of human activities (e.g. mining, laying pipelines, or constructing offshore oil extraction facilities). Planners should consider how such modifications affect the movement of species targeted for protection.

Gravel bed river systems have riparian corridors that extend well beyond their banks into the subsurface hyporheic zones (see Hauer et al., 2016.) Tusheti, Republic of Georgia © Juraj Švajda

Coral atolls may appear as separated islands but are connected across vast distances to form functional marine ecological networks, New Caledonia. © Dan Laffoley

The annual long-distance movement of certain species such as the wood stork (*Mycteria americana*), pictured here in Mato Grosso, Brazil, led to some of the first global and national policies to conserve migratory species. © Grégoire Dubois

The delineation of an ecological corridor should be based on ecological needs for connectivity rather than on land and sea ownership (cadastral) boundaries. However, where cadastral boundaries approximate ecological needs, it may be useful to use these boundaries for management and governance efficiency. For sites crossing political or jurisdictional boundaries for which it is not feasible to have a common governance mechanism, separate ecological corridors may need to be delineated. Otherwise, a governance mechanism comprising more than one entity coordinated under an umbrella decision-making process will be required. Here, harmonisation and coordination can be major challenges. Governance and management must be adapted to individual sites or sets of sites in multiple countries. This can be done through international frameworks, such as the Eastern Asian-Australasian Flyway Partnership, whose Flyway Site Network coordinates the conservation of migratory waterbirds.

Governance

Governance arrangements should be clearly articulated in the documentation. As with protected area and OECM governance, ecological corridor governance has three components: how and by whom decisions are made, and who should be held accountable.

The element of ‘who’ relates to the entities with authority over the ecological corridor. Ecological corridors with complex tenure situations (see next section) may involve many governance authorities (e.g. Indigenous Peoples), along with an agreed mechanism for coordination and oversight (see Annex, Case Studies 6 and 17). The same range of governance types that apply to protected areas and OECMs also apply to ecological corridors (Dudley, 2008; Stolton et al., 2013; Borrini-Feyerabend et al., 2013). These include:

- Governance by government (at various levels);
- Shared governance (sometimes called ‘co-management’), including:
  - Transboundary governance (formal arrangements between one or more sovereign States or Territories (see Annex, Case Study 20);
  - Collaborative governance (through various ways in which individuals and institutions work together (see Annex, Case Study 17);
  - Joint governance (e.g. through a pluralist board or other multiparty governing body);
- Governance by private individuals, organisations or companies (see Annex, Case Study 15); and
- Governance by Indigenous Peoples and/or local communities (see Annex, Case Study 3).

The element of ‘how’ concerns ensuring transparency, accountability, participation and justice in decision-making processes. Governance should strive to be equitable and reflect human rights norms recognised in international and regional instruments and national legislation (see Annex, Case Study 8). Evaluating the ecosystem services associated with proposed ecological corridors helps define the diversity of human benefits associated with them. Any designation of an ecological corridor requires the free, prior

Connectivity conservation provides an avenue to protect biodiversity within the mixed-use landscape matrix. Protected areas are supported by effective conservation outside their boundaries. Homes and agricultural fields in Costa Rica © Félix Zumbado Morales / ProDUS Universidad de Costa Rica

and informed consent of all relevant governance authorities. These principles are applicable to any decision making on allocation, design, establishment, management, redesign, monitoring or evaluation of ecological corridors.

The governance authority may be the same as the landowner or rightsholder of a given portion of an ecological corridor.

There are many mechanisms through which a corridor's ecological objectives might be achieved. An NGO such as a conservancy may do so through a conservation easement, or a written voluntary agreement might be reached in which the landowner/rightsholder agrees to manage a privately owned parcel of land for specific connectivity values (see Annex, Case Studies 13, 14 and 15). Likewise, a group of entities might enter a cooperative agreement, or a local Indigenous or Traditional community may hold legal rights (either by statute or customary law) to certain lands or a defined ocean space within the corridor for sustainable use of a fishery, or conservation and management of an important underwater cultural, historic, sacred or archaeological site.

Effective ecological corridor governance requires building trust, working towards shared values and goals, and developing collaboration across the full range of interests involved (Pullcord et al., 2015).

Tenure

Tenure is a separate consideration from governance (Lausche, 2011) and may take many forms. It involves the conditions and rights under which land, sea, freshwater or air space, or their associated natural resources, are held, occupied or used. While answers to questions of legal and customary tenure (i.e. who holds those rights) are important in determining governance type, they are not the sole determinant. On the contrary, a mix of tenure, whether legally or customarily defined, can be present under all governance types and be represented through a variety of instruments such as formal delegation, leasing, contracts or other agreements (Worboys et al., 2015, p. 181).

For a given ecological corridor, the tenure(s) of the area should be clear and articulated. Tenure rights, particularly for large-scale ecological corridors, may be diverse and complex, requiring a much larger scope of social alliances and cooperation to handle (Worboys et al., 2015). This requires identifying statutory and customary ownership and use rights, and negotiating with all rightsholders on their respective connectivity management roles. The fragmentation of tenure without a collaborative plan for connectivity management can be one of the main drivers of land, freshwater and seascape fragmentation.

Special issues may arise with Indigenous and local community tenure rights if there is lack of legal clarity or if they are in dispute. Sometimes this is because such peoples or communities are not recognised as collective legal entities but only as groups of individuals. This is the case in many places in Africa, Asia and Europe (Worboys et al., 2015, p. 193). In these situations, either a constitutional provision or legislative act may be needed to give collective legal recognition to such entities so they can define and defend access to their rights to use, control and transfer land or resources, as well as take on associated responsibilities.

Special problems also may arise with tenure in marine environments because issues there are often different than on land, where rights may be relatively clear (Day et al., 2012). In Exclusive Economic Zones (EEZs; see caption to Figure 1 for definition) under the UN Convention on the Law of the Sea (UNCLOS), for instance, there generally is no individual ownership of either the seabed or water column; rather, this rests with the nation. In many countries, coastal communities may own or have tenure use rights over certain marine areas or resources. These could include customary rights to traditional fishing grounds, access and management rights over sacred sites of cultural or spiritual value, or rights to sustainably use other renewable marine resources generally or on a project basis (Day et al., 2012).

Documentation of legal or other effective mechanisms

Documentation of the legal or other effective mechanisms that pertain to management of an ecological corridor should describe the governing authority and the legal or customary mechanisms that establish the area's tenure(s). Given the various contexts for the application of ecological corridors around the globe, there will be a diverse array of mechanisms for implementation. These may include:

- Land-use plans and zoning for landscapes;
- Marine spatial plans and zoning for seascapes;
- Covenants and easements;
- Incentives and disincentives;
- Regulatory controls for public health and safety;
- Development controls and building standards; and
- Written voluntary conservation agreements with specific landowners or rightsholders.

In many countries, voluntary conservation agreements are becoming an increasingly popular and effective tool for long-term conservation (see Lausche, 2011 for elaboration of elements and conditions of these agreements). Finally, an emerging area for legal attention is guidance and common rules-of-thumb for design and management of marine ecological corridors (see Lausche et al., 2013).

Longevity of the ecological corridor

Ecological corridors are expected to endure over significant periods of time, so long as the natural attributes and connectivity values for which they are designated remain. Longevity considerations especially pertain to spatially dynamic corridors, such as migration routes of large marine vertebrates (e.g. cetaceans, pinnipeds, sharks, tuna) that track shifting oceanographic patterns. The documentation needs to demonstrate the longevity and succession of the governance arrangements. In the case of written voluntary agreements, a process or mechanism to transfer implementation activities to subsequent owners should be obligatory. However, some governance mechanisms (e.g. hunting, grazing, soil

The future of the Asian elephant (*Elephas maximus*) depends on coherent conservation strategies that work across land-use tenures © Grégoire Dubois

Sea turtle migrations are some of the most wide-ranging in the marine realm, and yet the species are very site specific in their nest habitat fidelity. © Gary Tabor

conservation, fishing regulations, or seasonal use) may be time limited and subject to formal periodic review and renewal. Periodic reviews should include evaluations based on monitoring of ecological, social and economic consequences and performance metrics, when possible.

Management required to achieve objectives

The plan for an ecological corridor should describe management actions required to retain, restore or enhance ecological connectivity. The allowable activities within a corridor should relate directly to its purpose and therefore will be context specific (see Annex, Case Study 23). A multipurpose ecological corridor that is designed to facilitate the movement of all species due to climate change would likely need many more prohibited uses than one that is focused on facilitating the movement of a single species at a specific time of year. The plan should articulate management actions in terms of:

1. **Structural needs.** Are there structural ecological elements that are important to retain or enhance to ensure the corridor meets its objectives? Examples might include maintenance of a percentage of tree cover, restoration of a coral reef, implementation of riparian setbacks or maintenance of in-stream habitat components such as shaded areas, necessary water volume and velocity (see Chapter 2, section on 'Modelling Ecological Corridors' for a discussion of structural and functional connectivity; see also Annex, Case Study 21). Planned management actions should

Ecological communities can be heterogeneous and complex; functional connectivity is a reflection of its ecological context. Capivari River, Pantanal, Mato Grosso do Sul, Brazil © World Wildlife Fund (WWF), Photographer Jaime Rojo

Wildlife crossing structures such as this highway overpass in Croatia, one of 13 in the country, are no substitute for an intact landscape but have value in mitigating the effects of fragmentation for many species. © Djuro Huber

describe practices that achieve sustainable levels of structural ecological elements.

2. **Human activity management.** The management plan should prevent human pressures and threats that would increase fragmentation or undermine restoration efforts undertaken to achieve connectivity (see Annex, Case Study 5). Generally, livelihoods based on compatible activities and incentives that minimise or exclude extractive activities and other modern, industrial-scale activities should be encouraged. Decision makers (e.g. the governance authority) should determine which human activities need to be maintained, and which need to be controlled or prohibited, whether permanently or at specific times, to ensure that the corridor meets its connectivity conservation objectives. These objectives should form the foundation of a corridor's management plan or agreement.

Here are examples of some questions that planners may need to answer. If an ecological corridor includes a river, do human uses include dams, channelisation or other in-stream activities that compromise biodiversity dependent on specific habitats and natural flow regimes? If a corridor includes use by livestock, are there considerations of stocking intensity or fencing? If a corridor allows resource extraction, what management is needed to meet connectivity objectives? Are any human activities occurring that are incompatible with the ecological objectives, such as transportation infrastructure construction or industrial development? Can the design incorporate special wildlife connectivity needs, such as through the creation of wildlife overpasses or tunnels in cases where transportation or other infrastructure may otherwise impede ecological connectivity? Are there any Green Infrastructure plans, projects or methodologies being used or developed?

The management documentation for an ecological corridor should list prohibited or permissible activities and describe any restoration needed to achieve connectivity. For some activities, it may be necessary to specify a level (e.g. 'high', 'medium' or 'low') compatible with the connectivity objectives. One approach could be to create a decision framework for allowable activities (Saarman et al., 2013).

For corridors that traverse areas of poor habitat quality, restoration plans and metrics of success should be encouraged (see Annex, Case Study 11). It will be necessary to determine when an area under restoration is appropriate for inclusion within the corridor.

Corredor Florestal – Pontal do Paranapanema in Brazil demonstrates that large-scale restoration efforts can utilise connectivity conservation strategies. © IPE / Laury Cullen Jr; reproduced under Creative Commons.

Because some ecological corridors also conserve climate gradients in areas impacted by climate change, monitoring efforts can include specific climate variables in periodic assessments. Pinkwood (*Eucryphia moorei*) in higher-rainfall, moist sites on the Great Escarpment, Monga National Park, Great Eastern Ranges ecological corridor, Australia © Ian Pulsford

Monitoring, evaluation and reporting requirements

The documentation for an ecological corridor should include a monitoring and evaluation plan, along with a strategy for securing resources to implement it. Authorities responsible for an ecological corridor should plan and carry out monitoring to track progress, evaluate effectiveness in achieving stated objectives and adapt management strategies based on results. Monitoring and evaluation should support an adaptive approach to management and take into account climate change impacts. Benefits of a monitoring and evaluation plan include aiding effective resource allocation, promoting accountability and increasing public support (Hockings et al., 2006). The plan should recognise both aspirational and readily feasible components.

'Monitoring' is the collection of information about specific ecological indicators repeatedly over time to discover trends in the ecological status of a corridor and in the effectiveness of management. Monitoring provides data needed to assess the extent to which an ecological corridor is achieving its connectivity objectives (see Annex, Case Studies 6 and 14).

In conjunction with evaluation, monitoring helps assess the adequacy of management and identify necessary adjustments (Hockings et al., 2006). Monitoring and evaluation should be a long-term commitment of an ecological corridor's governance, supported by appropriate resource allocations (see Annex, Case Studies 7 and 10).

Monitoring the effectiveness of an ecological corridor for specific connectivity objectives can take various forms. These range from habitat suitability measures to empirical species movement data to conservation genetics indicators (Bennett, 2003). Where climate mitigation is an anticipated benefit, monitoring variables should include changes in the condition of ecosystems and, when feasible, in the size of carbon stocks and associated stability of storage.

In a growing number of instances, geospatial data technologies such as remote sensing, aerial photographs and satellite imagery may be combined with traditional knowledge and real-time feedback to assist with monitoring. Monitoring approaches may involve time-series collection of information or use of control groups for comparisons. Monitoring methods may be qualitative, quantitative, or both, and must be reliable, cost-effective, feasible and contextually appropriate. A monitoring plan should identify specific, achievable, relevant, time-bound and measurable indicators.

Monitoring data need to be analysed at an appropriate level to meet information needs. Data analysis should be done regularly so that adjustments to management strategies can be made as part of an adaptive management process (Conservation Measures Partnership, 2013).

Because transparency and accountability are essential components of the governance of ecological corridors, monitoring results and their meaning need to be documented and shared with the public. Documentation should include a communication plan indicating how results will be conveyed to key audiences. It is important to note that these audiences are likely to be quite diverse. They may include affected landowners, rightsholders and other stakeholders, such as local communities, project partners, agency staff, policy makers, scientific and technical advisers, and donors (see Annex, Case Study 7).

Basic documentation for reporting

Ecological corridors may be documented and tracked at both national and international levels. Appropriate mechanisms will need to be developed to report this information to global databases for area-based conservation measures, such as the Protected Planet Database managed by the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC). In addition to registering ecological corridors and networks, national and global databases will contribute to monitoring and tracking the status of these areas, as well as progress towards conservation commitments.

The basic documentation for reporting on an ecological corridor should include:

- Name of the site;
- Geographic description
- Map of location using a polygon shapefile;
- Year of establishment; and
- Contact information of reporting organisation.

Chilean flamingos (*Phoenicopterus chilensis*) rely on salt lagoons and soda lakes. These habitats are vulnerable to human disturbance. © Marie Read

Across the world, linear transportation infrastructure threatens wildlife via direct mortality and fragmentation of ecological connectivity. Top: A painted turtle (*Chrysemys picta*) makes a perilous crossing in Valentine National Wildlife Refuge, Nebraska, USA © Marcel Huijser; bottom: Greater rhea (*Rhea americana*) crossing the road near Bonito Mato Grosso do Sul Brazil © Marcel Huijser

Applications and benefits of ecological corridors in different environments

6

White-lipped tree frog (*Litoria infrafrenata*), a tropical rainforest inhabitant on Cape York, Australia © Ian Pulsford

Connectivity is relevant across a range of environments from terrestrial and marine to freshwater and airspaces. This chapter elaborates upon ecological corridor applications and benefits in different environments.

In ***terrestrial environments,*** ecological corridors may facilitate daily, migratory or dispersal movements. The last ensures gene flow between populations, such as when a young animal looks for a new home range, or wind disperses seeds. Ecological corridors can also serve multi-generational dispersals, such as climate-related range shifts over time and through space. Ecological corridors may vary greatly in size to facilitate migrations, such as those of caribou (*Rangifer tarandus*), which travel hundreds or thousands of kilometres, to those of a population of Jefferson salamanders (*Ambystoma jeffersonianum*) near Burlington, Ontario, Canada, which move a short distance from upland forests to temporary ponds where they lay their eggs.

A terrestrial ecological corridor may be a continuous space, such as that which connects populations of lions (*Panthera leo*) across communal pastoral lands in the Kavango–Zambezi Transfrontier Conservation Area (Angola, Botswana, Namibia, Zambia, Zimbabwe; see Annex, Case Study 2). Alternatively, an ecological corridor can be a series of discontinuous terrestrial spaces that serve as stopover sites for airborne migratory animals, such as monarch butterflies or red knots (*Calidris canutus*), the latter of which migrates between the Northern and Southern hemispheres. However, such discontinuous corridors function only when aligned with migratory pathways (e.g. flyways) to ensure connectivity.

Ecological corridors in ***freshwater systems*** should conserve water flows and riparian communities, along with the movement of sediments and other natural materials. They should also allow for movement by native animals and plants. Freshwater ecological corridors may also facilitate daily, migratory or dispersal movements. These corridors provide pathways for movement between habitat patches within a particular freshwater system or across freshwater habitats (e.g. between the main stems of rivers and floodplains, or between rivers, lakes and estuaries) for species that require access to multiple habitats to complete their life cycles. Freshwater corridors may conserve lateral connectivity, for example between a river channel and an adjacent floodplain, such as in gravel-bed ecosystems that require exchanges of matter and energy to sustain viable populations of certain species (Hauer et al., 2016). Particularly in rivers, natural flows of sediment and gravel are also critical for creating habitats upon which many species rely. The vegetation of riparian

The great monarch butterfly migration serves as the iconic continental-scale migration of all invertebrate species. Migrating across long distances and several life generations, monarch butterflies remind us of how vital movement ecology is for species survival. © Adobe Stock

Wetland systems are essential components of any freshwater connectivity conservation strategy. Kings Plains Lake on Kings Plains–South Endeavour Trust Reserve – a wetland in the wet/dry tropics on Cape York, Australia © Ian Pulsford

Rivers are the lifeblood of terrestrial ecosystems. Terrestrial and freshwater systems are inextricably linked. Gravel-bed stream in Costa Rica © Félix Zumbado Morales / ProDUS Universidad de Costa Rica areas and floodplains slows down and reduces peaks in the swellings of rivers while retaining sediments, thus decreasing the energy and destructive power of water flows. Freshwater ecological corridors may also help conserve aquifers and protect groundwater-dependent ecosystems such as springs, karst wetlands and certain types of floodplains (Tomlinson & Boulton, 2010). Such corridors often include and require maintenance of riparian vegetation, which influences the quality of freshwater habitat. The corridors may provide habitat and travel routes for terrestrial species, and may act as filters for pollutants and surface flow runoff. Freshwater ecological corridors with riparian vegetation also protect water bodies from undesired inputs of pollutants in highly developed landscapes (Bastian et al. 2015).

Freshwater ecological corridors may be established for water bodies that flow constantly or intermittently. In both cases, riparian zone restoration and prevention of impairments will often be required. As described above, wetlands and other freshwater areas may be part of a discontinuous terrestrial ecological corridor.

Ecological corridors in ***marine environments*** may connect marine protected areas (MPAs) or other key marine, coastal and estuarine habitats (Day et al., 2012). MPAs are unlikely to encompass the full movements of highly mobile marine mammals, fishes or reptiles, or to accommodate the complete larval stages of sessile fishes, invertebrates, plants and algae.

Ecological corridors, as essential elements of marine ecological networks for conservation, can conserve known migration routes and bottleneck zones, such as those between islands that are vulnerable to human activities. Conservation of marine connectivity is also important for juvenile fishes and invertebrate larvae that disperse via ocean currents over periods of days or months before settling on reefs or other substrates (Gotlanders et al., 2003; Cowen & Sponaugle, 2009), as well as for larger animals such as turtles and whales that migrate long distances.

Marine ecological corridors may be especially important for species that use different environments at different stages of their life cycles. For example, marine turtles nest on beaches and may use coastal waters before moving into the high seas, while certain fish may need to migrate to reach a spawning aggregation site. Ecological corridors also facilitate the role of MPAs as sources of species replenishment to populations elsewhere. Marine ecological corridors may need to be quite large given the extent to which oceanic currents, eddies and tides affect processes and the recruitment of organisms. Alternatively, marine ecological corridors could be relatively small to protect migrations of a few kilometres, such as those of red crabs (*Gecardoidea natalis*) on Australia's Christmas Island. Siting of three-dimensional ecological corridors may be affected by water depth; geological features, such as sea mounts; stratification of the water column; or seasonal currents or wind flows (Cowen et al., 2007).

Geophysical processes such as daily tides govern the natural processes that connect and sustain marine and coastal systems. Tropical coral reef on Upolu Island, Samoa © Adobe Stock

Over 50 million red crabs (*Gecarcoidea natalis*) traverse Christmas Island, Australia, to lay their eggs in the ocean. © Adobe Stock

Formal recognition of ecological corridors for marine species such as humpback whales (*Megaptera novaeangliae*) could extend recognised conservation areas from waters under national jurisdiction to the high seas, consistent with the CBD Conference of the Parties decision of 2008 (CBD Guidance on Marine and Coastal Protected Areas and Networks COP 2008 IX/20, Annexes I and II).

Mixed ecological corridors encompass two or all three types of environment (terrestrial, freshwater and/or marine). For example, ecological corridors that span marine and estuarine areas into freshwater reaches may facilitate essential life-cycle movement for anadromous and catadromous fish species (which move from the sea to rivers to spawn and vice versa). Such fish range so widely in marine and freshwater environments that an ecological corridor may not link specific protected or conserved areas but rather conserve critical migration pathways (see Annex, Case Studies 17 and 22).

Likewise, mixed ecological corridors may link MPAs to estuaries to facilitate the movement necessary to sustain species populations and evolutionary processes. These corridors also may connect MPAs with terrestrial protected areas to sustain ecological processes such as migration. There is also an opportunity to maximise the benefits for freshwater and terrestrial species by looking for synergies in migration pathways and habitat needs across realms.

Many birds, insects and other animals move through Earth's ***airspaces.*** The possibility of an air-based or air-column ecological corridor is beginning to be considered due to collisions of birds and bats with wind turbines, high-rise buildings and other human structures (Rydell et al., 2010; Loss et al., 2013). Furthermore, overhead power lines have recently been discovered to produce stroboscopic ultraviolet lights that may act as a barrier to the movement of some bird species (Tyler et al. 2014). Currently, airspace ecological corridors are theoretical, and further work is needed to determine if they are feasible in practice.

In all four of these realms of the biosphere, rapid climate change is increasing the need for ecosystem resilience and for species to adapt to changing conditions. Ecological corridors can contribute to both climate resilience and adaptation. Large, connected terrestrial and aquatic ecosystems are more resilient to climate change because ecological processes important for stability are more likely to be functioning there (Walker & Salt, 2006). Connecting protected areas, OECMs and other important biodiversity areas by means of ecological corridors allows species to adapt to climate change by shifting their ranges to new, suitable habitats and climates. In contrast, habitat loss and fragmentation can prohibit these range shifts. Therefore, protecting and establishing ecological corridors can be an

A toco toucan (*Ramphastos toco*) from Mato Grosso, Brazil, flies across habitat patches in search of food. © Grégoire Dubois

effective strategy to facilitate species persistence (reviewed in Keeley et al., 2018; see Annex, Case Study 8).

Ecological corridors can be designed and managed taking climate considerations into account. Approaches include (see also Gross et al., 2016):

- Ensuring that they contain diverse topography that provides different microclimates for species persistence;
- Establishing them to connect protected areas and conserved areas that can serve as climate refugia;
- Prioritising those that connect protected and conserved areas that together encompass temperature gradients;
- Managing them to account for the rapidity of climate change;
- Managing them to account for animal and plant population dynamics at the leading and trailing edges of ranges;
- Designing them for multiple species redistributions to maintain critical species interactions (e.g. those of mutualists);
- Designing them to facilitate redistribution of genetic diversity in a representative manner;
- Designing them so they can change spatially in sync with climate changes (e.g. those affecting winds, ocean currents, deep-sea chemistry and temperatures, or riparian zones);
- Ensuring that they are sufficiently wide to provide live-in habitat for slow-moving species; and
- Where appropriate, restoring or enhancing vegetation with drought-resistant species to provide resources for wildlife throughout the year.

The emergence of connectivity conservation law and policy

7

Indian rhinoceros (*Rhinoceros unicornis*), Kaziranga National Park, Assam, India © Grégoire Dubois

Most global and regional legal instruments dealing with biodiversity conservation, climate change and environmental sustainability have objectives that will not be met without addressing connectivity conservation effectively over the long term. As a result, at the international level there is growing recognition of ecological connectivity in law and policy. Maintaining connectivity as a core conservation objective can be found in the Aichi Biodiversity Targets of the CBD, the Call to Action for Landscape Connectivity of the World Business Council for Sustainable Development, *A Global Standard for Identification of Key Biodiversity Areas* (IUCN, 2016) and *Guidelines for Applying Protected Area Management Categories* (Dudley, 2008).

In 2010, the Parties to the CBD adopted a 10-year Strategic Plan for Biodiversity that included the 20 Aichi Biodiversity Targets (CBD, 2011). Aichi Target 11 states that by 2020 the planet's area under protection will be increased to at least 17% of terrestrial and inland waters, and 10% of marine and coastal areas, in "effectively and equitably managed, ecologically representative and well-connected systems of protected areas" (CBD, 2011). A recent review of 746 MPAs found that only 11% identified connectivity as a management consideration (Balbar & Metaxas, 2019). Most countries lag significantly behind in implementing the connectivity element of Aichi Target 11.

A principal recommendation of these Guidelines is that the designation 'ecological corridor' be recognised in law and policy internationally. Ecological corridors provide an important mechanism for countries to advance legal obligations and policy commitments, which notably include the CBD, Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention), Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention) and its ancillary instruments, World Heritage Convention, UNCLOS, UN Framework Convention on Climate Change, and UN Educational, Scientific and Cultural Organization's (UNESCO's) Man and the Biosphere Programme. There are also numerous regional conventions, including the Revised African Convention on the Conservation of Nature and Natural Resources (Maputo Convention) and the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention; promoting the European 'Emerald' Network), the UN Convention on Non-Navigational Uses of International Watercourses, and the Convention on the Protection and Use of Transboundary Watercourses.

At the international level there are also non-treaty conservation networks, such as the European Union's (EU's) Natura 2000, which covers terrestrial, freshwater and marine environments and applies to all EU Member States, and also includes other directives such as the Water, Marine Strategy, and Maritime Spatial Planning Frameworks (Lausche et al., 2013; European Parliament & Council, 2014). In addition, the IUCN WCPA's Transboundary Conservation Specialist Group has developed detailed guidance on transboundary conservation that is highly relevant to connectivity (Vasilijević et al., 2015).

Vicuñas (*Vicugna vicugna*) are found across the high slopes of the Andes. Reserva de Producción de Fauna Chimborazo, Ecuador © Gabriel Oppler

An Assam roofed turtle (*Pangshura sylhetensis*) takes advantage of a connected wetland area within and surrounding Kaziranga National Park, Assam, India.
© Grégoire Dubois

At the national level, a variety of policies, laws, administrative authorities, regulations and plans also require or benefit from connectivity conservation to meet their objectives (Lausche et al., 2013). Government policies and plans such as National Sustainable Development Strategies and National Biodiversity Strategies and Action Plans (NBSAPs) guide overall development. Virtually all national legal systems also have specific laws relevant to ecological corridors that deal with nature, wildlife and biodiversity conservation, and sustainable use (e.g. laws covering forestry, fisheries, grazing lands and water flows) and use direct regulation or voluntary conservation agreements, often with incentives.

Connectivity objectives are increasingly prevalent in national and sub-national planning and policy initiatives. Until recently, connectivity legislation was rare at the national or even sub-national level (Lausche et al. 2013). Now, countries such as Bhutan, Costa Rica and Tanzania, and sub-national jurisdictions such as California and New Mexico (USA), have enacted corridor legislation. Additionally, site-specific legislation has been enacted in some countries. For example, the South Korea Act on the Protection of the Baekdu Daegan Mountain System, 2003 (Act no. 7038), which came into effect in 2005, designates an area of 263,427 ha. Of this, 86% is made up of 183 existing protected areas and 14% consists of new buffer and core areas that create a biodiversity corridor along the main mountain range of the Korean Peninsula (Miller & Hyun, 2011; see also Farrier et al., 2013, and KLRI, 2014, for other case studies of legal actions to protect specific connectivity areas).

For the most part, however, current national and sub-national efforts to conserve connectivity utilise and adapt existing policies and laws. Conservation and sustainable resource use laws are the first tier for this purpose. These include protected areas laws, general biodiversity or nature conservation laws, and resource-specific laws such as those relating to sustainable use of forests, fisheries, soils or water. These instruments normally involve direct regulation and arguably should give attention to connectivity conservation to meet their objectives effectively. Supportive laws may extend to hunting controls, integrated resource management and environmental pollution controls. Major substantive areas of law beyond traditional conservation instruments are also important. These include laws and policies on land-use planning; development controls (e.g. through zoning); marine spatial planning; acquisition of rights by government permits and licences for transportation, infrastructure, mining and energy; conservation easements and voluntary agreements; and strategic and project-focused environmental assessments.

Economic instruments are another suite of available tools that may reinforce direct regulation or serve as an alternative approach to support connectivity conservation. These instruments may encourage certain behaviour that could include actions of landowners and rightsholders to further

Private land incentives are critical in supporting connectivity efforts that span private and public land domains. Intensively managed Naturpark Beverin, Switzerland © Juraj Švajda

Zebras from Masai Mara Reserve, Kenya, range widely into surrounding communal lands. The rise of private conservancies in Africa has potential to support connectivity conservation goals. © Gary Tabor

specific ecological corridor objectives. Such instruments include positive incentives (e.g. technical assistance, subsidies, tax credits, or reduced tax liability); negative incentives (e.g. tax increases or withholding of technical assistance); compensation for conservation actions or loss of economic productivity; payments for environmental services or stewardship (e.g. maintenance of forest cover, restoration of riparian areas, or other green infrastructure); and market-driven tools such as tradeable permits and conservation/bio-banking (see Lausche et al., 2013, for an extensive discussion of such tools for both terrestrial and marine environments).

The formal process of amending or enacting new legal instruments takes significant time and should not delay efforts to protect and secure ecological corridors. While legal approaches will vary, most countries' legal systems – national and sub-national (provincial, state, etc.) – already have a number of tools in place to begin the essential process of recognising and protecting ecological corridors, including through such instruments as NBSAPs and national Climate Change Action Plans (see Annex, Case Studies 1 and 2). These tools should be identified and analysed as soon as possible for key connectivity sites before their conservation is no longer economically or politically feasible, even as the longer-term process of amending or enacting new connectivity-specific legislation is pursued.

The development of ecological corridors contributes to the broader approach known as 'Nature-based Solutions', defined by IUCN as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." Guidance on Nature-based Solutions can be found in Cohen-Shacham et al. (2016).

Nomination of ecological corridors and ecological networks for conservation to the Protected Planet Database

Governance authorities may voluntarily report ecological corridors and ecological networks for conservation to the Protected Planet Database managed by UNEP-WCMC and IUCN, which encourage the practice. At the time of publication, the reporting structure is under development with partners. Check with www.protectedplanet.net to verify if this database is online.

Generally, a given country's focal point for the Protected Planet Database would report the ecological corridor or an ecological network for conservation using the reporting portal. There is also an opportunity for individual governance authorities to report directly to the Protected Planet Database. Landowners or rightsholders retain the right to object to the external nomination or recognition of their area as an ecological corridor in cases in which their free, prior and informed consent has not been obtained. This applies to all four governance types, as set out in the 'Governance' section of Chapter 5.

Inscribing an area as an ecological corridor or an ecological network for conservation in the Protected Planet Database places a heightened responsibility on the governance authority to continue to manage the area over the long term in ways that achieve its specific connectivity goals. The authority is responsible for reporting any changes in boundaries, governance or objectives. While national circumstances differ, it is hoped that national or regional legislation will provide greater support and recognition to existing governance systems and not supplant or unnecessarily alter any local arrangements.

Conclusion

8

Red-shouldered hawk (*Buteo lineatus*), Chesapeake & Ohio Canal National Historical Park, Maryland, USA © Nicholas Tait

Ecological corridors in terrestrial, freshwater and marine ecosystems are a critical conservation designation needed to ensure healthy ecosystems. They are a key component of ecological networks for conservation and complement the objectives of protected areas and OECMs by knitting together these core habitats and other intact natural areas. These Guidelines support the growing demand for connectivity conservation, recognised by scientists, policy makers and practitioners. Connectivity conservation requires innovative implementation approaches to conserve lands and water within the conservation matrix – across patterns of resource use, jurisdictions, cultures and geographies. These Guidelines provide direction on how to conserve vital ecological connectivity values in every conservation situation in a consistent and measurable fashion. The toolbox for connectivity conservation includes various types of formal and informal recognition, national legislation, local and regional zoning regulations, conservation easements, conservancy design and transportation planning. Our world needs such a diversity of actions to maintain and restore ecological connectivity, an essential part of halting biodiversity loss and adapting to climate change.

There are many dimensions of ecological connectivity, including gene flow, movement of individuals, metapopulation dynamics, migration, seasonal dispersal and flows of ecological processes. The terms ecological networks and ecological corridors have been defined and operationalised throughout these Guidelines to establish a common set of terms, principles and approaches that can be consistently applied, yet tailored to the specific contexts of ecological connectivity around the world. Connectivity conservation will be enhanced by speaking this common language and working together toward shared successes.

The science underpinning connectivity conservation clearly supports that larger, well-connected areas are more likely to maintain biodiversity and ecological integrity. Given the current biodiversity and climate crises, there is an urgent need to restore and sustain ecological connectivity among and between protected areas, OECMs and other intact natural areas. By connecting these areas with each other, it is possible to arrest and reverse ecosystem fragmentation.

Well-connected ecosystems support a diversity of ecological functions including migration, water and nutrient cycling, pollination, seed dispersal, food security, climate resilience and disease resistance.

The loss of ecological connectivity is most often a consequence of policy and management decisions made by the development, transportation, agriculture and extraction sectors. These Guidelines and Case Studies provide insights into examples and best practices to demonstrate approaches that can ensure ecological connectivity for different ecosystems and species, and at different spatial and temporal scales. An emphasis on human and technical capacity is required for mainstreaming and accelerating uptake of connectivity conservation measures to buffer and better adapt to the impacts of climate change.

Ecological connectivity often transcends national boundaries and can span different ecosystems within a country. The strategies and approaches outlined here take into careful consideration how national and regional transboundary measures can be formed and contribute to aggregated accomplishments internationally. Planning and implementing ecological networks and corridors require specific objectives to be set, and governance and management mechanisms to be aligned with achieving effective conservation outcomes.

Most global, regional and national targets for biodiversity conservation, climate change and environmental sustainability cannot be met unless ecological connectivity conservation is addressed. The importance of connectivity in achieving the objectives of the Convention on Biological Diversity cannot be overstated. As such, it is highly relevant for accomplishing the current and future objectives of many other Multilateral Environmental Agreements. Ecological connectivity – if further recognised in law and policy around the world – can serve as an integrative and cross-cutting mechanism to advance obligations and commitments within and across national borders. Overall, connectivity conservation, by linking together protected areas, OECMs and ecological corridors, offers scalable solutions for environmental, social and economic challenges. The world needs – and it is in our collective interest — to protect, maintain and restore ecological connectivity.

Glossary

Biodiversity: The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems (CBD Article 2, 1992).

Connectivity

- **Ecological connectivity:** The unimpeded movement of species and the flow of natural processes that sustain life on Earth (CMS, 2020).

  There are various sub-definitions of *ecological connectivity* that are useful in the context of these Guidelines:

  - **Ecological connectivity for species (scientific-detailed definition):** The movement of populations, individuals, genes, gametes and propagules between populations, communities and ecosystems, as well as that of non-living material from one location to another.
  - **Functional connectivity for species:** A description of how well genes, gametes, propagules or individuals move through land, freshwater and seascape (Rudnick et al., 2012; Weeks, 2017).
  - **Structural connectivity for species:** A measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances and other land, freshwater or seascape elements presumed to be important for organisms to move through their environment. Structural connectivity is used in efforts to restore or estimate functional connectivity where measures of it are lacking (Hilty et al., 2019).

Conservation: The protection, care, management and maintenance of ecosystems, habitats, wildlife species and populations, within or outside of their natural environments, in order to safeguard the natural conditions for their long-term permanence.

Dispersal: The condition of individuals or seeds moving from one site to a breeding or growing site.

Ecological corridor: A clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity. The following terms are often used similarly: 'linkages', 'safe passages', 'ecological connectivity areas', 'ecological connectivity zones', and 'permeability areas'.

Ecological indicator: A measurable entity related to a specific ecological information need, such as the status of a population, a change in a threat or progress toward an ecological objective (Hilty & Merenlender, 2000).

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 (see Bennett & Mulongoy, 2006).

Ecosystem: A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit. It is the sum total of all the abiotic and biotic processes going on in an ecosystem that transfer energy and matter within and between ecosystems (e.g. biogeochemical cycles, primary production, etc.) (CBD Article 2, 1992).

- **Ecosystem functioning:** The collective life activities of plants, animals and microbes and the effects these activities – feeding, growing, moving, excreting waste, etc. – have on the physical and chemical conditions of the environment (Naeem et al., 1999).
- **Ecosystem services:** The benefits people obtain from ecosystems. These include provisioning services such as food and water production; regulating services such as flood and disease control; cultural services such as spiritual, recreational and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth (Millennium Ecosystem Assessment, 2005).
- **Ecosystem structure:** The biophysical architecture of an ecosystem; the composition and arrangement of all the living and non-living physical matter at a location (Russi et al., 2013).

Flyway: The entire range of a migratory bird species, distinct populations of a species, or groups of related species through which individuals move on an annual, seasonal or multi-year basis from breeding grounds to non-breeding areas. The term also includes intermediate resting and feeding places, as well as the areas within which the birds migrate (Boere & Stroud, 2006).

Fragmentation: The breaking up of a habitat, ecosystem or land-use type into smaller and, often, more isolated parcels, thereby reducing the number of species that can be supported.

Governance authority: The institution, agency, individual, Indigenous Peoples or community group, or other body acknowledged as having authority and responsibility for decision making over an area, and whose authority may include management of an area (IUCN WCPA, 2019; Borrini-Feyerabend et al., 2013). It is to be recognised that there may be multiple governance authorities, both formal and informal.

Governed: The condition in which an area is under the authority of a specified entity or entities conducting the actions, policy and affairs of the area. Ecological corridors can be governed under the same range of governance types as protected areas.

Habitat: The place or type of site where an organism or population naturally occurs (CBD Article 2, 1992).

Indigenous Peoples: Tribal peoples whose social, cultural and economic conditions distinguish them from other sections of the national community, and whose status is regulated wholly or partially by their own customs or traditions or by special laws or regulations. The term also includes peoples in independent countries who are regarded as indigenous on account of their descent from the populations that inhabited the country, or a geographical region to which the country belongs, at the time of conquest or colonisation or the establishment of present state boundaries and who, irrespective of their legal status, retain some or all of their own social, economic, cultural and political institutions (Borrini-Feyerabend et al., 2004; following IUCN's use of the International Labour Organization's ILO Convention 169 on Indigenous and Tribal Peoples). Preferred terminology varies around the world, and terms such as 'Aboriginal' or 'Traditional Peoples' are sometimes used instead.

Landscape: A heterogeneous space comprising a cluster of interacting ecosystems, geological features and ecological processes, and often including human influences (Forman & Godron, 1986; Wu, 2008). Landscapes are generally large, but can be defined at a range of spatial scales. Interaction of landscape spatial elements can result in emergent effects not inherent to each element separately (e.g. viability of populations, microclimates, runoff regulation, aesthetic quality, etc.).

Local community: A human group sharing a territory and involved in different but related aspects of livelihoods such as managing natural resources, producing knowledge and culture, and developing productive technologies and practices. Since this definition can apply to a range of community sizes, it can be further specified that the members of a 'local community' are those who are likely to have face-to-face encounters and/or direct mutual influences in their daily lives. In this sense, a rural village, a clan or the inhabitants of an urban neighbourhood can be considered a 'local community', but not all the inhabitants of a district, a city quarter or even a rural town. A 'local community' could be permanently settled or mobile (Borrini-Feyerabend et al., 2004).

Managed: In the context of an ecological corridor, the condition of taking active steps to conserve or restore the natural (and possibly other) values to ensure functionality. Note that 'managed' can include decisions not to intervene in an area.

Migration: The regular annual or seasonal movement of individual animals or populations of animals between distinct habitats, each of which is occupied during different parts of the year (Lindenmayer & Burgman, 2005).

Migratory species: The entire population or any geographically separate part of the population of any species or lower taxon of wild animals, a significant proportion of whose members cyclically and predictably cross one or more national jurisdiction boundaries (CMS Article 1, 1979).

Monitoring: The collecting of information on indicators and/or targets repeatedly over time to evaluate trends in the status of conservation targets, often related to effectiveness of management and/or governance activities (e.g., Hilty & Merenlender, 2000).

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).

Populations: All the organisms of the same species that live in a specific geographic area at the same time and have the capability of interbreeding.

Protected area: A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008; Stolton et al., 2013).

Resilience: In the context of ecological networks for conservation, the capacity of a part or the whole of an ecological network to withstand changes to the processes that control its structures and functions (Holling & Gunderson 2002).

Restoration: In the context of ecological corridors, the recovery of ecological connectivity that has been diminished, impaired or destroyed (modified from Society for Ecological Restoration International Science & Policy Working Group, 2004). Restoration is guided by scientific inputs that help prioritise actions.

Rightsholders, stakeholders: In the context of protected areas and conservation, the term 'rightsholders' refers to people (such as but not limited to landowners) socially endowed with legal or customary rights with respect to land, water and natural resources. By contrast, 'stakeholders' possess direct or indirect interests and concerns about these resources but do not necessarily enjoy a legally or socially recognised entitlement to them (Borrini-Feyerabend et al., 2013).

Seascape: A spatially heterogeneous marine region that can be delineated at a range of scales and which includes physical, geological and chemical aspects of oceans. It can be a combination of adjacent coastline and sea, such as mangroves, coral reefs, seagrass beds, tidal marshes and deep seas. It includes the features of the geology and morphology of the sea floor as well as the living communities of the benthos, water column and surface, and often includes the influence of humans (Pittman, 2017; Fuller, 2013). Seascapes are generally large, but can be defined at a range of spatial scales.

Sustainable use: The use of components of biological diversity in a way and at a rate that does not lead to the long-term decline of biological diversity, thereby maintaining the potential to meet the needs and aspirations of present and future generations (CBD Article 2, 1992).

The Russian River corridor in California, USA, maintains ecological connectivity as the river passes through agricultural, residential and urban landscapes.
© Adina Merenlender

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Annex: Approaches to conserving ecological corridors in ecological networks

Introduction

This compendium of case studies illustrates initiatives around the world that are working toward protecting or restoring ecological connectivity. The case studies offer insight into the breadth of approaches being used to advance conservation of ecological corridors to benefit ecological networks in terrestrial, freshwater and marine realms (Table 5). Each case study describes the context and challenges to connectivity in the study region, explains the approach to conservation, presents an example of an ecological corridor in the network, and shares some results. The case studies were selected to demonstrate a variety of ecological networks for conservation and ecological corridors within them, as well as a variety of approaches to their conservation. These examples can help us understand both the diversity of current efforts and the need to move toward formalising ecological corridors as elements of ecological networks for conservation

Table 5. Schematic overview of the case studies.

Case study title	Type of study region	Greatest threat to connectivity	Approaches to conserving ecological corridors
1. Kilimanjaro Landscape: Ensuring the viability of wildlife populations	terrestrial, rural	habitat loss and fragmentation	• conservation lease programme for private landowners
2. Connectivity conservation in the Kavango Zambezi Transfrontier Conservation Area: The Zambezi-Chobe Floodplain Wildlife Dispersal Area	terrestrial, rural	deforestation, uncontrolled settlements, overgrazing, over-exploitation of fish, uncontrolled fires	• establishment of a five-country transfrontier conservation area • development of integrated development plans • creating awareness and engaging local stakeholders • establishment of community conservancies • promotion of conservation agriculture • establishment of wildlife sanctuaries
3. Conserving six landscapes of the Albertine Rift to ensure connectivity	terrestrial, rural	habitat loss and fragmentation	• facilitating cooperation • developing sustainable-use community areas
4. The Kilombero Valley Ramsar site, United Republic of Tanzania	terrestrial, rural	sustained human immigration and growing settlements and agriculture	• designation as a Ramsar site • transitional governance approach from central management of large protected areas to management of a mosaic of smaller protected areas
5. Ecological corridor for the reunion of giant pandas in the Qinling landscape	terrestrial, rural	highway and human land use	• baseline survey and mapping • habitat restoration • community engagement • traffic management • capacity enhancement • wildlife monitoring
6. Thailand's experience in ecologically connecting its protected areas	terrestrial, rural	deforestation and conversion of forests into plantations	• establishment of non-hunting areas and buffer zones • management of lands for connectivity
7. East Coast Conservation Corridor in Tasmania	terrestrial, rural	land-use change	• restoration • land-use planning • management for connectivity
8. The Great Eastern Ranges: Australia's first continental-scale ecological network for conservation	terrestrial, rural	land degradation	• restoration • conservation by private landowners • community education • biological surveys • research programs

Table 5 (continued). Schematic overview of the case studies.

Case study title	Type of study region	Greatest threat to connectivity	Approaches to conserving ecological corridors
9. COREHABS to BearConnect: Securing ROAMing in the wilderness corner of Europe	terrestrial, rural	rapid infrastructure development	• identification and assessment of ecological corridors • integration of protected areas and ecological corridors into cadastral plans and land registers
10. Ecological connectivity in an urban context: Utrechtse Heuvelrug, Netherlands	terrestrial, urbanised	pressures from infrastructure, urban expansion, intensive agriculture and recreation	• landscape defragmentation through road crossings and open space preservation
11. The Spanish National Network of Drover's Roads (Vías Pecuarias)	terrestrial, rural and urbanised	loss of extensive livestock farming and transhumance	• legal protection • ecological corridor demarcation • fostering of extensive livestock farming, encouragement of young people to transhumance and cattle farming • restoration • education • exploitation of multifunctionality
12. ECONET: Ecological network in the Kostroma Region, Russia	terrestrial, rural	deforestation	• ecological network consisting of protected areas and ecological corridors • protected areas with different regimes of multifunctional activities
13. Sustaining forested landscape connections in the northern Appalachians: The Staying Connected Initiative	terrestrial, rural and urbanised	fragmentation from roads and human development	• focus work in nine highest-priority linkage areas • strategic land protection • land-use planning • community outreach and engagement • habitat restoration • transportation mitigation
14. Yellowstone to Yukon (Y2Y): Connecting and protecting one of the most intact mountain ecosystems	terrestrial, rural	fragmentation from roads and human development	• protection of areas important for biodiversity • restoration and maintenance of areas for ecological connectivity • direction of development away from areas of biological importance • promotion of people and wildlife living in harmony
15. Conserving long-distance migration: The Red Desert to Hoback Mule Deer Corridor, Wyoming, USA	terrestrial, rural	human development	• detailed mapping of migration routes • assessments of land-use patterns and threats along the routes • land protection • land management • road crossings
16. Corridors for life: Improving livelihoods and connecting forests in Brazil	terrestrial, rural	landscape fragmentation from agriculture and settlements	• vision plan for large-scale reforestation • enlargement and eventual connection of forest fragments through reforestation • adoption of biodiversity-friendly land-use options • promotion of change in land-use practices • adoption of sustainable agriculture and agroforestry • improvement of farmers' livelihoods • carbon offsets
17. Connectivity, ecosystem services and Nature-based Solutions in land-use planning in Costa Rica	terrestrial, rural	human development	• municipal land management plans

Table 5 (continued). Schematic overview of the case studies.

Case study title	Type of study region	Greatest threat to connectivity	Approaches to conserving ecological corridors
18. The Jaguar Corridor Initiative: A range-wide species conservation strategy	terrestrial, rural	human land-use changes	• modelled ecological corridors • prioritised populations and ecological corridors • validated modelled corridors using a rapid-assessment interview-based methodology • varied implementation action at local level
19. Grassroots reserves have strong benefit for river ecosystems in the Salween River Basin	freshwater, rural	overfishing	• ecological networks of small riverine reserves
20. The ecological corridor Mura-Drava-Danube and future five-country biosphere reserve	freshwater, rural	human land-use changes	• transboundary cooperation for harmonised conservation, integrated management and restoration • establishment of a transboundary biosphere reserve
21. Pacific salmon watersheds: Restoring lost connections	freshwater, rural	dams hindering fish migrations	• dam removal and mitigation to benefit salmon and other migratory fishes
22. Fragmentation of riparian protections throughout catchments, Oregon, USA	freshwater, rural	human land uses and fragmented land protections along the continuum of the river	• development of an understanding of the mosaic of protective efforts to identify gaps in them
23. Protection of the free-flowing Bita River	freshwater, rural	extractive industries, livestock grazing, large timber plantations, and urbanisation	• formation of an alliance • working with local stakeholders • decision-making framework to choose best conservation actions • protection as a Ramsar site
24. The Great Barrier Reef – Systematically protecting connectivity without connectivity data	marine	recurrent coral reef bleaching, cyclones, invasive species outbreaks, poor water quality, unsustainable fishing, dredging and coastal development	• networks of strategically placed marine reserves • zoning based on systematic planning principles
25. Northern Channel Islands: Connectivity across a network of marine protected areas contributes to positive population and ecosystem consequences	marine	human impacts such as fisheries, invasive species, and climate change	• marine protected area network with resulting ecological corridors

Terrestrial connectivity: Africa

1. Kilimanjaro Landscape: Ensuring the viability of wildlife populations

Kathleen H. Fitzgerald, *African Wildlife Foundation*

Key lesson

Conservation lease agreements support the viability of Amboseli National Park wildlife populations, and could move toward being enduring ecological corridor(s) recognised by the world.

Context and challenge

The transboundary Kilimanjaro Landscape stretches from Amboseli National Park to Chyulu National Park and Tsavo West National Park in Kenya to Mount Kilimanjaro National Park in Tanzania (Figure 1). Amboseli National Park, 392 km^2, forms the core of the ecosystem while six community lands, group ranches, surround the park. Amboseli National Park is world-renowned for its elephants and magnificent views of Mount Kilimanjaro, but the park is too small to support viable populations of wildlife. Wildlife depends on the unprotected areas outside the park. If the ecosystem is to support wildlife in the long term, the areas surrounding the park must be protected.

The greatest threat in the landscape is habitat loss and fragmentation (Figure 2). A majority of the group ranch land surrounding the park was subdivided into 0.8-ha, 4-ha and 24-ha lots allocated to individual Maasai landowners. The subdivision is primarily due to a breakdown in communal systems, failure of the group ranch system to deliver equitable benefits and improve community livelihoods, and a more sedentary way of life. Some Maasai landowners are selling their land for development and agriculture.

Approach

In 2008, the African Wildlife Foundation (AWF, www.awf.org) launched a conservation lease program to:

- Contribute to the sustainability of Amboseli National Park by protecting strategic ecological corridors;
- Prevent conversion of habitat; and
- Provide incentives directly to landowners to keep their land open and passable to wildlife.

AWF worked with individual landowners to help them understand that collectively their land was more valuable than individually, which resulted in the landowners forming associations. This enabled them to make collective decisions while retaining and benefitting from their individual landownership. These associations range in size from 50 to 90 landowners. Through these associations, AWF engaged the landowners in a discussion about conservation leases and payment for ecosystem services (PES). AWF proposed to lease land from the Maasai via a PES arrangement and pay them to keep their land open for wildlife. Different organisations now manage and pay for the leases in the Amboseli ecological corridors, including AWF, Tawi Lodge

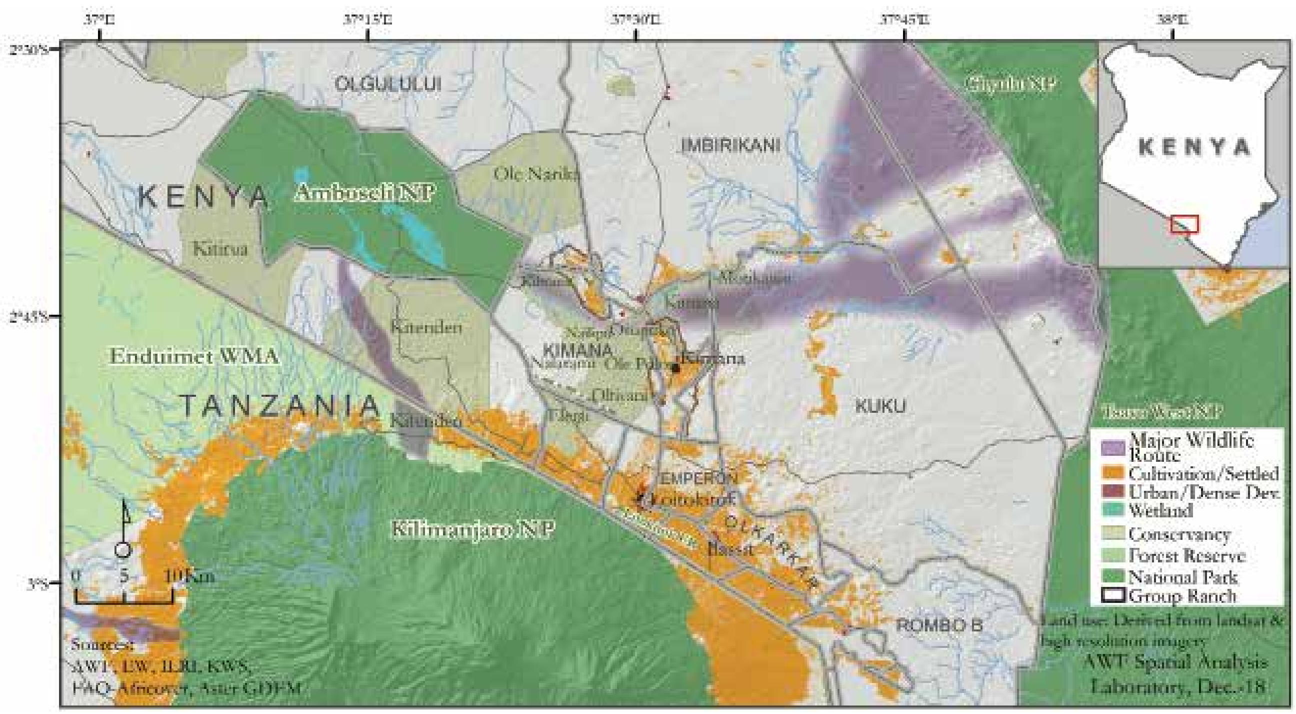


Figure 1. The Kilimanjaro landscapes showing community-owned wildlife conservancies established by AWF to protect key ecological corridors

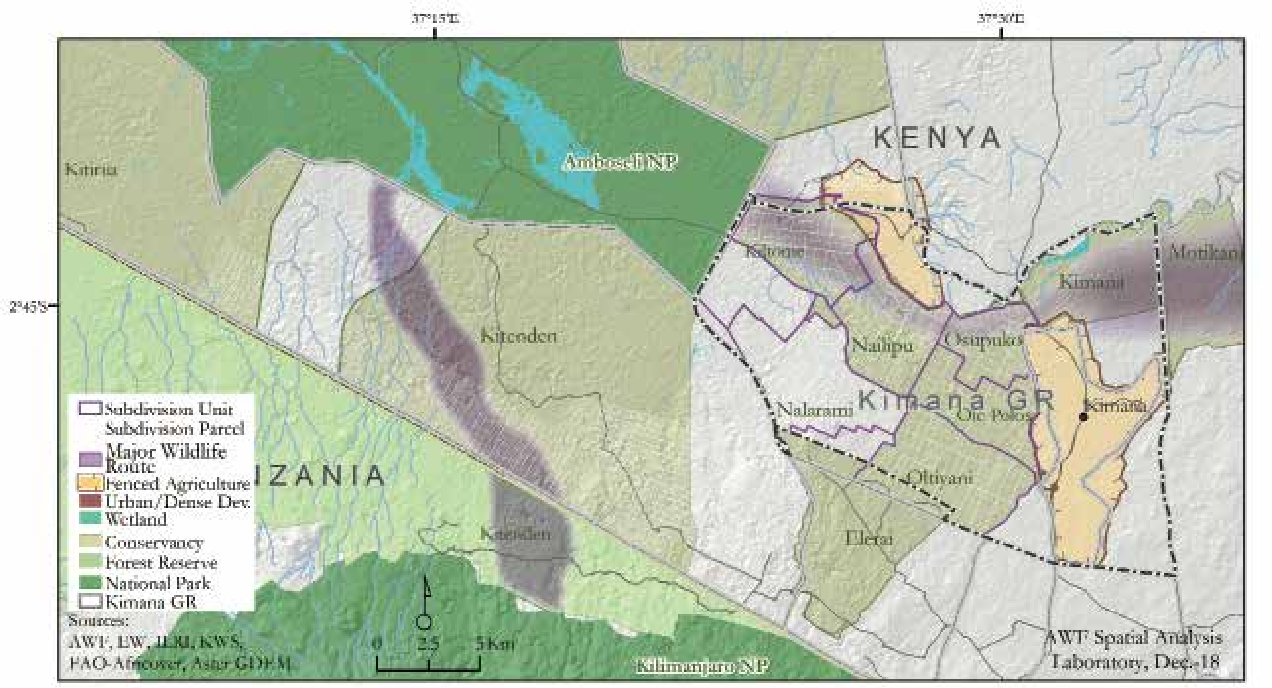


Figure 2. Land subdivision in the Kilimanjaro landscape. The Kimana Group Ranch is located east of Amboseli National Park. © African Wildlife Foundation

(www.tawilodge.com), the Big Life Foundation (www.biglife.org), and IFAW, the International Fund for Animal Welfare (www.ifaw.org).

Example of an ecological corridor

In one specific area, the Kimana Group Ranch, directly east of Amboseli, AWF worked with the landowners and presented a conservation lease agreement in a series of community meetings. Women, youth and men participated in these meetings. They were held in the local language, Kimaasai, with translation as needed into Swahili and English. AWF's community organiser, who was from the Kimana community, was pivotal in organising and facilitating these meetings.

The conservation lease outlines the purpose, terms, land-use restrictions, retained rights, payment requirements, how violations will be addressed, and other relevant issues. The purpose of the conservation lease is to "provide habitat, dispersal and movement areas for wildlife" and to help "connect conservation areas" and "contribute to the survival of wildlife areas in the Amboseli ecosystem as well as the continued existence of ecotourism as a means of poverty reduction and economic development and overall public benefit by ensuring that wildlife species endure for the benefit of future generations."

The conservation lease prohibits building new houses, fencing, logging, mining, dredging, agriculture, resource extraction, non-tourism-related commercial activity, and illegal taking of wildlife. Grazing is permitted in compliance with a management plan. The community selected a Maasai attorney who met with them (in the absence of AWF) to review the lease agreement in its final stage before signing. By having this meeting without AWF, community members were free to voice concerns, and changes were made as a result. AWF paid the fees of the attorney for the community. The extensive community engagement took approximately eight months. AWF determined the value of the lease by doing a market assessment of other leases related to tourism and agriculture in the region. While these leases are not permanent, the hope is that this will be a step toward permanent protection.

Results

Currently there are five community conservancies involving more than 350 individual landowners that protect approximately 8,000 ha of ecological corridors that connect protected areas. With an average household of seven, the lease program is directly benefitting over 2,450 individuals, and this does not include employment beneficiaries, such as scouts.

One of the challenges with PES programs is sourcing the funds. The protected area authority recognises the importance of the ecological corridors, but is unable to pay; thus, the project relies on donors. Because the land is privately owned and the program entirely voluntary, there are landowners who have chosen not to participate. This has resulted in fragmentation and fencing, putting at risk the long-term viability of the program.

2. Connectivity conservation in the Kavango Zambezi Transfrontier Conservation Area: The Zambezi-Chobe Floodplain Wildlife Dispersal Area

Lésa van Rooyen, *Peace Parks Foundation*

Context and challenge

The Kavango Zambezi (KAZA) Transfrontier Conservation Area (TFCA) is situated in the Kavango and Zambezi river basins where the borders of Angola, Botswana, Namibia, Zambia and Zimbabwe converge (Figure 1). It spans an area of approximately 520,000 km^2 and includes 36 proclaimed protected areas. The KAZA TFCA countries support over 200,000 elephants, most of which are found south of the Zambezi River. Due to human activities, the KAZA TFCA faces habitat fragmentation and loss of connectivity. Protected areas could become isolated ecological islands, leading to reduced biodiversity and blocked elephant movement. The major threats to the area are as follows:

- the deforestation of the area to create fields for agriculture and for making charcoal;
- uncontrolled settlements along main roads and watercourses, which cause fragmentation of the landscape;
- overgrazing of the area due to uncontrolled cattle numbers;
- over-exploitation of fish due to unsustainable fishing practices; and
- uncontrolled fires in the Simalaha floodplain wetland ecosystem.

A key objective of the KAZA TFCA is to form a transboundary ecological network to ensure connectivity between key protected wildlife areas and, where necessary, reconnect isolated wildlife areas.

Key lesson

Designated wildlife dispersal areas established in collaboration with local communities are a promising step toward legal agreements to maintain connectivity for wildlife.

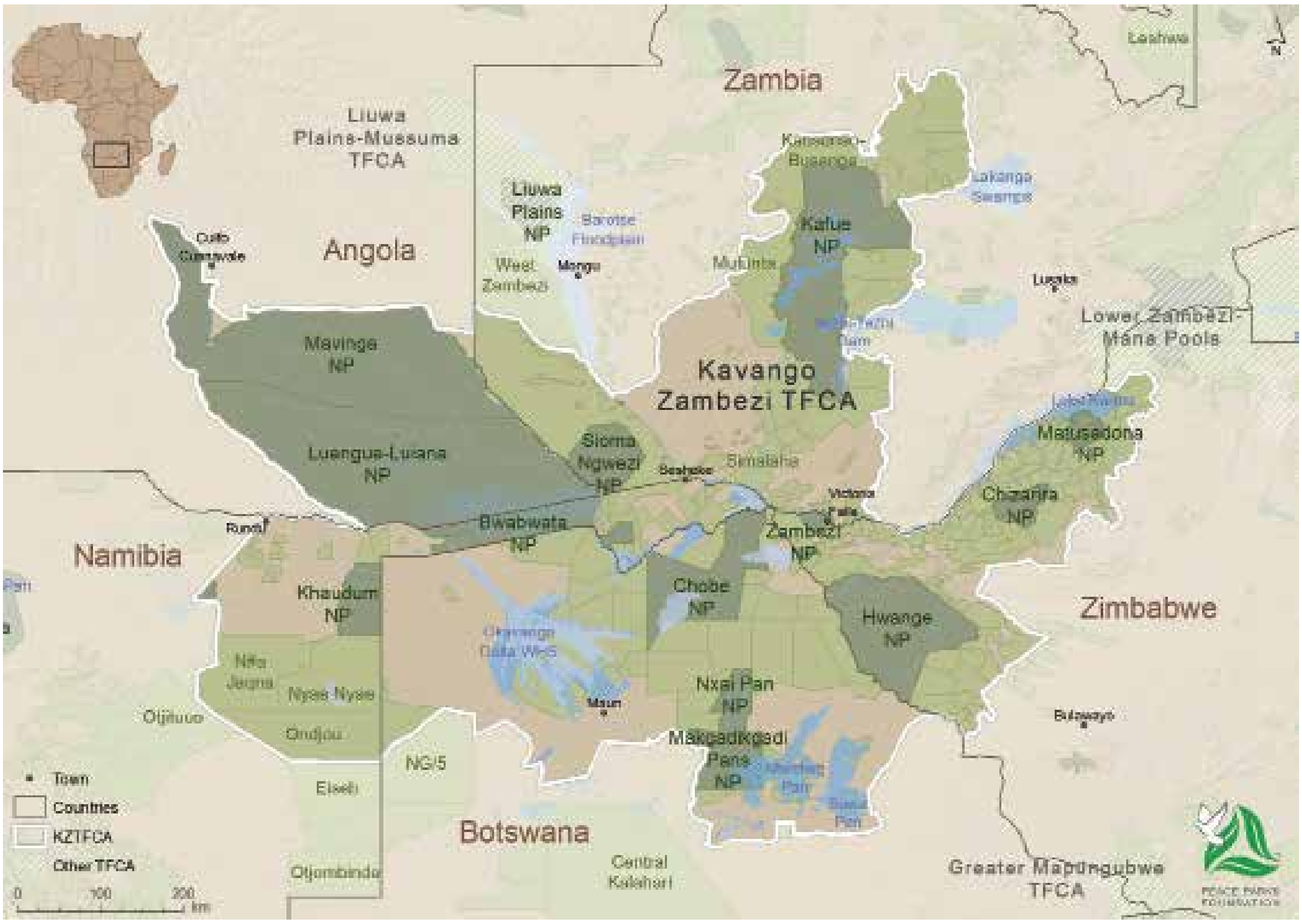


Figure 1. Kavango Zambezi Transfrontier Conservation Area. The major threat to biodiversity in the project area is the over-utilisation of resources in the sensitive wetlands of the Simalaha Floodplain, identified in the centre of the figure. The Kasaya River marks the boundary between the two chiefdoms and flows through the middle of the Simalaha Community Conservancy. © Peace Parks Foundation

Approach

The KAZA TFCA commenced in 2006 when a memorandum of understanding was signed by the five partner countries to establish the world's largest transfrontier conservation area. Each of the five countries agreed to create an Integrated Development Plan to indicate how the national development plans will link across borders. The process was also used to create awareness and engage local stakeholders. A Master Integrated Development Plan was created that identifies six transboundary wildlife dispersal areas (WDAs), which are critical to re-establish connectivity and conserve large-scale ecological systems that extend beyond the boundaries of protected areas.

Example of an ecological corridor

The Zambezi-Chobe Floodplain WDA contains several sensitive areas, mainly along the rivers and associated floodplains, which are not formally protected. Located centrally in this WDA is the Simalaha floodplain in Zambia, which was identified by the communities as a critically important area that should be secured to ensure connectivity between Chobe National Park in Botswana and Kafue National Park in Zambia. The communities recalled that the area used to be a haven for animals, and mobile species such as elephant and buffalo used to move through the area.

Peace Parks Foundation has worked with the Sesheke and Sekute chiefdoms over the past ten years to establish and develop the Simalaha Community Conservancies (180,000 ha) in collaboration with the local traditional leadership and communities to secure the land for conservation. The Sesheke and Sekute chiefdoms created a steering committee made up of members of the Kutas, the two traditional councils. A working group was established, with representation from the Kutas and Peace Parks Foundation, to coordinate activities such as acting as liaison with communities and developing a land-use plan. Peace Parks was requested to assist with fundraising to implement the project. The first funds received assisted with an awareness and sensitisation programme during which the working group members visited different villages to explain the community conservancy concept. During this time the boundaries of the conservancy were delineated with input from the community. The two chiefs confirmed the boundary by signing a copy of the map, and submitted it to the Ministry of Land for its records.

The Simalaha Community Conservancy is managed on business principles and registered as a legal entity. A local attorney was appointed to assist with the drafting of a constitution and the establishment of an appropriate legal structure. A community trust was created that is the owner of the assets. The trust established a for-profit company that manages the business side of things and also looks after the wildlife management and tourism development. Any profits made by the company are paid to the trust for distribution to the beneficiaries according to a predetermined formula. Seven Village Action Groups were formed to represent the communities. The Simalaha Community Conservancy was officially launched in 2012.

Results

From the start, there was general acceptance of the project and great enthusiasm from the traditional leadership. However, because the development of a wildlife product takes time and significant resources, it was important also to create alternative livelihood options. Conservation agriculture was successfully introduced and became the preferred farming method, producing higher yields than traditional methods.

A 24,000-ha wildlife sanctuary was fenced and stocked with plains game species (wildebeest, *Connochaetes* spp.; zebra, *Equus* spp.; defassa waterbuck, *Kobus defassa*; impala, *Aepyceros melampus*; red lechwe, *Kobus leche*; puku, *Kobus vardonii*; giraffe, *Giraffa camelopardalis*; and buffalo, *Syncerus caffer*). Initially, around 780 animals were translocated, a number which increased to over 1,400 animals by the end of 2018.

Twenty village scouts were trained to look after the wildlife. In the five years that wildlife has been in the sanctuary, only one poaching incident was recorded – a person from outside the area set snares. The local community reported the incident, showing that the communities have taken ownership of the wildlife. Although fences initially played an important role in containing the translocated wildlife, the long-term plan is to remove them and allow the wildlife to move freely. Seasonal migration of wildlife is already observed, as wildlife move into the woodlands and higher ground during the flooding period and back to the floodplain along the Zambezi River during the dry winter period.

The story of the Simalaha Community Conservancy spread quickly between traditional leaderships and soon other chiefs visited the area to learn more about the project. Other conservancies are being established as a result. Exchange visits with traditional leaders in Namibia may lead to the expansion of existing conservancies on the Namibian side to ensure a link between Chobe National Park to Simalaha Community Conservancy.

The Zambezi-Chobe Floodplain is, at this stage, not a functional WDA. Once existing community conservancies have been expanded and new ones added, the Zambezi-Chobe Floodplain is expected to start functioning as a WDA. Improved law enforcement capacity in Angola and Zambia along the Kwando river is increasing the numbers of elephants moving into Luengue Luiana National Park in Angola because of the increased safety.

3. Conserving six landscapes of the Albertine Rift to ensure connectivity

Andrew J. Plumptre, *Key Biodiversity Areas Secretariat (formerly of Wildlife Conservation Society)*

Key lesson
Local communities are engaged in connectivity conservation by recognising that designating areas for ecological connectivity will also protect their ancestral lands from new settlers. Recognition of local connectivity areas at the federal and/or global level would help local connectivity conservation.

Context and challenge
The Albertine Rift region spans six countries (Burundi, Democratic Republic of Congo, Rwanda, Uganda, United Republic of Tanzania, Zambia) and is one of the most biodiverse parts of Africa, with more endemic and threatened species of vertebrates than elsewhere on the continent (Figure 1) (Plumptre et al., 2007). It is also a region with one of the highest human population densities in Africa, and as a result has lost 30% of its natural habitat to agriculture and settlement (Ayebare et al., 2018). While relatively well covered by protected areas, many of them are separated from each other and in danger of becoming isolated islands of natural habitat in a sea of agriculture.

Approach
In 2000, the MacArthur Foundation financed a collaborative planning approach for the Albertine Rift that brought together the national governments and many conservation organisations to develop a conservation framework plan.

This overarching framework identified six key landscapes in the Albertine Rift that potentially could be managed at the landscape level to ensure connectivity between protected areas (Figure 1).

Detailed conservation plans were developed for each of the six landscapes. The two transboundary landscapes (the Greater Virunga Landscape and the Congo-Nile Divide) each developed a memorandum of understanding (MOU) for

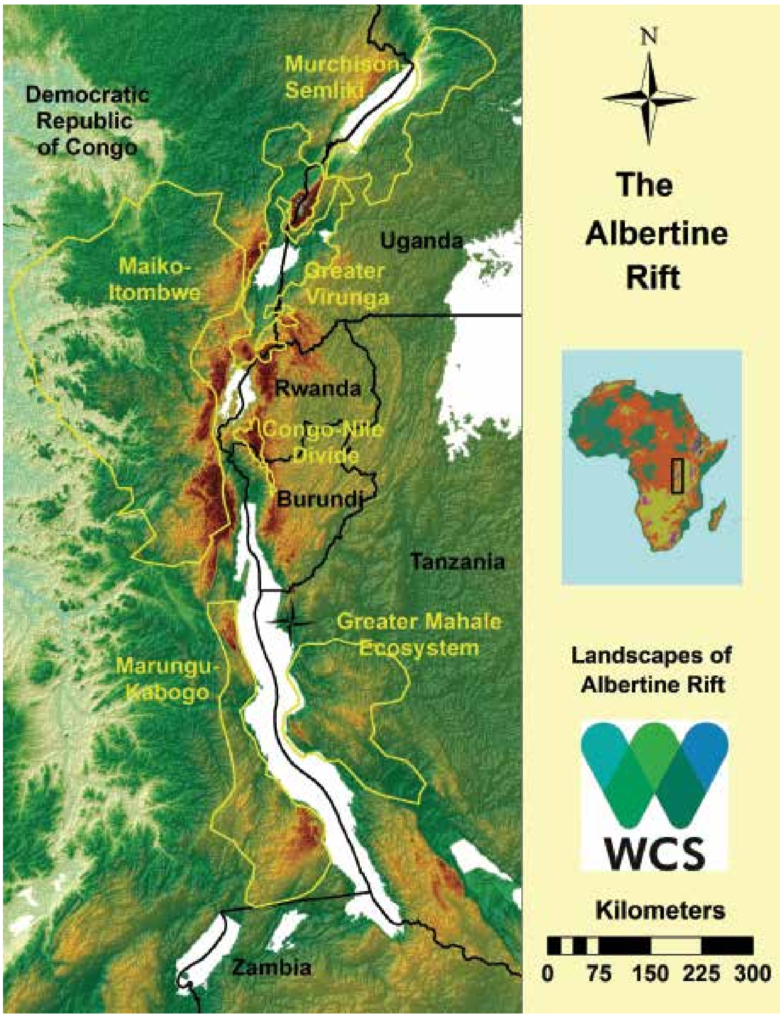


Figure 1. The six landscapes of the Albertine Rift © A.J. Plumptre

collaboration. In the Greater Virunga Landscape the MOU evolved into a transboundary treaty for conservation of the landscape. Funds were then raised to implement the plans. In some regions, biodiversity surveys were conducted, and systematic conservation planning was done using distribution models of endemic species in the region. This analysis identified additional critical areas outside the existing ecological networks for conservation in the six landscapes (Plumptre et al., 2017).

Examples of ecological corridors

Implementation of connectivity conservation in the Albertine Rift varied greatly. In the Murchison-Semliki Landscape, a highly populated, fragmented region with many immigrants looking for land, the focus was on conserving remaining ecological corridors (Figure 2). Forest corridors along streams and rivers and a savannah corridor along the escarpment above Lake Albert were protected. In the Maiko-Itombwe Landscape, large areas of contiguous tropical forest still exist. Therefore, the focus was on working with local people to set aside some of the most important areas as protected areas and linking them with ecological corridors in the form of sustainable-use community areas (Figure 3). Local communities were willing to engage in the process because they realised that it would help them protect their ancestral lands from people migrating into the area from outside their culture.

In the two transboundary landscapes the main focus was on the protected areas because most natural habitat outside of them had already been lost. However, landscape-scale conservation and management are still important for species moving long distances, such as lions, elephants, spotted hyenas, leopards, chimpanzees, mountain gorillas and vultures. Ensuring that the existing connectivity between protected areas will not be severed by park developments and tourism infrastructure is important for these species.

Results

Since 2000, conservation action plans have been developed for each of the six landscapes and are recognised locally, nationally, and for the transboundary landscapes, internationally. Maintaining or restoring connectivity between existing protected areas has been more successful in some landscapes than others.

Biodiversity surveys in parts of the Democratic Republic of Congo led to the creation of four new protected areas: Itombwe Natural Reserve and Tayna Reserve in the Maiko-Itombwe Landscape, and Kabobo and Ngandja reserves in the Marungu-Kabobo Landscape. They ensure maintenance of connectivity and conservation of endemic and threatened species in these two landscapes. To maintain connectivity, several other community reserves were designated and are

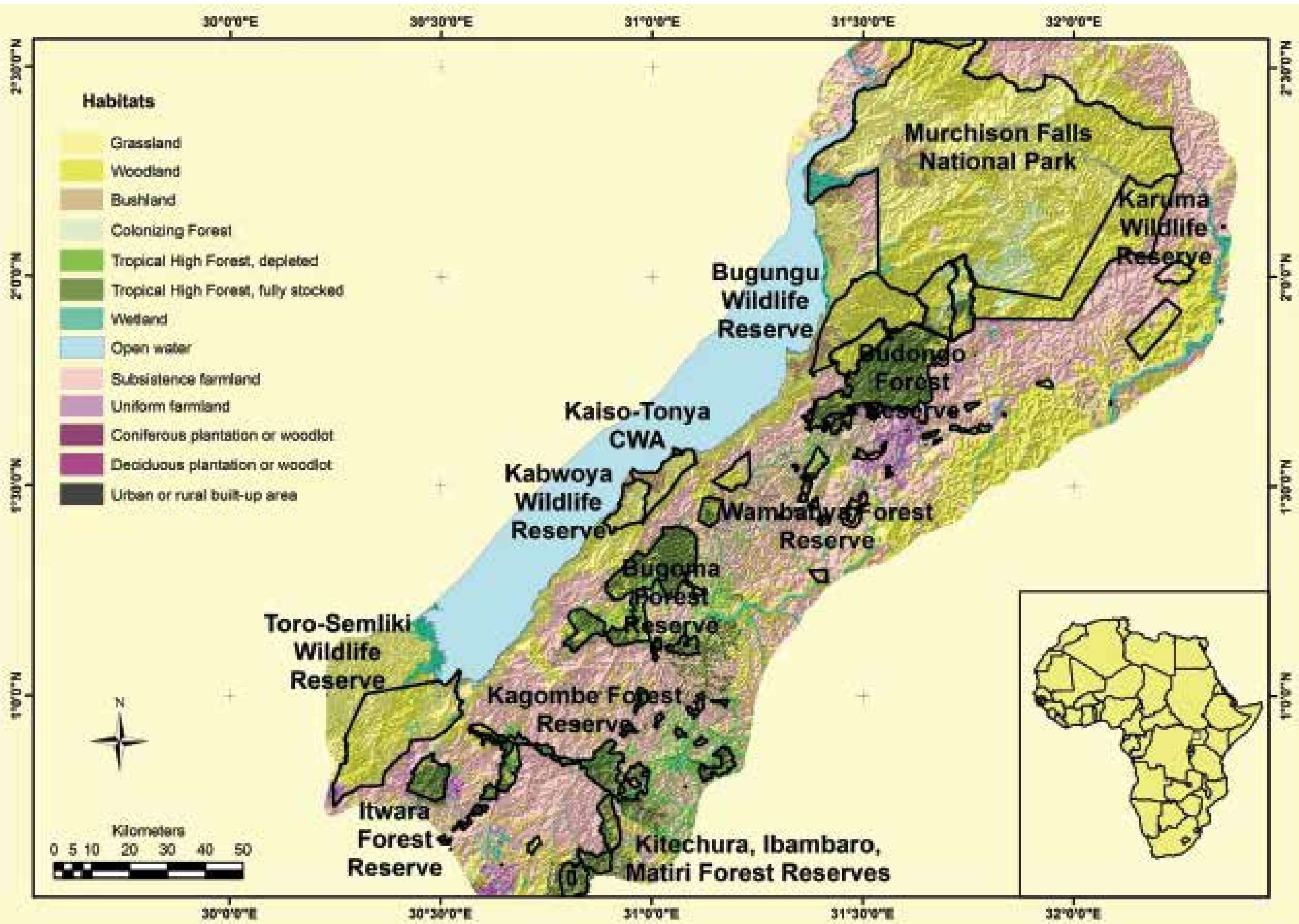


Figure 2. The main protected areas and natural habitats in the Murchison-Semliki Landscape © A.J. Plumptre

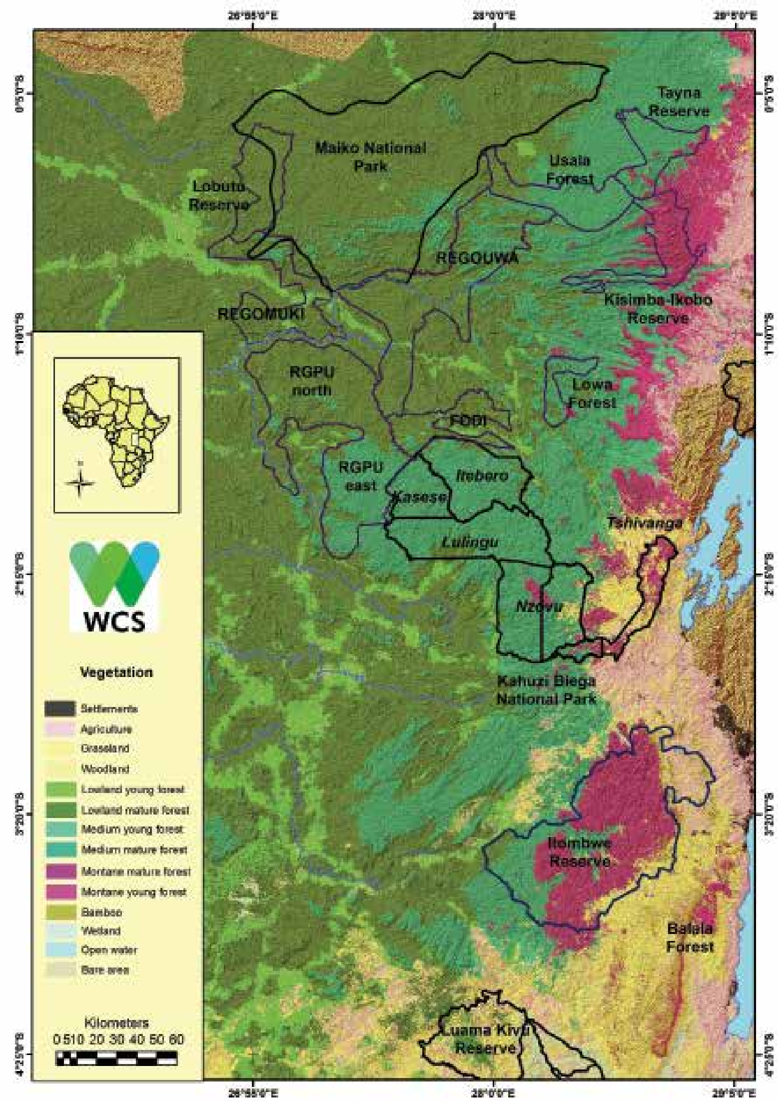


Figure 3. The main protected areas (black borders), community reserves (blue borders) and natural habitat in the Maiko-Itombwe Landscape © A.J. Plumptre

locally recognised in the Maiko-Itombwe Landscape, but have not been legally recognised at the national level. In addition, a fifth protected area, Oku Primate Reserve, is being established by local communities in the same landscape to better connect and conserve Grauer's gorilla and elephant populations.

In the Marungo-Kabobo region, efforts were made to establish these two contiguous protected areas, which represent the largest block of forest along Lake Tanganyika.

While connectivity still exists in the Greater Mahale Landscape, a too-narrow focus on chimpanzees is hindering the conservation of several other endemic species, many of which have different habitat and connectivity requirements. There is a need to develop conservation plans that consider the broader biodiversity of this region. However, the recognition of these large landscapes is helping with their longer-term conservation and management. More resources are needed to implement conservation action, but limited resources are being used effectively to maintain connectivity at the landscape scale.

4. The Kilombero Valley Ramsar site, United Republic of Tanzania

Giuseppe Daconto, *formerly of the Belgian Development Agency / Tanzanian Ministry of Natural Resources and Tourism*

Key lesson
This Ramsar site requires a framework for conservation that includes ecological corridors to guide efforts by the central government and local stakeholders.

Context and challenge

The Kilombero Valley is a floodplain about 220 km long and up to 70 km wide in the Rufiji River catchment in southern Tanzania, sandwiched between the Udzungwa Mountains and the Mahenge Hills (Figure 1). Multiple tributaries converge in the valley, forming the Kilombero River. During the rainy season, water runoff from the steep tributaries rapidly reaches the valley floor and transforms it into a large swamp. The extensive valley used to be a dry-season refuge and offered multiple connectivity routes for wildlife populations moving between the Udzungwa range and the Selous Game Reserve, and thus played a critical role for connectivity at a regional scale in southern Tanzania. The floodplain used to host significant wildlife populations, including elephants and a large number of the near-threatened puku antelope. Starting in the 1990s, the landscape underwent radical change, driven by sustained human immigration and growing settlements, massive expansion of rice farming and livestock grazing, deforestation and development of infrastructure. Rice growing and grazing have drastically reduced the natural wetland habitat. Land-use changes and settlements have almost completely disrupted wildlife connectivity across the valley. Game populations have been decimated (Leemhuis et al., 2017).

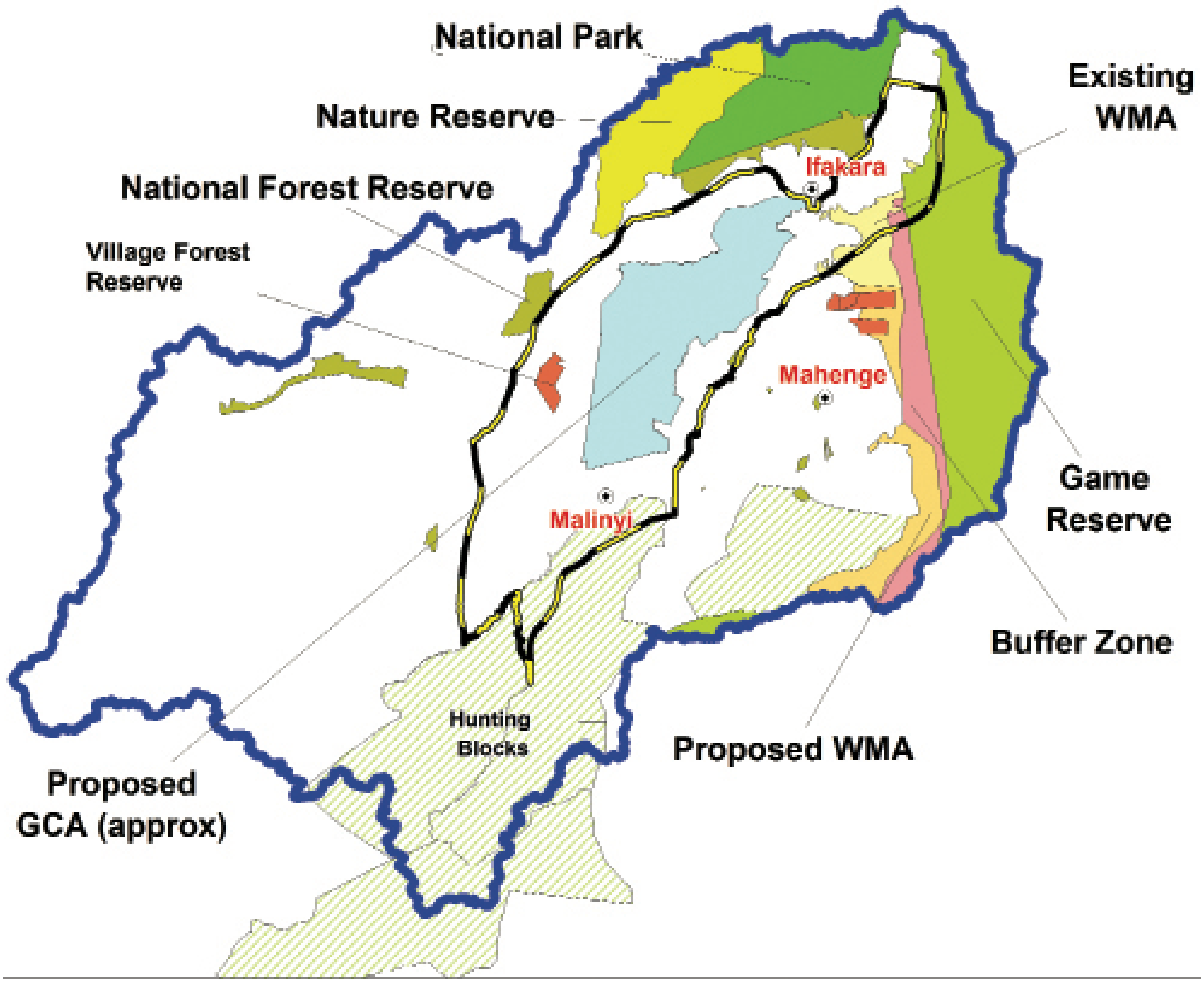


Figure 1. Protected areas in the Kilombero catchment (source: plan document). The Ruipa Ecological Corridor connects Udzungwa National Park and Kilombero Nature Reserve to the Selous Game Reserve, crossing the Kilombero Valley south of Ifakara. The black-and-yellow line outlines the Ramsar site.

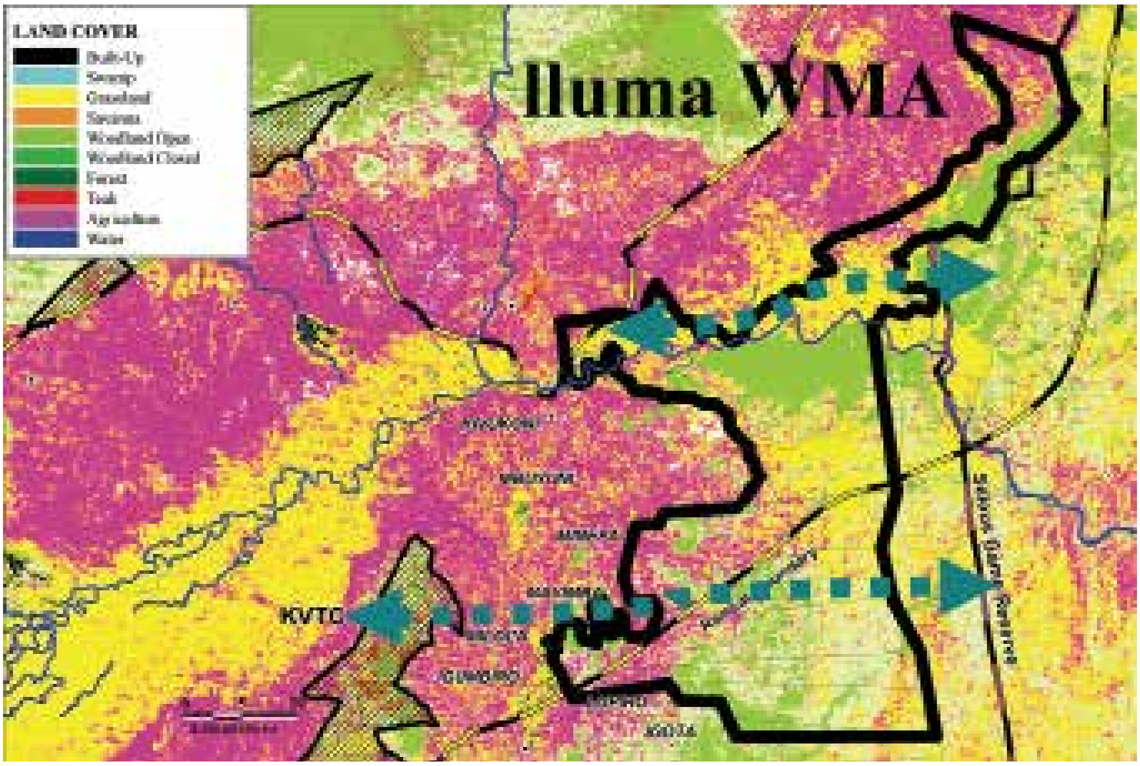


Figure 2. Detailed land-use analysis of the Ruipa-East corridor connecting the valley to Selous Game Reserve. Source: Plan documents.

Approach

The central government has maintained nominal authority over the core area and large tracts of land in the watersheds. The designation of the area as a Ramsar site in 2000 underscored the importance of the landscape. However, social and economic change has been mostly unregulated. Land conflicts abound and are heavily politicised. The management of the landscape, including the conservation of residual wildlife areas, maintenance of connectivity, and the preservation of broader ecological values and functions of the valley requires mediation across several local and national interests. Management of the valley needs to include several sectorial agencies, four district authorities and hundreds of villages, which are the ultimate land management authorities in Tanzania. The governance approach needs to transition from the traditional central management of large protected areas to management of a mosaic of smaller ones embedded in thriving agricultural areas, some under central government, and others under local control. The Integrated Management Plan for the Kilombero Valley Ramsar Site, developed 2016–2018 by the Ministry of Natural Resources and Tourism, is a framework to enable this gradual transition. The preparation of the plan was supported by Belgian Aid and the European Union, through the Kilombero and Lower Rufiji Ecosystem Management Project. Background analysis and planning documents are available from https://kilomberovalley.wordpress.com/.

Maintaining and restoring ecological connectivity will require actions at local, regional and national levels:

1. Consolidation of the core area of the valley (about 2,000 km^2) under central government control.
2. Management of development pressure in the agricultural and settlement belt around the core area. The population of this belt is projected to exceed 1 million by about 2040 at the present trend.
3. Consolidation and effective protection of a constellation of small areas across the landscape. Some of these are owned by villages and managed under the devolved statutes of wildlife management areas or village forest reserves; others are hunting concessions, private land leased for forestry and farming, or areas protected by a local government.
4. Protection and rehabilitation of residual natural habitat on farmland along the tributaries to the main river. This requires effective planning and control over village land use and farming practice, which are mostly very weak, and the coordination of land use across multiple villages, which is almost non-existent.
5. Preservation of the hydrological cycle of the river and its seasonal pulse through effective catchment-scale water resource management.

Example of an ecological corridor

The Ruipa ecological corridor is a link for wildlife moving between Selous Game Reserve in the east and the Udzungwa Mountains in the west (Figure 2). This large-mammal corridor (0.5–6 km wide, 20 km long) crosses a mosaic of habitats, including riverine forest, woodland, scrub, degraded pasture and swamp. Much of the western part of the corridor is degraded but the eastern part still retains limited functionality. Elephants (*Loxodonta* spp.) and buffalo (*Syncerus caffer*) use the corridor annually to migrate between protected areas, although their numbers have declined significantly in recent years. Other animals historically reported

Buffalo (*Syncerus caffer*) © Adobe Stock

from the corridor include the aardvark (*Orycteropus afer*), Angolan black-and-white colobus (*Colobus angolensis*), bushbuck (*Tragelaphus sylvaticus*), crested porcupine (*Hystrix cristata*), Harvey's duiker (*Cephalophus harveyi*), hippopotamus (*Hippopotamus amphibius*), leopard (*Panthera pardus*), lion (*Panthera leo*), puku (*Kobus vardonii*), spotted hyaena (*Crocuta crocuta*), waterbuck (*Kobus ellipsiprymnus*) and the Udzungwa red colobus (*Procolobus gordonorum*), which is endemic to the Udzungwa Mountains. The Ruipa Corridor and several others that cross the Kilombero floodplain have a high conservation significance, as they are perhaps the only viable links remaining between the western and southern Tanzania elephant populations.

Results

The plan provides an overall framework for the very complex undertaking of managing this landscape and rehabilitating its ecological connectivity. Extensive appraisals during the plan preparatory process and other works have identified several action priorities. The implementation requires an institutional mechanism able to:

1. Coordinate many local stakeholders and diverging priorities for land and water use;
2. Establish an effective coordination between the government's sectors of land administration, conservation and water resource management;
3. Bridge central government control and effective devolution and decentralisation (mostly through the national framework for community-based natural resource management, but also by ensuring that local authorities receive some minimum budget transfers from the central government); and
4. Negotiate land-use coordination in priority connectivity areas.

A long-term vision anchored in the conservation agencies could in principle underpin a long-term adaptive management process, but a shared vision, financial resources and institutional capacities are not yet available for the implementation of the plan. The plan proposes a key near-term milestone: the mobilisation of financial resources through central and local government budgets to establish an initial mechanism of local coordination. An appraisal showed that this would be financially feasible. This first step would be independent of external support (which eventually will be required), and would therefore promote local ownership and leadership of managing the landscape for ecological connectivity.

Note: Images produced by the KILOREWMP project, funded by the European Union and Belgian Aid and implemented by the Ministry of Natural Resources and Tourism (via the Wildlife Division and the Tanzania Wildlife Management Authority) and the Belgian Development Agency (Enabel) in collaboration with the districts of Ulanga, Kilombero and Malinyi of Morogoro Region and of Rufiji of Coast Region.

Terrestrial connectivity: Asia

5. Ecological corridor for the reunion of giant pandas in the Qinling Landscape

Hui Wan, *formerly of WWF*

Key lesson

Mitigating fragmentation caused by roads with underground tunnels can be an effective way of restoring connectivity for wildlife; monitoring of the restoration is important to document outcomes.

Context and challenge

National Road 108 was built in the 1970s through the Qinling Landscape in central China and over time brought heavy traffic (Figure 1). The road divided an intact forest and caused the fragmentation of previously connected panda habitat. It also gave the local human population access to the forest. Consequent use of wild resources further degraded the habitat. The resident panda population was gradually split in two: the Xinglongling subgroup to the west and the Tianhuashan subgroup to the east.

Approach

In 2000, a tunnel was built by the government to accommodate a new road. The abandonment of the old road and the re-establishment of habitat on land on top of the tunnel provided the opportunity to reconnect the separated panda groups. In 2003, Shaanxi Guanyinshan Nature Reserve was legally established, and in 2005 the World Wildlife Fund (WWF) together with the reserve launched the G108 Qinling vehicle tunnel corridor restoration project (Figure 2). The main strategic activities in the ecological corridor include:

- Baseline survey and mapping to understand the population status of the panda subgroups, the physical distance between them, the socio-economic condition of local communities, the management capacity of the reserve and the forest tenure in the area.
- Habitat restoration through bamboo plantings in gap plots to improve habitat quality, providing connected habitat and thereby a path for panda movement.
- Local community engagement, including providing support to local households, demonstrations of sustainable forest management and education programs about the significance of habitat conservation.
- Traffic management to enforce the ban on humans and vehicles using the abandoned road.

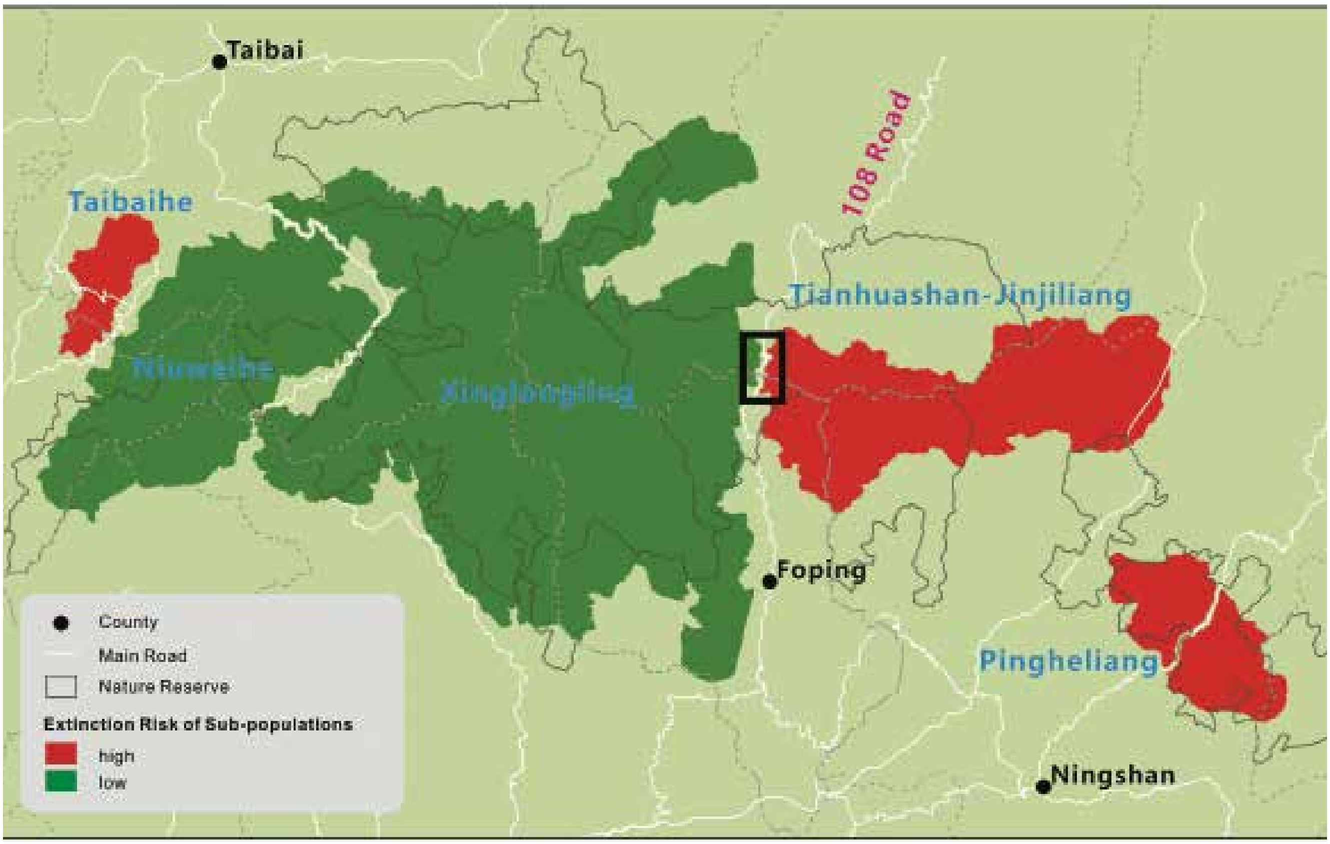


Figure 1. Panda subpopulations in the Qinling landscape. National Road 108 is running from north to south. The black rectangle indicates the location of the ecological corridor. © WWF China

- Capacity enhancement to improve the management effectiveness of Guanyinshan Nature Reserve.
- Wildlife monitoring.

Results

Giant pandas have been documented in the ecological corridor, which includes land on top of the road tunnel and surrounding lands connecting the core areas. The ecological distance between the subgroups has been reduced and is now shorter than the daily activity range of a panda. The number of mammal and pheasant species found in the corridor area has increased from zero to 15.

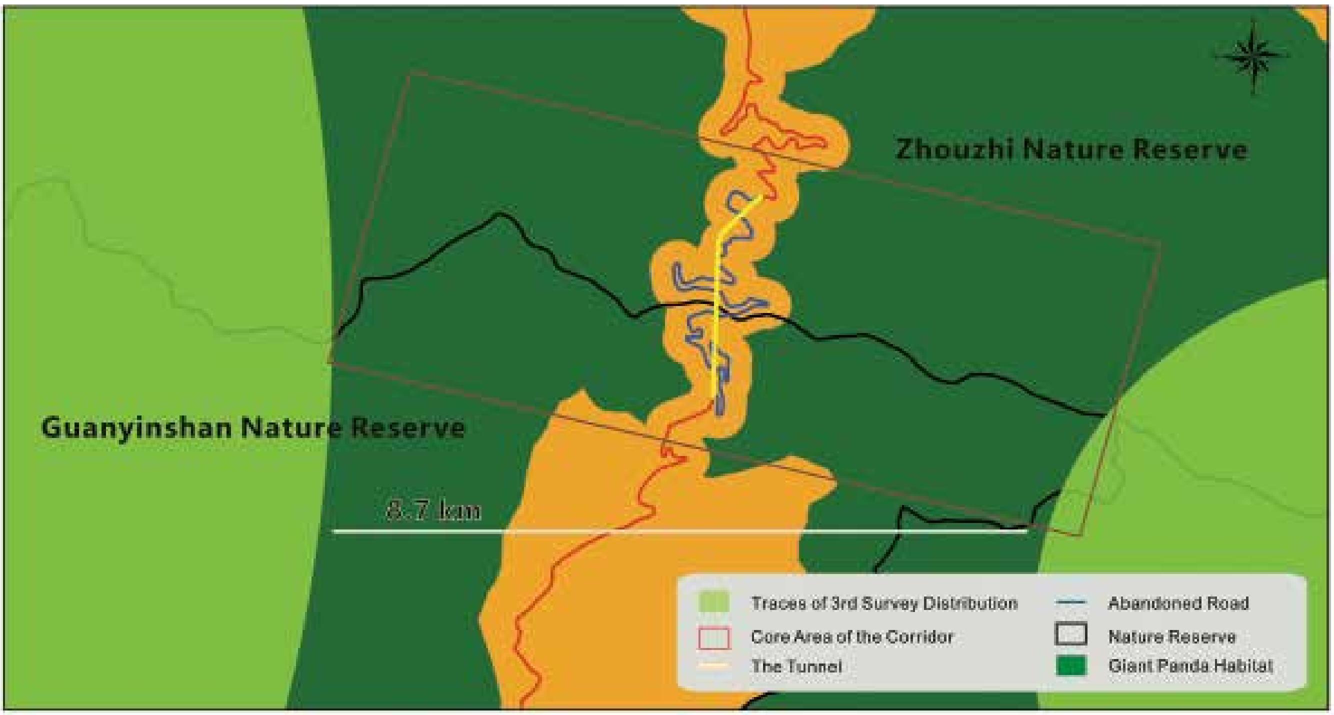


Figure 2. The ecological corridor includes the non-protected area on both sides of the road (orange). The corridor is now connecting the habitat of two panda subgroups. © WWF China

Giant panda (*Ailuropoda melanoleuca*) © Adobe Stock

6. Thailand's experience in ecologically connecting its protected areas

Songtam Suksawang, *Thailand National Parks Office, Department of National Parks Wildlife and Plant Conservation, Ministry of Natural Resources and Environment*

Key lesson
Monitoring and evaluation of identified corridors suggest that some corridors are already working; management of allowable activities in these corridors will be important over the long term.

Context and challenge

In recent years, Thailand has markedly expanded its protected areas system. The kingdom now has 128 terrestrial national parks, 26 marine national parks, 60 wildlife sanctuaries, and 63 non-hunting areas managed by the Department of National Parks, Wildlife and Plant Conservation (DNP). These protected areas cover about 23% of Thailand's territory, a figure justified by the numerous benefits conservation delivers to the Thai people. Where protected areas are adjacent or close together, they can be managed as ecological networks for conservation, but many of them are smaller areas fragmented by highways, railroads and other infrastructure.

Thailand's protected areas are generally effective at curtailing deforestation within their boundaries (a significant exception being the continued poaching of particularly valuable timber such as rosewood). But continued deforestation and conversion of forests into plantations in areas surrounding many of Thailand's protected areas is making them islands of nature in a sea of agriculture, too small to support all the species that occupied the landscape before it became fragmented.

Approach

To promote landscape connectivity, DNP has adopted the concept of ecological networks, which are referred to as 'forest complexes'. National parks and wildlife sanctuaries are ecologically linked to form a larger area that will be able to support viable populations of wide-ranging species of plants and animals, as well as contribute to regional social and economic development through provision of ecosystem services. These areas can be connected by ecological

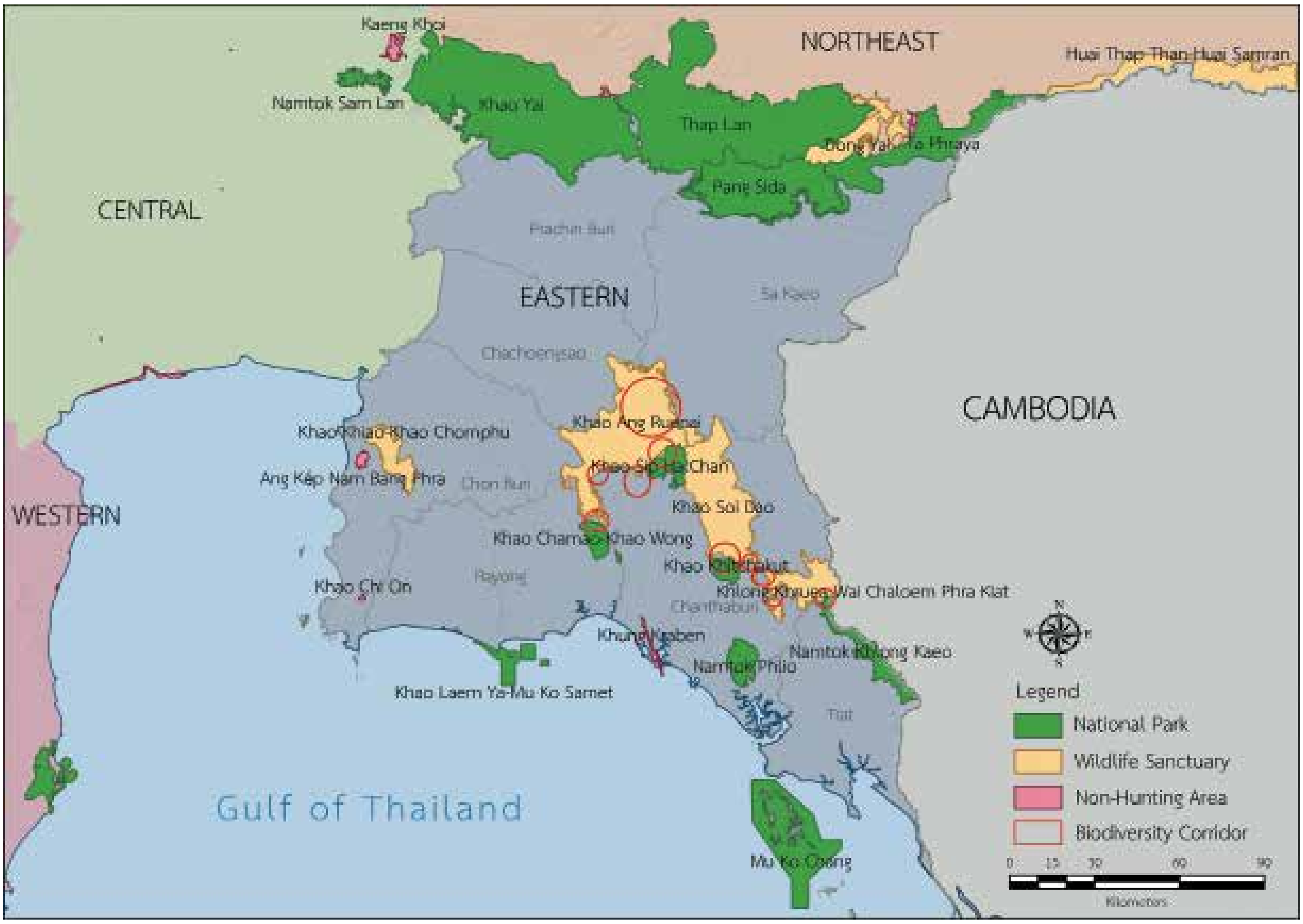


Figure 1. Ecological corridors in the Eastern Forest Complex © Songtam Suksawang / Thailand National Parks Office, Department of National Parks Wildlife and Plant Conservation, Ministry of Natural Resources and Environment

corridors that include non-hunting areas, buffer zones, lands managed by government agencies other than DNP and private lands. This approach requires senior protected area staff to consider managing their sites as parts of larger landscapes.

DNP has been learning lessons about ecosystem complexes by establishing pilot activities in selected sites in two complexes: the Eastern Forest Complex (Figure 1, previous page) and the Western Forest Complex (Figure 2). A forum brought together about 50 of Thailand's most experienced protected area managers and other experts on forest

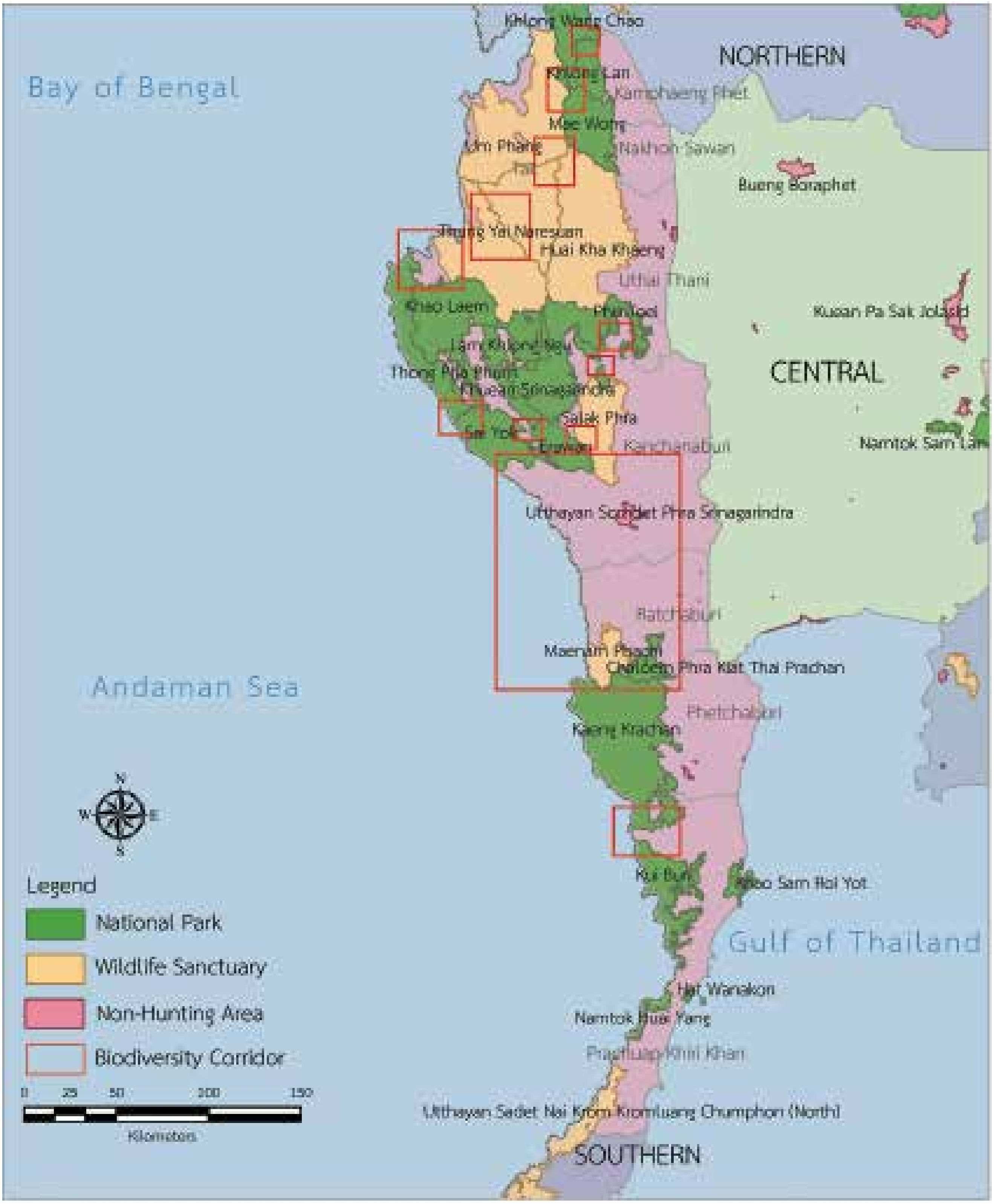


Figure 2. Ecological corridors in the Western Forest Complex. © Songtam Suksawang / Thailand National Parks Office, Department of National Parks Wildlife and Plant Conservation, Ministry of Natural Resources and Environment

Khao Ang Rue Nai Wildlife Sanctuary, Thailand © Adobe Stock

complexes to discuss how ecological corridors can connect protected areas, expanding their effective size to enable the movement of plants and animals between them, physically linking habitats and providing an effective means of adapting ecosystems to climate change.

The forest complexes approach is promising but DNP also needs to consider how to manage any potential negative ecological impacts of connectivity. Without proper management, the connecting corridors could facilitate the spread of disease, invasive alien species, forest fires, and other natural hazards. Ecological corridors may also pose some visitor management challenges. For example, it will be important to ensure that visitors who have paid for admission to a national park do not then expect that they necessarily have the right to enter an adjacent, strictly protected wildlife sanctuary that limits visitation (a potential issue in the case of Huay Kha Khaeng Wildlife Sanctuary).

Examples of ecological corridors

The Eastern Forest Complex includes eight protected areas (Figure 1). Khao Chamao-Khao Wong National Park (84 km^2) is slightly separated from Khao Ang Rue Nai Wildlife Sanctuary (1078 km^2), but an ecological corridor has been shown to be feasible; its establishment depends on the owners of the connecting land being convinced to work with the protected areas. Khao Sipha Chan National Park (118 km^2) is adjacent to Khao Ang Rue Nai and forms part of a naturally connected ecosystem. Similarly, the relatively small Khao Khitchakut National Park (58 km^2) is connected to Khao Soi Dao Wildlife Sanctuary (744 km^2), so they also form a natural unit. Klong Krua Wai Wildlife Sanctuary is connected to Namtok Khlong Kaew National Park, making them part of a long and rather narrow natural unit. They share a boundary with Cambodia, and DNP is working on transboundary protected area conservation with Cambodia's Samlout Protected Area (this is being promoted by the Asian Development Bank).

All the protected areas of the Western Forest Complex are ecologically connected and form Thailand's largest contiguous forest ecosystem complex, covering 14,866 km^2 (Figure 2). Three national parks (part of Khao Laem National Park, Thong Pha Phum National Park, and Sai Yok National Park) are separated from the other sites in the western complex by a highway and various commercial developments along the highway, posing an ecological barrier that will need mitigations with crossing structures, such as broad overpasses covered with vegetation to enable free movement of large mammals.

Results

There is conclusive evidence that tigers, which are well protected in Huay Kha Khaeng Wildlife Sanctuary in the Western Forest Complex, are expanding their population, with "new" tigers dispersing northward to Mae Wong and Klong Lan national parks, where they have become well established. Many other species, including the reintroduced Eld's deer, may also repopulate these national parks from Huay Kha Khaeng, indicating its importance as a source of wildlife for other areas due to the existence of ecological corridors. Local communities have been involved in demarcating boundaries in Mae Wong National Park and have benefitted from multiple-use zones, which can serve as ecological corridors. Communities surrounding Huay Kha Khaeng Wildlife Sanctuary have established community development zones that have been formally recognised as contributing to the objectives of the protected area. More work is clearly needed to develop and implement connectivity conservation in the protected area complexes, but the Eastern and Western forest complexes have shown the practical utility of the approach.

Terrestrial connectivity: Australia

7. East Coast Conservation Corridor in Tasmania

Todd Dudley, *North East Bioregional Network*

Context and challenge

The East Coast Conservation Corridor (ECCC) is a landscape-scale ecological network for conservation extending 280 km north–south from Cape Portland to Cape Pillar, covering 2½ degrees of latitude on the East Coast and hinterland of Tasmania. The existing protected area system and ongoing conservation projects provide a solid foundation for realising what is known as the 'WildCountry vision' of a protected connected landscape in North East Tasmania (Figure 1). In 2012, noted natural heritage expert Peter Hitchcock stated that "the East Coast connectivity corridors have been assessed collectively to have National Heritage significance – one of the more important latitudinally connected tracts of native habitat in Australia."

While the ECCC still has a high level of landscape connectivity, it is under threat from a variety of impacts, including expansion of intensive agriculture and associated dams, forestry (plantations and native forest), coastal development, invasive plants and feral animals. The challenge is to extend the existing protected area system to limit the extent and impact of threats and to strategically restore areas important for connectivity.

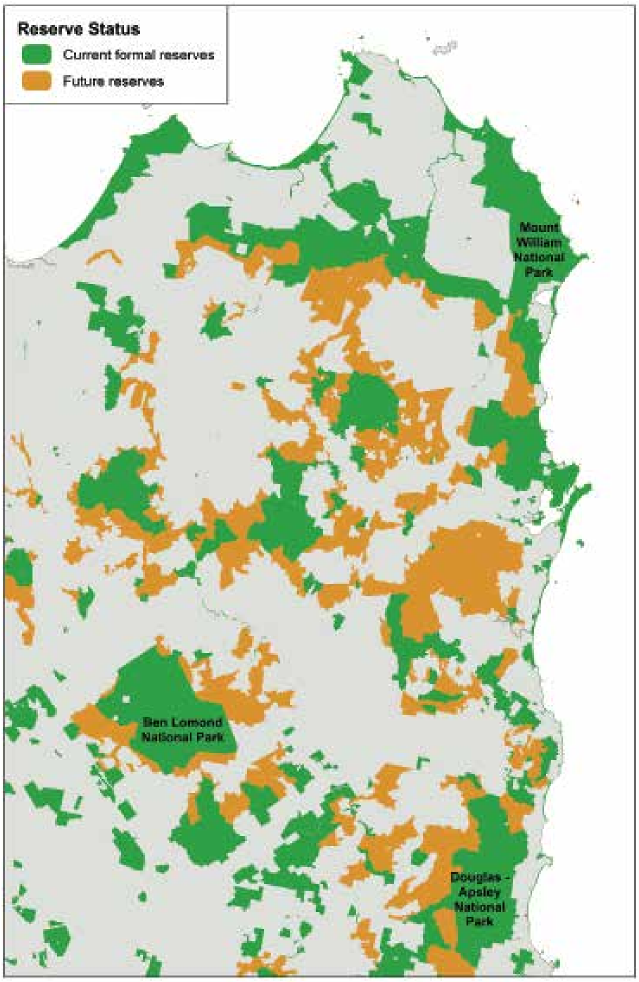


Figure 1. Reserves to improve landscape connectivity in North-East Tasmania © North East Bioregional Network

Key lesson

Finding common interests among many entities and communicating with different types of partners can lead to the ecological restoration of connectivity; long-term efforts, including monitoring, can be ensured through endowments.

Approach

The approach is focused on holistic cross-tenure conservation land management with an emphasis on increasing the extent and improving the condition and landscape connectivity of native vegetation and habitat. Identifying and addressing the physical and ethical causes of ecological decline, such as human population growth, consumption and the ideological support of growth economics in a finite world, is part of the strategy.

The North East Bioregional Network is an entirely voluntary organisation that works with about 45 government entities, communities, companies, private organisations and private landholders on issues where common ground can be found. They are in the process of establishing an endowment fund that will enable a long-term commitment to protect and restore the unique flora, fauna and landscapes of eastern Tasmania.

Example of an ecological corridor

The Skyline Tier restoration project is returning 2,000 ha of non-native radiata pine plantation back to biodiverse native forest (Figure 2). By re-establishing the native ecosystem, this ecological corridor will reconnect protected coastal and hinterland areas. The land is owned by the government but leased to a private company, and now co-managed by the company and the North East Bioregional Network.

Results

Activities that have contributed to improved landscape connectivity in the ECCC area since 2005 include:

- Creation of 30 permanent conservation covenants and 60 registrations under the Land-for-Wildlife program on private land.
- Facilitation of the employment and training of over 80 people over the last five years through ecological restoration projects of the North East Bioregional Network, which has had significant ecological, social and

economic benefits and helped consolidate conservation as a highly beneficial activity in remote rural communities.
- Prohibition of new subdivisions within 1 km from the coast in the Break O'Day municipality, thus maintaining an ecological corridor between the coast and hinterland.
- Establishment of a North East Tasmania Land Trust as a non-government organisation to purchase and receive tax-deductible donations of private land for nature conservation.
- Transfer of management of over 100,000 ha of public native forest from the department of Forestry to that of National Parks and Wildlife in North East Tasmania (Figure 1).
- Release of a conservation action plan for the Break O'Day municipality.
- Consideration of connectivity conservation plans in municipal land planning.
- Production of connectivity conservation plans that explicitly seek to protect wildlife corridors and landscape linkages from inappropriate development and are legally binding in municipal planning schemes.

Learn more: www.northeastbioregionalnetwork.org.au

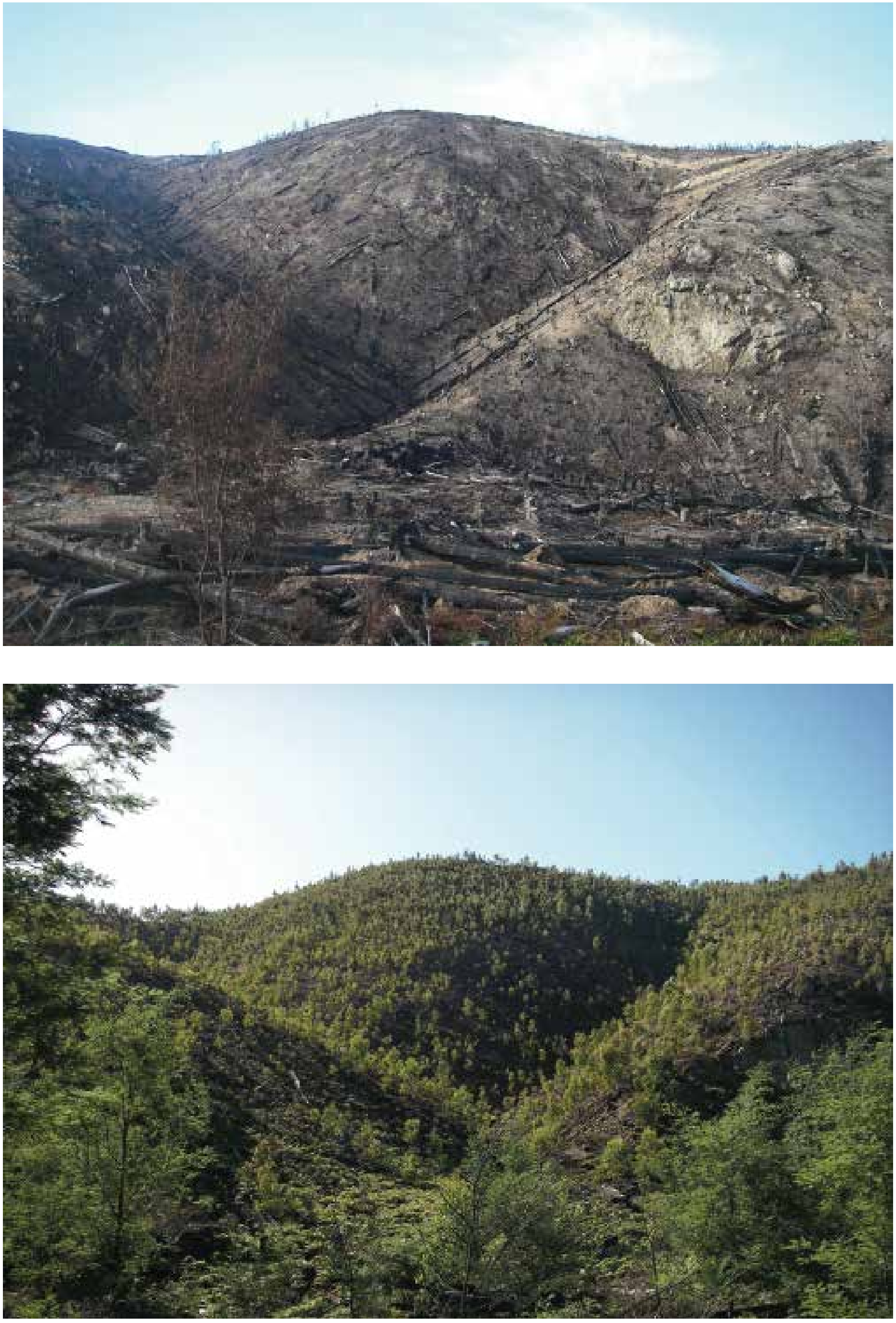


Figure 2. Skyline Tier Ecological Restoration Project. (top) A mature radiata pine plantation was harvested, followed by a hot ecological burn. (bottom) Six years later, intensive restoration work helped regenerate native forest. © North East Bioregional Network

8. The Great Eastern Ranges: Australia's first continental-scale ecological network for conservation

Ian Pulsford, *Connectivity Conservation and Protected Area Consultant*
Gary Howling, *Great Eastern Ranges Initiative*

Key lesson

A bold mission to protect, restore and relink habitat to allow nature and people to continue to thrive despite changing climatic conditions can lead to engagement of many parts of society and on-ground conservation activities.

Challenge

Australia is one of 17 mega-diverse nations globally, with 6,794 vertebrate fauna species – including 1,350 endemic terrestrial vertebrate species, the highest number for any nation – as well as 22,000 species of flora. The greatest concentration of this outstanding biodiversity is found along the rugged eastern mountains and coast. This area comprises a substantial part of Conservation International's "Forests of East Australia" global high-biodiversity hotspot. Substantial sections are conserved in an archipelago of embedded protected areas, including three World Heritage areas, as well as lands used for agriculture, mining, urban development, infrastructure and forestry. Clearing and fragmentation of habitat; land degradation; introduced exotic species of plants, animals and pathogens; and climate change are major threats that degrade and fragment this ecological network for conservation.

Approach

The Great Eastern Ranges (GER) Initiative was established in 2007 with a bold mission to protect, restore and relink habitat to allow nature and people to continue to thrive. The initiative comprises natural lands that extend along the mountainous ranges on the eastern seaboard of Australia for more than 3,600 km from the Grampian Mountains in Victoria, through eastern New South Wales (NSW) and the Australian Capital Territory (ACT), to Cape York in the far north of Queensland (Figure 1). Countless species rely on the Great Eastern Ranges to move and adapt to a climate of extremes. The GER Initiative is an ecological network for conservation that helps people to work together to restore and reconnect nature in areas of high biological importance such as gaps and areas that are fragmented. This work is guided by a vision for the ecosystems of Australia's Great Eastern Ranges to be healthy and connected, which will contribute to the long-term economic, social, cultural and spiritual well-being of the community, and of native plants and animals.

The GER Initiative is one of a very few connectivity conservation initiatives worldwide that have been initiated by government. The initiative began in 2007 with funding from the state of NSW, enabling its Department of Environment, Climate Change and Water to demonstrate a new approach to conservation based on collaborative partnerships. Five 'regional partnerships' were established in five priority connectivity areas. Partners included non-governmental conservation organisations, land care groups, Aboriginal groups, academic institutions, local governments and other government agencies. In 2010, governance devolved to a public–private partnership group of five non-governmental lead partners. Regional groups expanded to ten by 2016. In 2017, governance was transferred to Great Eastern Ranges Ltd. with a board of eight independent directors.

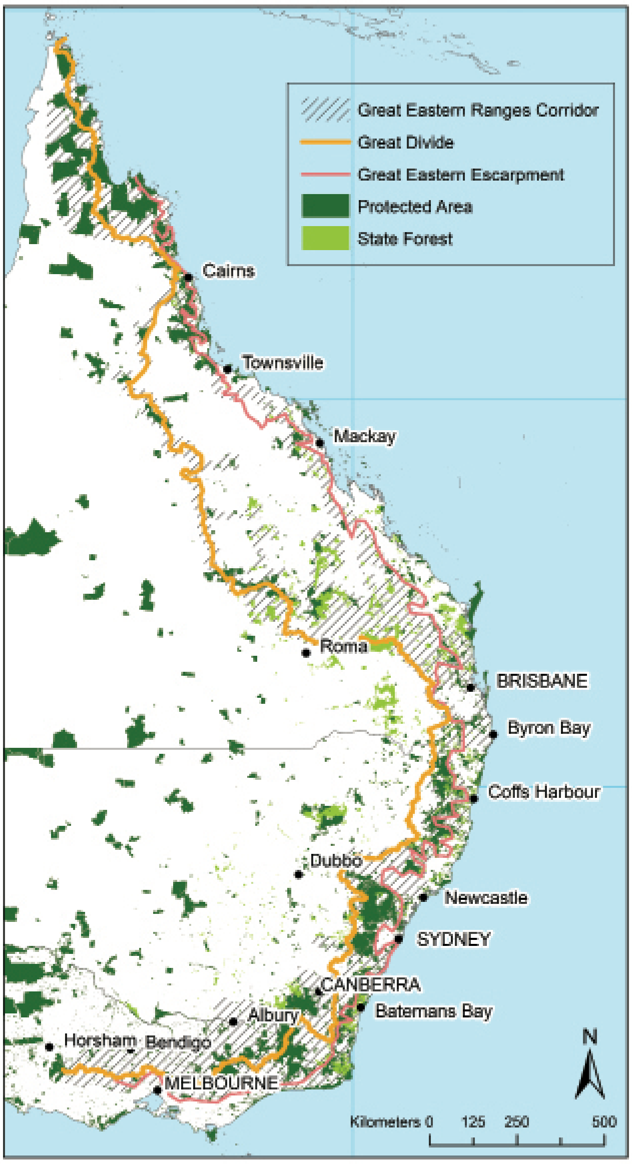


Figure 1. The Great Eastern Ranges ecological network for conservation forms a 3,600-km arc of mostly interconnected natural lands that extends from the Grampians in Victoria to Cape York in far north Queensland. © Great Eastern Ranges Ltd.

Great Eastern Ranges Ltd. is now a not-for-profit entity that operates as an equal partner in a national network of regional partners in 10 partnership areas in Victoria, NSW, the ACT and Queensland.

Examples of ecological corridors

Regional partnership groups consist of public and private organisations and individuals involved in on-ground voluntary conservation activities that come together to collaborate and share resources and capacity (Figure 2). A number of the connectivity partnership areas link north–south along the central mountainous spine and several areas extend east to the coast and west onto the slopes connecting the mountains to the inland. For example, the Slopes to Summit and Kanangra to Wyangala are ecological networks linking alpine and montane forest to the inland. The Kosciuszko2Coast ecological network links the Alps to the east coast. The Victorian Biolinks Alliance works to connect tall-forest landscapes in the central Victorian highlands and the transboundary Border Ranges Alliance works to maintain and improve connectivity of World Heritage-listed rainforests and tall eucalypt forest on the border between NSW and Queensland.

Results

From funding provided by the NSW and Australian governments over 10 years, the GER Initiative and partners coordinated voluntary conservation activities through a suite of instruments. These included whole-of-paddock restoration agreements, voluntary conservation agreements, land for wildlife agreements, grants to fence stream banks, tree planting, habitat restoration, feral animal and weed control, community education through community field days, development of a range of communication products including videos and a web site, biological surveys, and research programs.

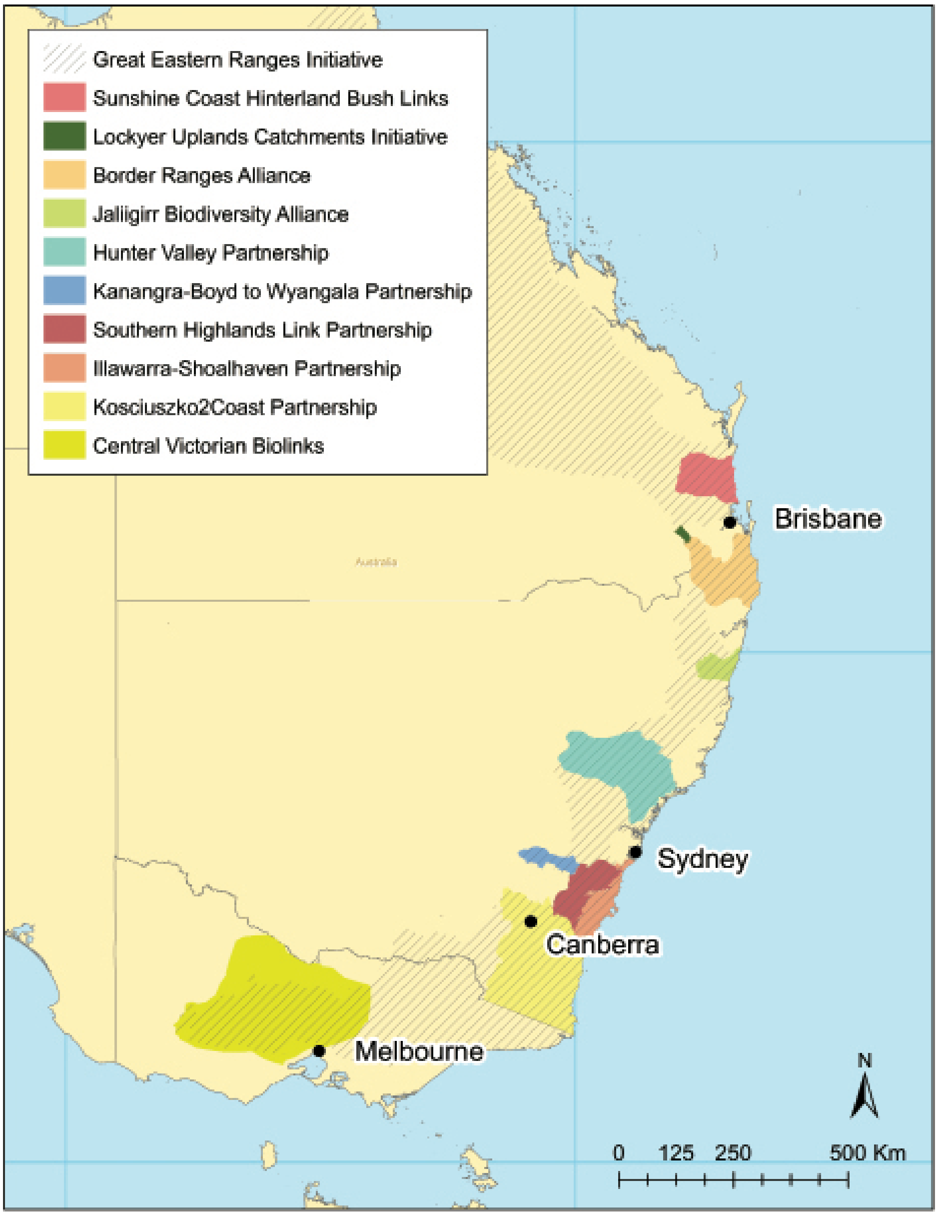


Figure 2. Great Eastern Ranges network of regional partnership areas of connectivity conservation © Great Eastern Ranges Ltd.

Terrestrial connectivity: Europe

9. COREHABS to BearConnect: Securing ROAMing in the wilderness corner of Europe

Ancuta Fedorca, *Transilvania University*

Context and challenge

The Romanian portion of the Carpathian Mountains holds the biggest continuous forest ecosystems in Europe, harbours many well-preserved natural habitats, and is home to large herbivores and carnivores, including brown bear (*Ursus arctos arctos*), wolf (*Canis lupus lupus*) and lynx (*Lynx lynx*) (Figure 1). The mountain range is a biodiversity hotspot situated at the crossroads of several important biogeographic regions. Recent changes in land ownership and rapid infrastructure development (highways, industrial and human settlements, tourist facilities) are threatening the largely intact nature of the Romanian Carpathians. A total of 30.2% of the national territory is covered by forest, including virgin forests and ancient beech forests. While some of the forest is in public ownership, a large proportion is privately owned due to restitution that took place in recent decades. A large number of sites, adding up to 24.46% of the terrestrial national territory, are included in the Natura 2000 network; however, these sites are spatially disconnected.

Key lesson

Romanian legislation requires modelling to identify ecological corridors that can help maintain genetic diversity of wildlife and facilitate adaptation to climate change.

Approach

In 2015, an initiative called COREHABS (Ecological corridors for habitats and species in Romania) brought together six entities (two public universities, one national research institute and three NGOs) to design a national ecological network for ensuring habitat connectivity in tandem with sustainable development. COREHABS is providing corridor modelling as a decision support tool for stakeholders, giving them the opportunity to develop infrastructure while considering the ecological measures necessary to ensure the long-term viability of species and habitats. In 2017, COREHABS combined forces with BearConnect (Functional connectivity

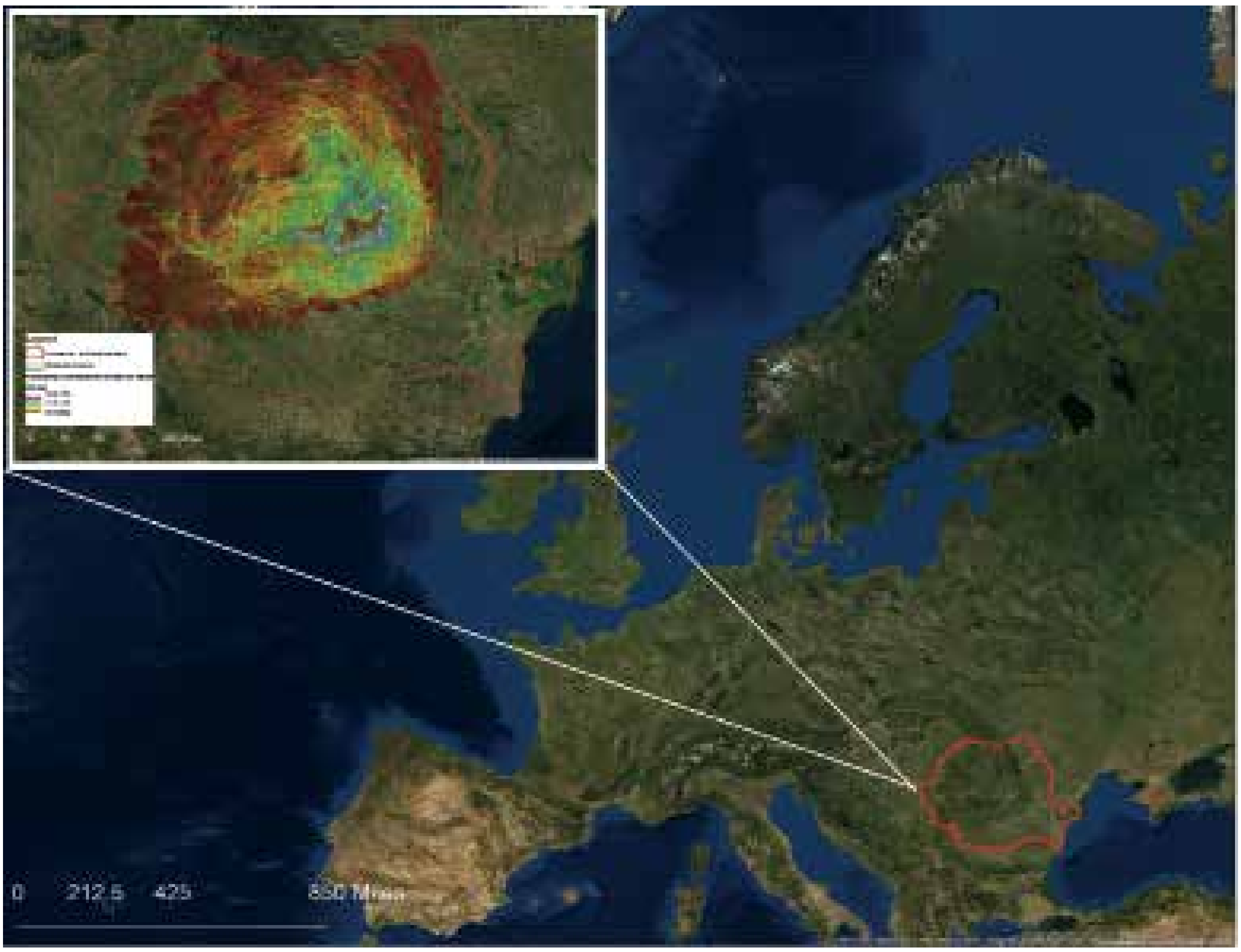


Figure 1. The Carpathian mountain range runs in an arc through the centre of Romania. This map shows modelled values for predicted functional connectivity across brown bear habitat, overlaid with protected areas in Romania. © Ancuta Fedorca

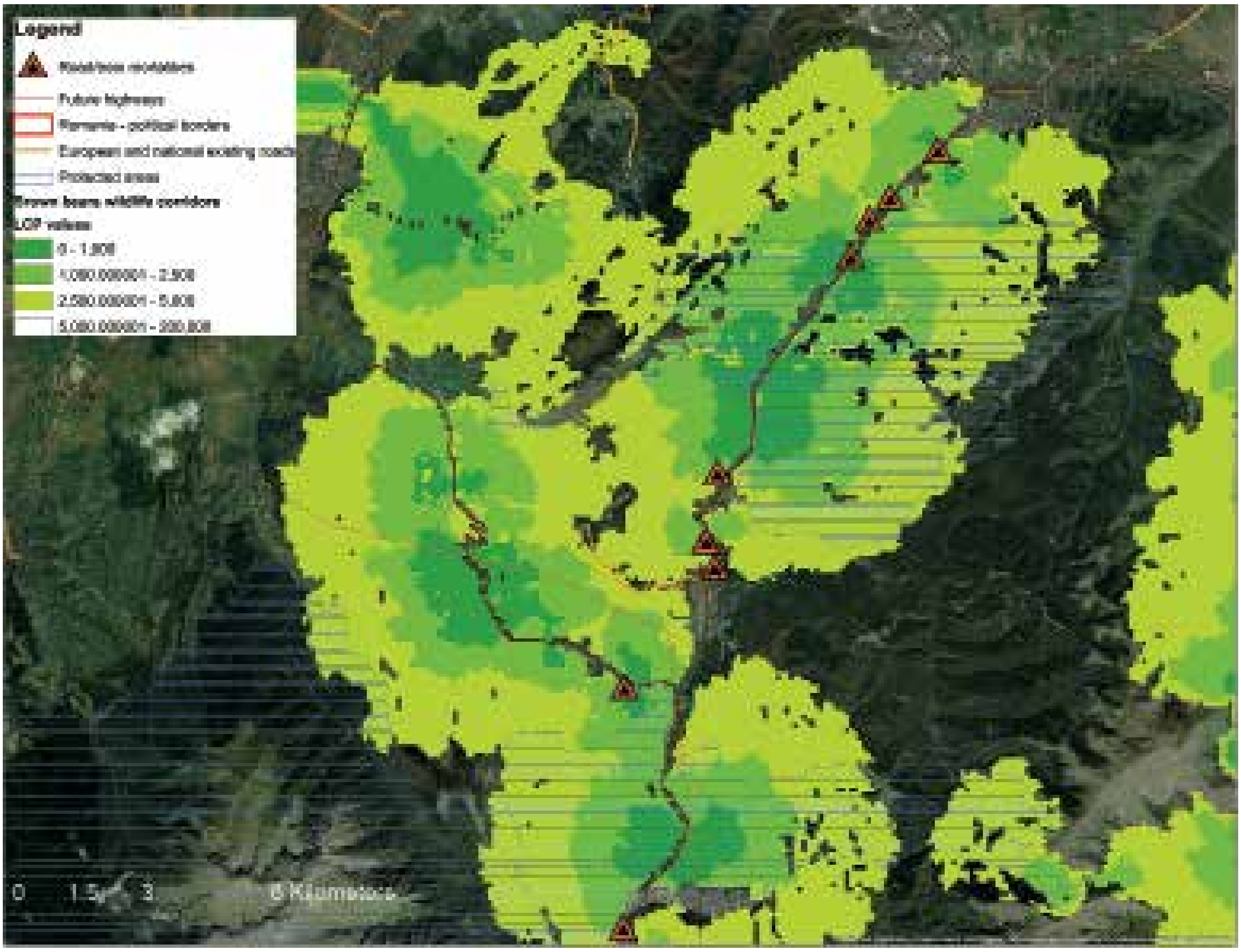


Figure 2. The protected areas in blue need to be connected (Bucegi Nature Reserve, Bucegi Natural Park, and Bucegi Protected Area in the north and Piatra Mare Protected Area and Postavaru Protected Area in the south). The shades of green show highest (darkest green) to lowest (lightest green) areas of predicted connectivity to help prioritise where conservation activities should occur. © Ancuta Fedorca

and ecological sustainability of European ecological networks), an organisation focusing on the brown bear. To achieve ecological corridor conservation and facilitate specific ecosystem processes, the organisations are investigating the degree to which existing ecological networks, which include national protected areas and the Natura 2000 network, ensure landscape functional connectivity and ecological sustainability at different scales, and provide practical recommendations for connectivity conservation.

Romanian legislation on ecological corridor designation (GO 57/2007) mandates the protection of connectivity by designating spatially explicit ecological corridors based on field-informed modelling and empirical validation. Ecological corridors are established on the basis of scientific studies and are designated by an order of the head of the Authority for Forest and the Environment after receiving the acceptance of the Romanian Academy of Science. Protected areas and ecological corridors are integrated into national, regional and local rural and urban planning, cadastral plans and land registers by the National Agency for Cadastre and Real Estate Advertising, and noted in the parcel identification system. Partners for implementation include ministries and agencies responsible for natural resources and infrastructure, Transilvania University of Brasov, and the National Institute for Research and Development, local and regional councils, private forest owners and NGOs.

Examples of ecological corridors

An area of about 10x10 km has been identified as important to connectivity for brown bears between the Bucegi protected areas in the south and the Piatra Mare and Postavaru protected areas in the north (Figure 2). The majority of the land is owned by the state, with small areas being held by the community and private owners.

Results

COREHABS developed an efficient mechanism for identification and assessment of ecological corridors, and is providing specialists in local planning and implementation of a national ecological network for conservation. Romania is on track to protecting a coherent ecological network of protected areas and ecological corridors, which will allow wildlife populations to interbreed, improving long-term genetic viability and climate change resilience.

10. Ecological connectivity in an urban context: Utrechtse Heuvelrug, Netherlands

Rob H.G. Jongman, *Independent Scientist*
Chris Klemann, *Province of Utrecht*

Key lesson
Netherlands offers a model of 'the polluter pays' that helps finance connectivity, such as safe passage across roads, and allows activities compatible with connectivity goals (e.g. recreation) to occur in the corridors.

Context and challenge

Netherlands is a largely urbanised country and nature faces pressures from urban expansion, infrastructure, intensive agriculture and recreation. The Utrecht Hills (Utrechtse Heuvelrug) stretch from north-west to south-east and comprise several important nature reserves and a national park. This area is dissected by several motorways and railroad lines, which were making it nearly impossible for fauna to move through the landscape. However, the area is part of the Netherlands Nature Network. Therefore the province of Utrecht and the responsible nature management agencies, Utrechts Landschap (https://www.utrechtslandschap.nl/) and Goois Natuurreservaat (https://gnr.nl/), were mandated to restore connectivity for wildlife.

'The polluter pays' is a basic principle in environmental policy in Netherlands. Therefore, the owner and manager of transportation infrastructure is responsible for financing and implementing all ecopassages (green bridges and culverts); the funds do not come out of the nature conservation budget. This is the main reason why ecopassages were not implemented in the 1990s. The district's mandate to restore connectivity and lack of actions by the national road authorities (which have an implementation budget) created tensions. Coordination between national and provincial authorities was needed for realising necessary connecting measures for provincial roads for an optimal return on investments.

Approach

A renewed effort was made to speed up the process of landscape defragmentation through the Netherlands Nature Network, which consists of protected areas and the linkages between them, and a national defragmentation plan that came with extra funds. Both programs were scheduled for implementation from 2004 to 2018.

Examples of ecological corridors

For the province of Utrecht, priority measures were planned for the Utrecht Hills to improve wildlife movement across national motorways and railroad lines, which is a national responsibility. The province was expected to contribute to the plan by implementing defragmentation measures for the roads under their responsibility.

Accordingly, the province of Utrecht has elaborated plans and actions for the Utrecht Hills (http://www.hartvandeheuvelrug.nl/projecten/ecologische-verbindingen/). The project 'Hart van

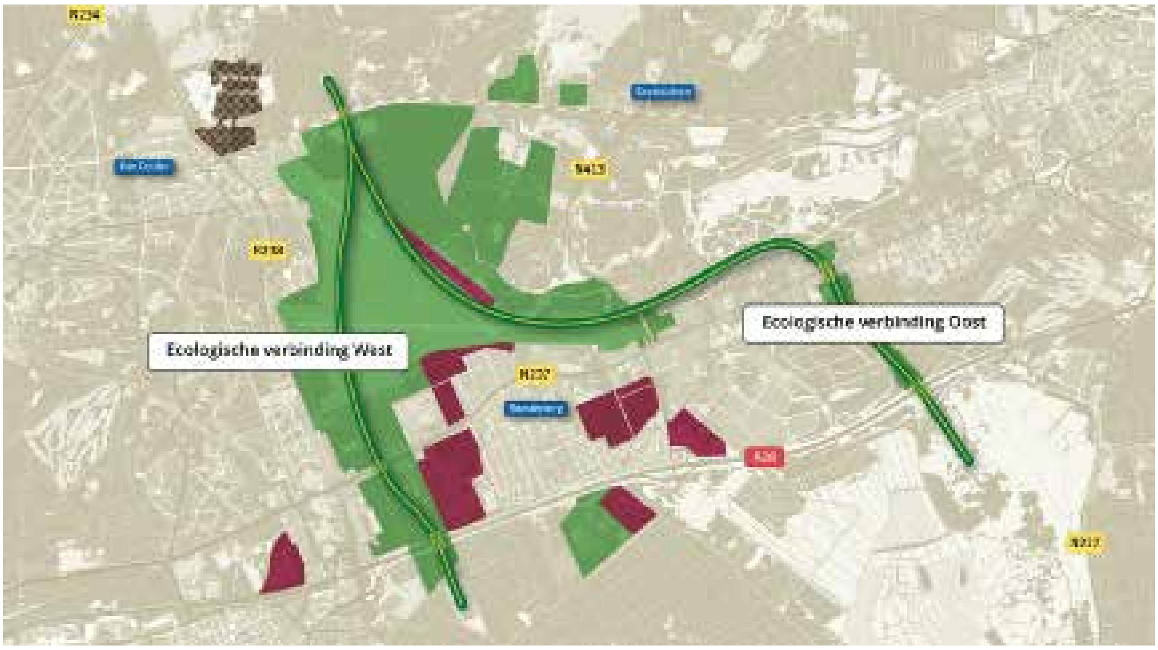


Figure 1. The West and East ecological corridors in the Utrecht hills. The numbers indicate motorways (red) and link roads (yellow). The blue names indicate built-up areas; purple: heathland; green: forest. © Provincie Utrecht

Figure 2. Ecoduct Op Hees, crossing the Utrecht–Amersfoort rail line. The recreation cycle path is situated at the foreground side of the bridge © ProRail

de Heuvelrug' consists of two main ecological corridors that merge in the north (Figure 1).

The western part of the project area is a forest corridor, with the eastern part a heathland corridor. Both corridors contain many small tunnels that cross under roads (such as a tunnel in the south-east of the province under road N225; https://www.youtube.com/watch?v=hHAn-Clwy8Q&feature=youtu.be). To realise connectivity, an additional five ecoducts have been built in these two ecological corridors, including the Ecoduct Op Hees (Figure 2), which was completed in 2013 and crosses a busy railroad line between the cities of Amersfoort and Utrecht. In addition to facilitating wildlife movements, it also serves as a recreation corridor. For this purpose, the ecoduct has been made wider to accommodate cyclists and pedestrians.

Results

The two ecological corridors act as movement routes for mammals (such as roe deer, *Capreolus capreolus*; badger, *Meles meles*; and tree marten, *Martes martes*) and as a temporary living and breeding area for smaller mammal species. Through these ecological corridors, plants and animals can spread and move from Gooimeer (Gooi Lake) in the north-west to the Veluwe National Park in the south-east.

11. The Spanish National Network of Drover's Roads (Vías Pecuarias)

Marcos Pradas, *Independent Forest Engineer*

Context and challenge

The Spanish National Network of Vías Pecuarias is a network of drover's roads (routes traditionally used to drive livestock on foot from one place to another, e.g. to market or to summer pastures) and additional elements used for transhumance and smaller cattle movements (Figure 1). They criss-cross Spain some 125,000 km in length and covering an area of 400,000 ha, linking a wide variety of protected, unprotected and urban areas. They hark back to prehistory, having been first documented in Roman times and legally protected by decrees issued in AD 654, 1273 and 1995. The Mediterranean region is a biodiversity hotspot where humans are such an integral part of the environment that rural exodus and disappearance of traditional uses are regarded as two of the major ecological threats to the Iberian Peninsula.

Droves are not just trodden and dusty ways, but are open or wooded pastures with a trail in the middle. They often contain trees, hedgerows, dry-stone walls, ponds, wells and watering holes. They can be very biodiverse, many times more so than their surroundings. In addition, they are important for the protection of many ancient breeds of farm animals, many of which are in danger of extinction. They serve as ecological corridors in different ways. Cattle and sheep spread organisms along them. It is estimated that herds of 1,000 sheep or 100 cows spread 3 to 5 million seeds and some 3 tons of dung on a daily basis, thus contributing to species range shifts, a useful adaptation to climate change (Manzano & Malo, 2006). Drover's roads cross protected, conserved and unprotected areas, including urban areas, and

Key lesson
A transportation network originally established for moving livestock can provide ecological connectivity among protected areas, especially when restored for that function.

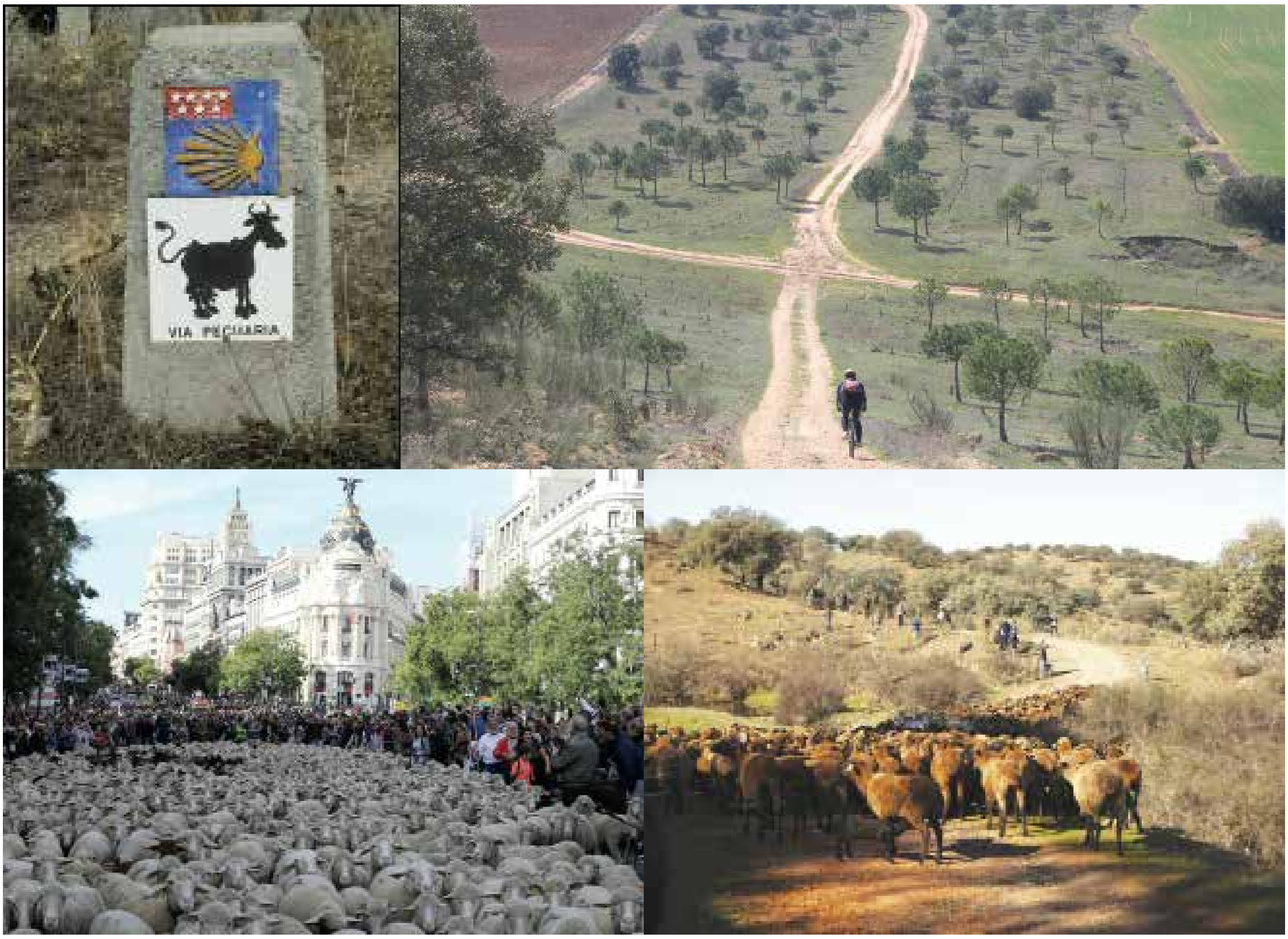


Figure 1. Scenes from drover's roads in Spain.
(upper left) A standard marker (courtesy of Juan Díaz Hidalgo)
(upper right) The Droveway of Salamanca, illustrating its multifunctionality and value as an ecological corridor © Federico Sanz
(lower left) The Fiesta de la Transhumancia in Madrid (courtesy of Diario de Madrid)
(lower right) A road important for four local domestic animal races: the white and black Merina sheep, Verata goat, and Andalusian donkey, which is the oldest donkey breed of Europe and now classified as being in critical danger of extinction © Agustín Pérez, la Siberia Extremeña Biosphere Reserve

are vital for connecting the Natura 2000 network of protected areas. They are particularly important for promoting functional connectivity between isolated grasslands. Because they are linear structures in the landscape, migrating species, including birds, follow them and also use them to rest, drink and feed.

The ecological significance of drover's roads, including their role as ecological corridors, is now being fully acknowledged, and the necessity to protect them has been recognised under Article 8 of the Convention for Biological Diversity, the Sustainable Development Goals, and covenants such as the United Nations Convention to Combat Desertification and the United Nations Framework Convention on Climate Change, among others. The main threat to drover's roads is the decline of extensive livestock farming and transhumance. Other threats include the lack of a true strategy for conservation, reluctance of the government to protect the Vías, illegal settlements, dumping, fencing, resource extraction, pesticides and capping of wells. Many drove ways are now irretrievably occupied and their status as public domain has been or is in the process of being revoked.

Approach

State law 'Ley 3/1995, de 23 de marzo, de Vías Pecuarias' specifies that drover's roads are in the public domain, are unseizable, inalienable and imprescriptible. The law protects an important ecological corridor, and obliges governments to demarcate them. Numerous individuals, agencies, associations, universities, NGOs and working groups are exploring different ways to protect, recover, and foster the droves and bring them to the attention of a wider sector of society. They work toward restoring and fostering extensive livestock farming, attracting young people to transhumance and cattle farming, and rapidly finishing the demarcation of all drove ways. Other actions include pressing governments to enforce the laws; fully exploiting the multifunctionality (livestock transport, ecosystem services, biodiversity conservation, recreation, etc.) of the Vías Pecuarias; and reaching out to a wider sector of society.

Example of an ecological corridor

In Spain, the network of drover's roads is densest in the Autonomous Community of Madrid (Figure 2). Many actions are being taken to protect them. For instance, ecological functionality of the Real Cañada Segoviana (Royal Segovian Droveway) is being improved by the Repsol Foundation and Reforesta through reforestation with native species, fencing of endangered plants, restoration of ponds and creation of new ones, establishment and fencing of refugia for different animal species, habitat improvement for insects, environmental education and monitoring.

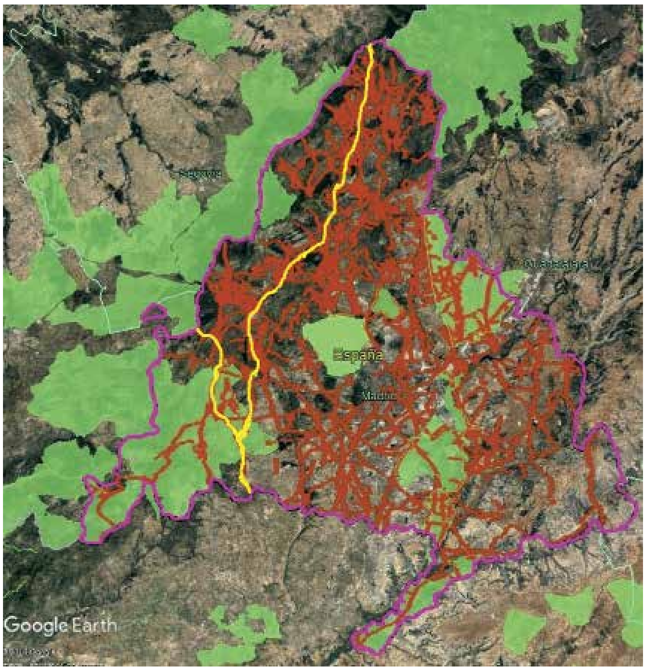


Figure 2. Vías pecuarias of the Autonomous Community of Madrid superimposed on protected areas. Note how they link rural, urban, protected and unprotected areas. In yellow, the Cañada Real Segoviana. Droves outside the Autonomous Community are not depicted. © Marcos Pradas, Spanish Instituto Geográfico Nacional and the Community of Madrid; Base data courtesy of Google Earth

Results

Governments tend to be ambivalent about the issue. On the one hand, of 125,000 km of droves, 40,000 km may already be lost. Governments often permit a change of use of these roads. When their utility for cattle is lost, they decree by law the land-use change and take them out of the public domain. The Autonomous Community of Madrid is no exception and may have lost around 38% of its drover's roads over the past 20 years. One example is the Cañada de Madrid: a linear city was built illegally along 14.2 km of the Galiana's Royal Droveway. On the other hand, many governments are demarcating drover's roads, educating the public, and taking action in the field to protect them and maximise their ecosystem services. In a world that urgently presses to reduce the environmental impacts of meat consumption, a new generation of transhumance practitioners offers the responsible consumer the opportunity to eat animal products that have a positive ecological footprint. Protecting Spain's drover's roads will support this market and, in addition, allow these ecological corridors to continue to deliver their much-needed ecosystem services.

Learn more:
http://www.pastos.es/
https://www.viaspecuariasdemadrid.org/
http://transhumancia.cat/es/inicio/
http://trashumanciadehoy.emiweb.es/paginas/cartografia-y-conocimiento-de-los-caminos.html

12. ECONET: Ecological network in the Kostroma Region, Russia

Alexander V. Khoroshev, *Lomonosov Moscow State University*

Key lesson

Ecological corridors that encompass riparian and forested corridors can have multiple benefits such as decreasing erosion and improving water quality.

Context and challenge

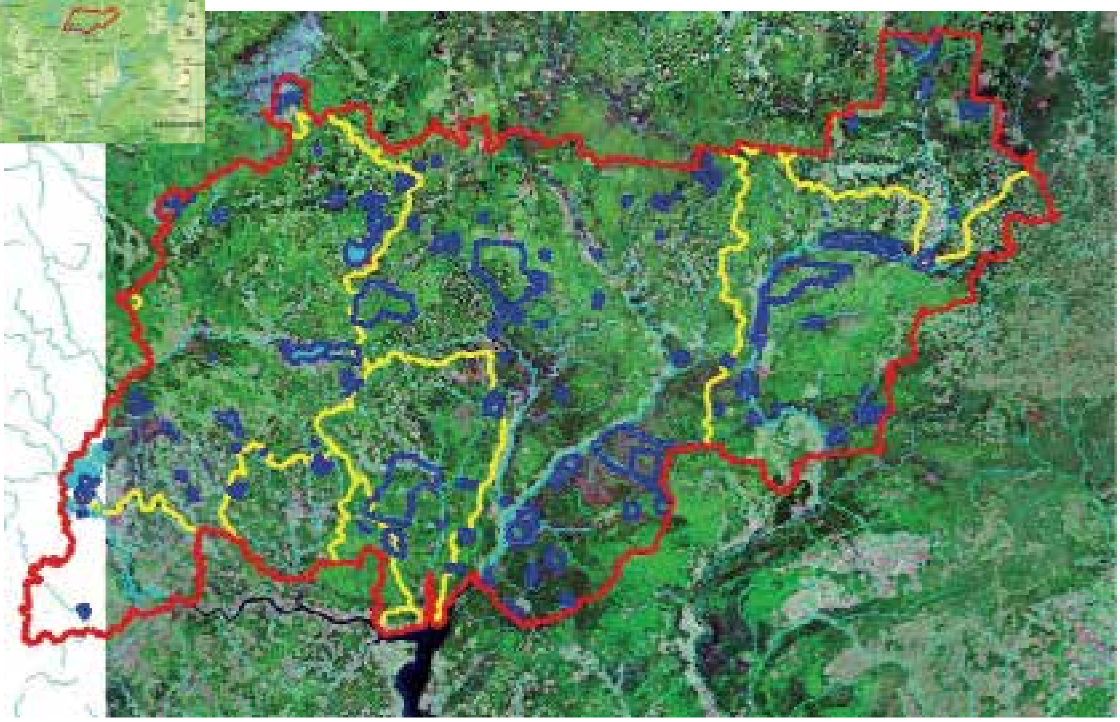
Recent undesirable changes to the landscape of the Kostroma region in central European Russia revealed the need for a strong ecological network for conservation. The region is located in the watershed divide between the Caspian and the White seas. Here, Siberian species transition to European species, and taiga is replaced by broad-leaved forest. Landscape diversity is highest where depressions among morainic hills are combined with post-glacial lakes, fens, bogs, and old-growth and secondary forests that control water runoff and ensure valuable wetland habitats. In recent decades, vast forest areas decreased considerably due to timber harvesting. This harvesting expanded to remote catchment areas, which caused a decrease of runoff volume, loss of opportunities for navigation on rivers, and the degradation of fish resources, all with obvious negative economic consequences for local people. This resulted in the need to preserve the remnants of virgin southern taiga stands within an ecological network.

Approach

The mission of the Kostroma ECONET project, launched in 2003 with strong support of the regional government, was to ensure the protection and connectivity of the most ecologically valuable landscapes as well as to facilitate restoration of lost traditional economic opportunities for local people. The Kostroma ECONET project is based on the idea of critical significance of a connected landscape.

The core areas of the ecological network for conservation are composed of four types of landscapes: (1) intact landscapes representative of the European southern taiga, such as moraine plains with spruce and fir forests (e.g. Kologriv Forest Nature Reserve); (2) fluvioglacial terraces with pine forests, and mires; (3) rare and unique landscapes (e.g. larch forests on sandy terraces); and (4) landscapes with key habitats for migratory birds and mammals (e.g. floodplains used by geese on their spring migration from western Europe to northern Siberia). The full range of typical interfluvial and river valley landscapes is represented in the network (Figure 1), with a higher concentration of protected areas in the upper parts of the river basins that have a higher proportion of mires close to watershed divides. The legal regime of the ECONET prohibits clearcutting in key locations to ensure runoff formation in the interfluves and safeguards the necessary proportion of forests

Figure 1. Ecological network for conservation in the Kostroma region, Russia. Blue lines: borders of natural protected areas. Yellow lines: borders of the river basins © Alexander Khoroshev



Kostroma Taiga, Russia © Adobe Stock

in a given basin. The process of planning protected areas included intensive consultations with local stakeholders.

Example of an ecological corridor

The protected areas are connected by ecological corridors consisting either of riparian forests or of zonal coniferous forests embedded in a matrix of timber harvesting areas. The ecological network recognises the crucial contribution of the regional landscapes to the functioning of the larger watershed, the Volga River basin, because the three largest tributaries in its upper reaches come from the Kostroma region. The ecological corridors comprise hydrologically important zones along the slopes of river valleys, terraces and floodplains. Thus, in addition to connecting core protected areas, the ecological corridors decrease erosion, water eutrophication and undesirable surface runoff.

Results

A scheme to develop an ecological network for conservation was adopted by the regional authorities in 2008. Fifty-nine protected areas are being established, with reasonable limitations on timber harvesting, human development, and, if necessary, hunting and fishing embedded in land-use plans. The scheme is now an obligatory part of territorial planning at both the regional and municipal levels.

The experience of the Kologriv Forest Nature Reserve provided evidence that prohibiting hunting in rather small areas can result in an increase of game species populations, their expansion to the adjacent non-protected landscapes and, therefore, an increase in game resources. Some of the established protected areas successfully combine nature protection, recreation and ecological tourism. This is of particular importance to communities in Kostroma's remote districts who struggle with insufficient sources of income. The most serious current challenge to the ECONET project is the delayed designation of protected area borders by state authorities, which results in conflicts with the timber industry and agricultural producers.

Terrestrial connectivity: North and South America

13. Sustaining forested landscape connections in the northern Appalachians: The Staying Connected Initiative

Jessica Levine, *The Nature Conservancy*

Context and challenge

The 32 million-ha Northern Appalachian–Acadian ecoregion – which includes parts of five US states and three Canadian provinces – contains the largest expanse of temperate broadleaf forest remaining in the world. Protected areas within the region include a national forest, state and provincial parks, national parks and conservation easements. Yet these tracts are nested within a matrix of rural development and human uses. The region is only a half-day's drive from several major urban centres, including New York, Boston and Montreal, and is increasingly in danger of fragmentation from roads and other human development. In 2009, public agencies and private organisations from across the bi-national region formed the Staying Connected Initiative (SCI) to address this challenge.

Approach

The SCI is a partnership of over 55 organisations, including natural resource and transportation departments from the US states and Canadian provinces of the region, conservation organisations and universities. Partners actively collaborate to maintain, enhance and restore landscape connectivity across this large region. On-the-ground efforts are focused on ensuring landscape permeability, today and into the future as the climate changes, in nine highest-priority linkage areas (Figure 1). In these, partners apply a combination of strategies to conserve connectivity, recognising that no single strategy is sufficient and that partners have different areas of influence and expertise. Primary strategies include:

- Strategic land protection of priority parcels for connectivity such as forested pathways and riparian corridors;

> **Key lesson**
> In the United States, conservation easements are an important tool to permanently secure connectivity.

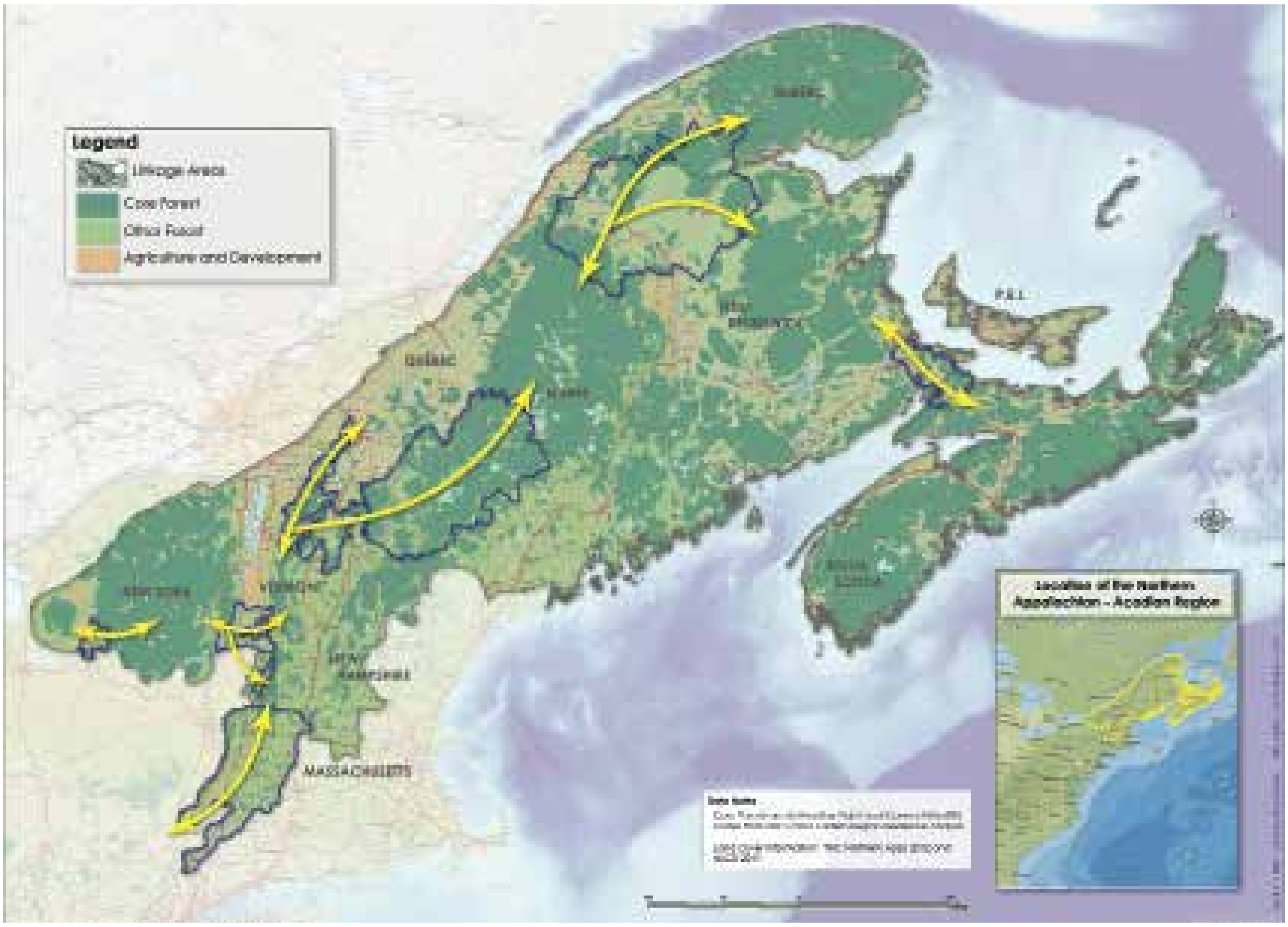


Figure 1. Staying Connected Initiative region and linkage areas © The Nature Conservancy

- Land-use planning to steer development away from critical connectivity areas;
- Community outreach and engagement to build awareness and appreciation among private landowners and encourage private land management to maintain landscape permeability;
- Habitat restoration in key locations such as wetlands and roadside parcels; and
- Facilitation of the movement of wildlife under roads by means of improved bridges and culverts, signage and fencing.

At the regional scale, partners share best practices and lessons learnt through webinars, meetings and written communications.

Example of an ecological corridor

The Northern Green Mountain linkage area encompasses 2,923 km^2 and is centred on the spine of the Green Mountains. The linkage area stretches from Mt. Mansfield State Forest, which contains Vermont's highest peak, north to Mont Orford National Park in Quebec. Most of the area is forested, with agriculture and small towns and villages in the many valleys that bisect the mountain spine. Within this linkage area, Jackson Valley is an important ecological corridor along the US–Canada border (Figure 2). A 2010 study of the 379-ha parcel found that it served as a key trans-border ecological corridor for a range of animals. Jackson Valley links conserved Atlas Timberlands to the south, Jay State Forest to the east, and a 652-ha preserve in Quebec, protected by Nature Conservancy of Canada, to the north. In 2012, with funding from the US Forest Legacy Program, The Trust for Public Land completed years of work to conserve Jackson Valley. A conservation easement, held by the state of Vermont, prevents development and subdivision in the ecological corridor and requires sustainable management for wildlife, timber, public recreation and soil conservation. The corridor is open to hikers and skiers, and for other forms of non-motorised recreation.

Conservation of this parcel as an ecological corridor is leveraged by the work of many SCI partners on both sides of the border. This work includes land protection in other parts of the linkage (over 12,140 ha to date), technical assistance to municipalities on land-use planning to steer development away from critical ecological corridors, scientific studies along major roadways to identify potential sites for wildlife mitigation measures, and outreach to private landowners on sustainable forest management.

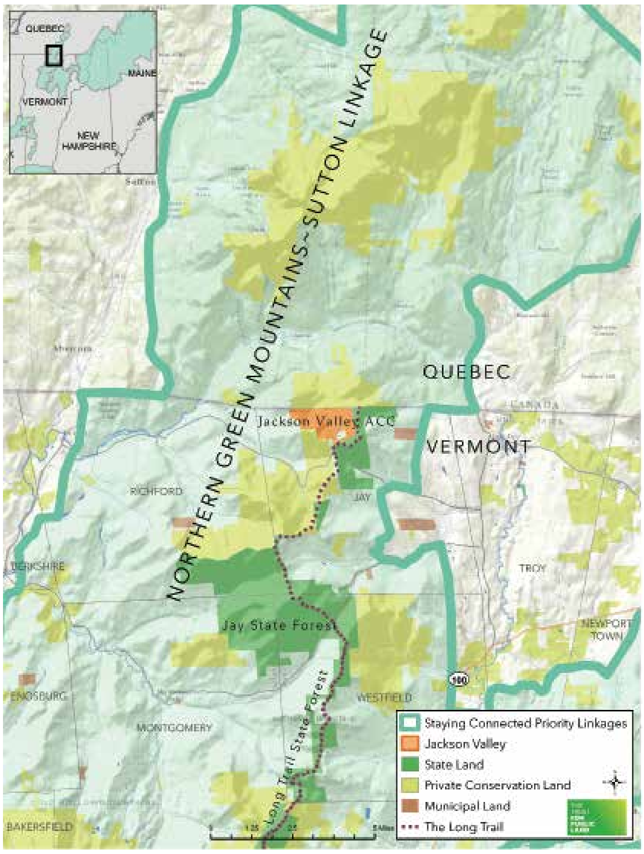


Figure 2. Jackson Valley Ecological Corridor in the Northern Green Mountains linkage area © The Trust for Public Land

Results

Since 2009, SCI government and land trust partners have secured permanent protection of over 222,500 ha in the nine linkage areas. At least 30 land-use plans in the linkage areas, and all five state Wildlife Action Plans in the region, explicitly incorporate wildlife connectivity. Partners from SCI helped to develop and advance the 2016 Resolution on Ecological Connectivity passed by the Conference of New England Governors and Eastern Canadian Premiers, and SCI government agency partners are leading its implementation. The resolution acknowledges the importance of ecological connectivity from a climate adaptation perspective and calls on relevant agencies within the 11 jurisdictions to work together for improved connectivity through transportation improvements, land protection, forest management and other efforts.

Learn more about SCI and the resolution at http://stayingconnectedinitiative.org/ and https://www.coneg.org/wp-content/uploads/2019/01/40-3-Ecological-Connectivity-EN.pdf.

14. Yellowstone to Yukon (Y2Y): Connecting and protecting one the of the most intact mountain ecosystems

Jodi Hilty, *Yellowstone to Yukon Conservation Initiative*

Context and challenge

Increasing human activities threaten to fragment the 3,200-km-long Yellowstone to Yukon (Y2Y) mountain region in western North America (Figure 1), thus impacting natural processes, wild areas and wildlife, ranging from grizzly bears (*Ursus arctos horribilis*) and mountain caribou (*Rangifer tarandus caribou*) to

Key lesson

Realisation of a larger ecological network vision requires science, on-the-ground action, and monitoring the impact of the collaborative conservation efforts in order to assess whether connectivity goals are ultimately met.

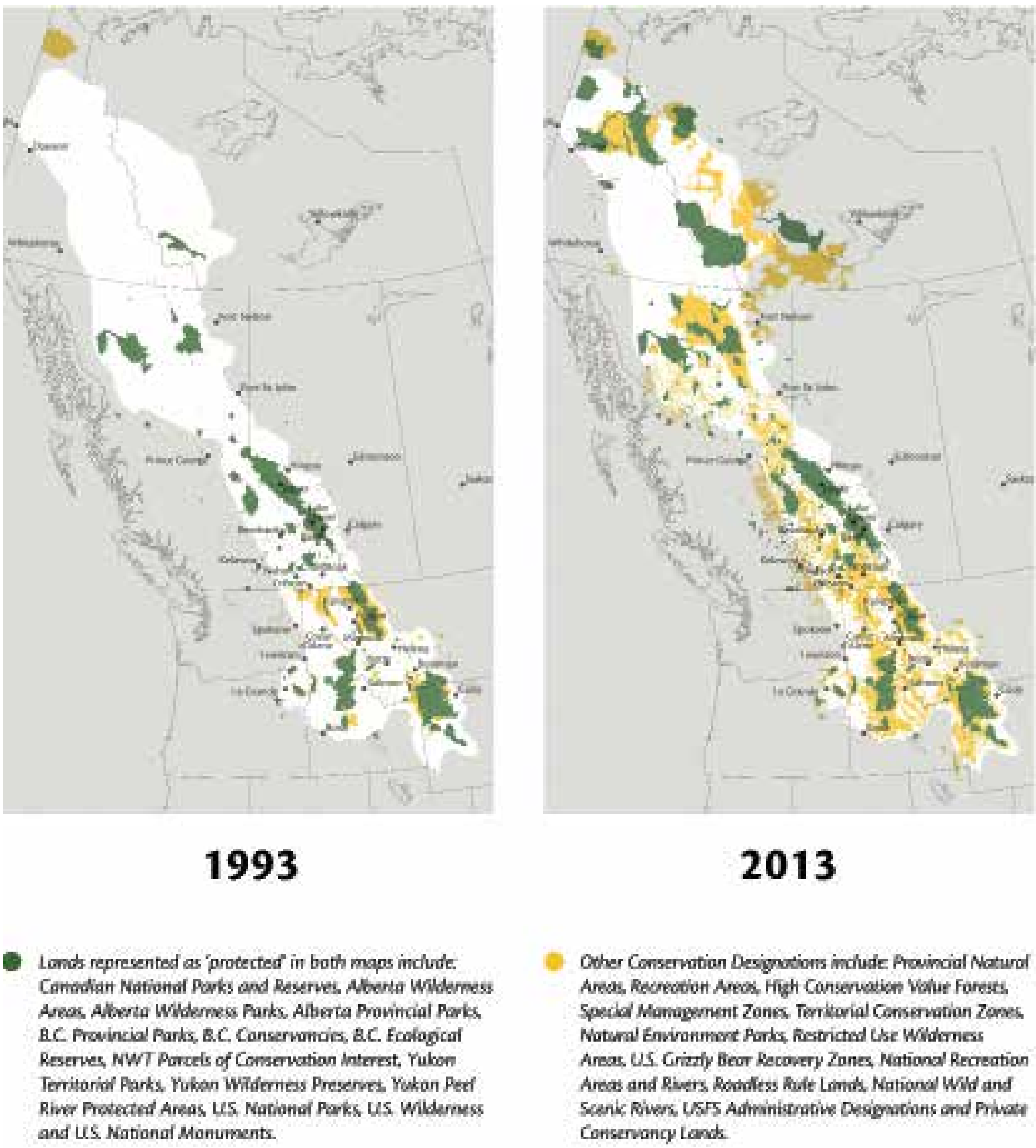


Figure 1. Increase in protected areas over two decades in the Y2Y region of North America © Y2Y

jumping slugs (*Hemphillia dromedarius*) and migratory birds. The region has a myriad of jurisdictions, including many Indigenous territories. The US and Canadian governments have classified approximately 80% of Y2Y lands as public and 20% as private or tribal reservation lands.

Approach

Since 1993, a joint Canada–US not-for-profit organisation, the Yellowstone to Yukon Conservation Initiative, has brought partners together to achieve the vision of connecting and protecting the region so that people and nature can thrive within an ecological network for conservation. More than 400 different entities have been or currently are engaged in collaborative conservation that advances the vision across this ecological network. These include conservation groups, local landowners, Indigenous entities, businesses, government agencies, funders and donors, and scientists. The conservation progress across the Y2Y region is due to the collective work of these different groups. Conservation priorities range from protecting areas important for biodiversity and restoring and maintaining areas between protected areas for ecological connectivity, to directing development away from areas of biological importance and promoting people and wildlife to live in harmony across the region. Protected areas include designations such as national, state and provincial parks, and wilderness areas. In the Y2Y region, increased connectivity may be achieved through large and well-placed protected areas, privately conserved lands, or other lands designated for long-term management that allows for connectivity.

Examples of ecological corridors

Within the Y2Y landscape, a variety of groups has been working in the British Columbia, Montana and Idaho trans-border region to identify and reconnect small, isolated grizzly bear populations along the Canada–US border in southeast British Columbia. Using genetics, scientists identified that once-continuous grizzly bear populations had begun to fragment; the scientists then identified the best remnant corridors (Figure 2). Many different groups worked to implement connectivity-friendly management (such as securing private lands and providing tools for coexistence). Ultimately, a decade later, it was possible to demonstrate movements of grizzly bears between previously fragmented ecosystems, accompanied by reproduction (Proctor et al., 2018).

Results

Progress toward protecting a regional ecological network is being made. Protected areas increased more than 50% across the Y2Y region, and a number of ecological corridors and other areas conserving connectivity have been identified, restored and/or maintained between protected areas. Likewise, conservation projects have multiplied across the region to significantly decrease human–wildlife conflicts. Some animals, such as grizzly bears and wolves (*Canis lupus*) in the lower 48 US states, have increased in number and range, but significant conservation remains to be done, as other animals such as mountain caribou have continued to decline in numbers across the region.

Figure 2. The Y2Y transboundary region including key grizzly bear distribution and linkages. The three arrows point to three different linkages – Duck Lake, Kidd Creek and Yaak River – where private land acquisitions have secured ecological corridors for grizzly bears. © Y2Y

15. Conserving long-distance migration: The Red Desert to Hoback Mule Deer Corridor, Wyoming, USA

Matthew J. Kauffman, *Wyoming Cooperative Fish and Wildlife Research Unit*
Holly Copeland, *Wyoming Cooperative Fish and Wildlife Research Unit; Hall Sawyer, Western EcoSystems Technology, Inc.*

Key lesson

This work demonstrates how scientific studies documented migratory corridors for wildlife, resulting in the purchase of private lands that otherwise would have been developed.

Context and challenge

Effective protection of landscapes for migratory species is recognised as a global conservation challenge in the face of ever-increasing anthropogenic land-use changes. Ungulates that migrate long distances must move across a variety

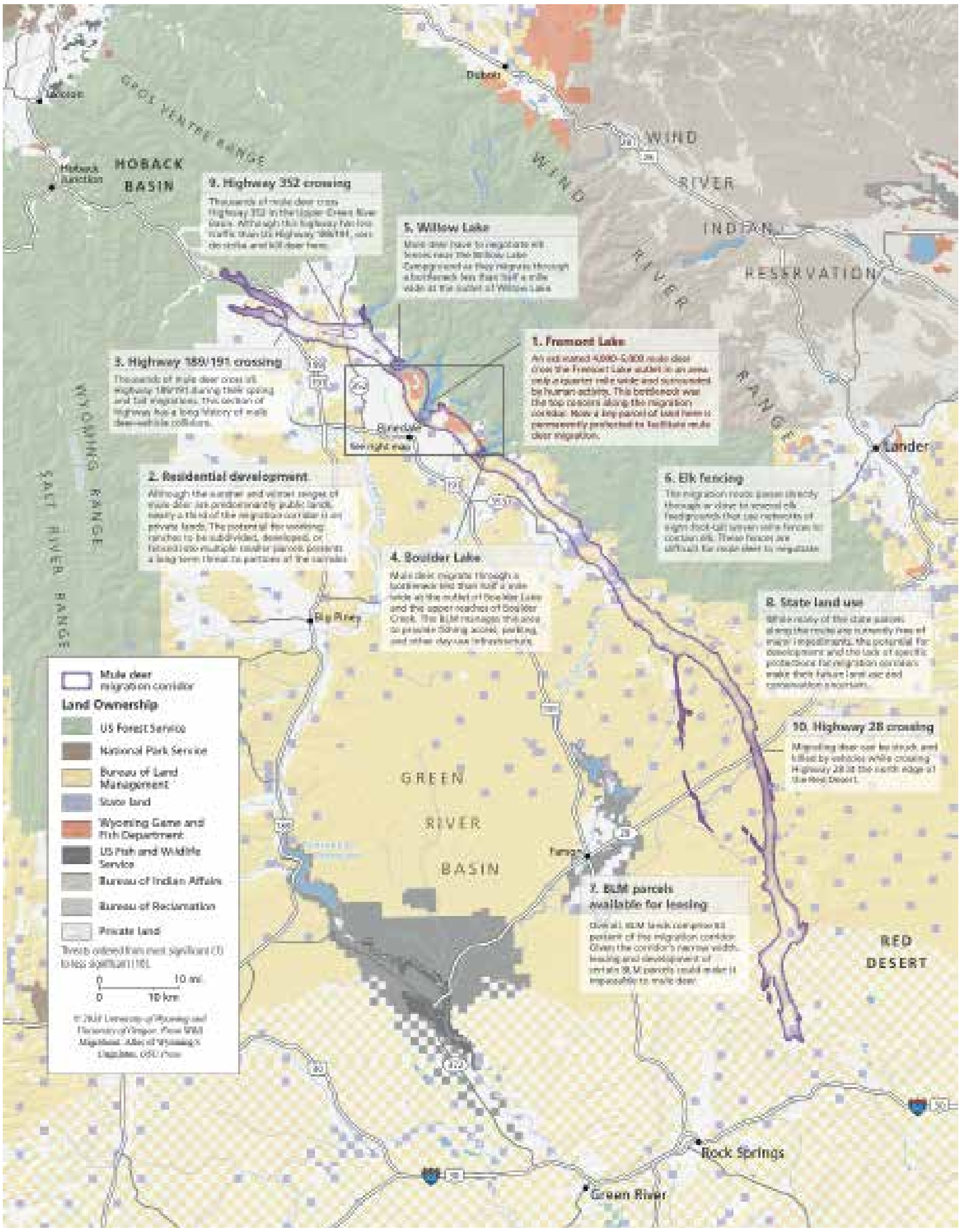


Figure 1. The Red Desert to Hoback mule deer migration corridor spans 240 km in southwest Wyoming, USA, crossing a multiple-use landscape. The top ten potential obstacles to the continuity of the corridor are noted. Map from *Wild Migrations: Atlas of Wyoming's Ungulates,* Oregon State University Press. © 2018 University of Wyoming and University of Oregon. Image courtesy of Wyoming Migration Initiative (migrationinitiative.org).

of jurisdictional boundaries, altered or degraded habitats, and human obstacles such as roads, fences, housing and energy development. Globally, long-distance terrestrial migrants continue to decline as a result of these challenges, and ungulates in the American West are no exception. Mule deer (*Odocoileus hemionus*) are an iconic migratory species of the western US, and Wyoming has some of the longest, most intact mule deer migrations in the lower 48 states. In western Wyoming, the Upper Green River Basin is a region known to contain some of the largest mule deer populations in North America. Dozens of long-distance migration routes traveled by mule deer, elk (*Cervus canadensis*) and pronghorn (*Antilocapra americana*) have now been mapped across Wyoming's mountains and plains. As anthropogenic influences increase and migratory ungulates continue to decline worldwide, a focus on landscape connectivity is needed to broaden conservation efforts beyond winter and summer ranges to include migration routes as critical habitat.

Approach

Detailed mapping of migration routes has emerged as a first step towards identifying threats and implementing long-term conservation, aided by new data on ungulate movements from global positioning system (GPS) telemetry studies. The new maps allow assessments of land-use patterns and threats along the routes, which can directly inform conservation action.

Example of an ecological corridor

In 2014, scientists discovered a 240-km-long mule deer migration route, stretching from the desert basins in southwest Wyoming to surrounding mountain ranges. It is known as the Red Desert to Hoback corridor (Figure 1). An estimated 1,000 mule deer travel a one-way distance of 240 km from the Red Desert to the Hoback Basin and surrounding mountain ranges, where they merge with 4,000 to 5,000 other deer that winter in the foothills of the Wind River Range. They all then travel a narrow corridor along the base of the mountains for 96 km before crossing the upper Green River Basin.

Researchers mapped the ecological corridor in detail and then published an assessment analysing land-use patterns and threats for each section (Sawyer et al., 2014). This assessment identified the top ten threats along the length of the corridor and provided conservation organisations with information needed to direct scarce funds to sites where they are most needed, such as specific bottlenecks, road crossings or unprotected segments of private land. At the top of the threats list was the Fremont Lake 'bottleneck', a 400-m-wide constriction created by the lake and the expanding town of Pinedale, where 4,000 to 5,000 deer squeezed through twice a year. The deer were required to either swim (or, when frozen, walk across) the lake, or ford its outlet, which put them on the wrong side of a 2.5-m-high woven wire fence.

Results

The Fremont Lake bottleneck consisted largely of a 145-ha parcel of private lands that was slated for subdivision and conversion to lakeside cottages which, if developed, would have blocked deer migration. Guided by information within the assessment, The Conservation Fund, a national non-profit conservation organisation, identified and purchased the parcel. The land was given to the Wyoming Game and Fish Department, which subsequently protected it through designation as the Luke Lynch Wildlife Habitat Management Area, thereby maintaining in perpetuity the connectivity of the ecological corridor at this key pinch point (Figure 2).

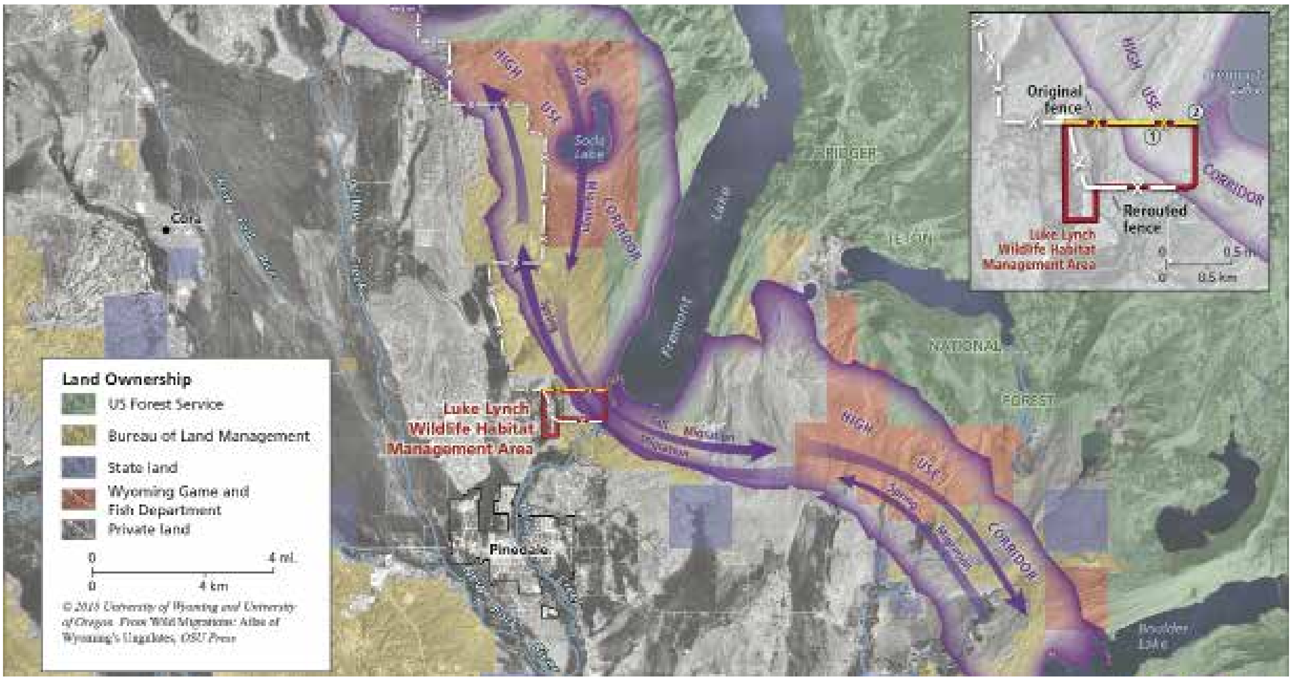


Figure 2. Location of the Fremont Lake bottleneck, now conserved as the Luke Lynch Wildlife Habitat Management Area. Map from *Wild Migrations: Atlas of Wyoming's Ungulates,* Oregon State University Press. © 2018 University of Wyoming and University of Oregon. Image courtesy of Wyoming Migration Initiative (migrationinitiative.org)

16. Corridors for life: Improving livelihoods and connecting forests in Brazil

Laury Cullen, *Instituto de Pesquisas Ecológicas, Brazil*

Context and challenge

In Brazil, the largest Atlantic Forest remnants in the interior lie in the Pontal do Paranapanema area of western São Paulo state. Originally a 124,000-ha public forest reserve was designated, but it was progressively encroached upon during 1960–1990 by large-scale ranching and sugarcane establishments. In the mid-1990s, with pressure for land redistribution from the Landless Rural Workers' Movement (MST) and other groups, many such forests were first occupied by families of MST affiliates and later expropriated for public land reform settlements, dramatically increasing the density of human occupation. After the settlement of many landless households, the pace of land redistribution slowed, and national policies now seek to consolidate existing settlements. Promoting income generation for settlers is urgently needed, as is protecting the remaining fragmented forests within this productive landscape before further pressures ensue. Although agrarian reform settlements and large landowners pose a series of barriers to biodiversity conservation, they also offer important and replicable opportunities for large-scale landscape forest restoration.

Key lesson

When working with agricultural communities, focusing on multiple benefits of restoring ecological corridors, such as improving livelihoods and obtaining carbon sequestration funding, is vital.

Approach

The Corridors for Life project focuses on (1) encouraging the adoption of 'biodiversity-friendly' land-use options; (2) promoting changes in land-use practices of small- and large-scale farmers in rural fragmented landscapes, and enhancing the adoption of sustainable agriculture and agroforestry on their lands; (3) improving the farmers' livelihoods; and (4) providing investors a return in the form of high-quality carbon offsets. Strategically selected areas for agroforestry and restoration will increase habitat viability by means of ecological corridors to increase connectivity between 'core' forest fragments, ensuring genetic exchange. Where corridors are not feasible, this exchange will be achieved through

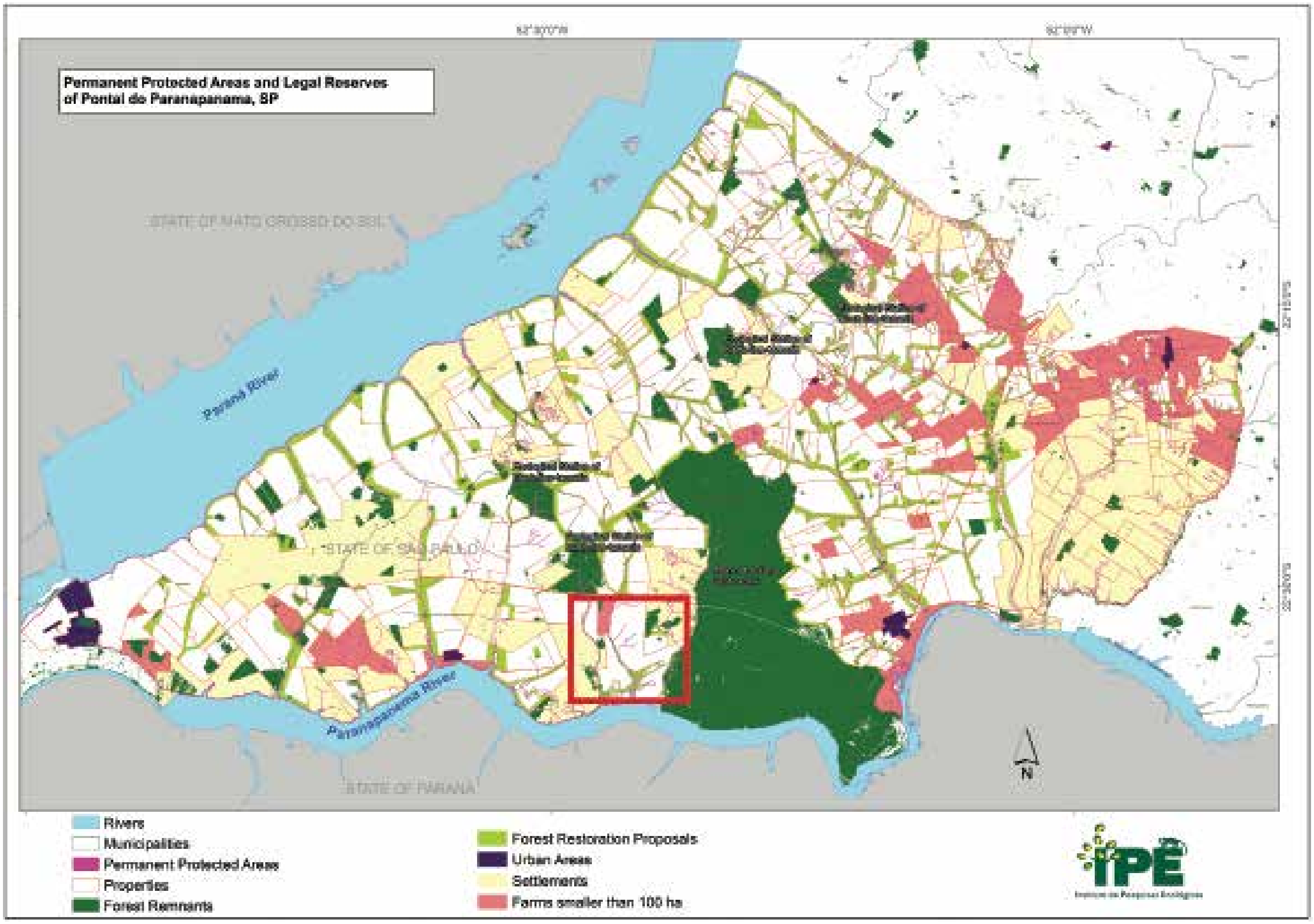


Figure 1. IPÊ's 'dream map' for Pontal de Paranapanema uses ecological and property data in order to create the best approach for reforestation efforts. The red polygon contains the largest ecological corridor (1,200 ha) restored in the Atlantic Forest, linking Morro do Diabo State Park and Black Lion Tamarin Ecological Station. © Instituto de Pesquisas Ecológicas

developing stepping stones. Agroforestry and restoration will also minimise degradation around biologically important landmarks, including Morro do Diabo State Park, as the main reservoir of populations of key and endangered species. Enlarging and eventually connecting forest fragments are two main goals of reforestation projects. From an ecological perspective, this is essential to maintaining viable populations of flora and fauna and mitigating harmful edge effects, such as exposure to light and wind, diseases and invasive species. The Instituto de Pesquisas Ecológicas (IPÊ) developed a 'dream map' for Pontal de Paranapanema, the extreme western municipality of São Paulo, where the institute was founded. This plan for wide-scale reforestation of the Atlantic Forest takes into consideration information on local properties as well as proximity to public protected areas and existing forest fragments to calculate where reforestation efforts would be most effective (Figure 1, previous page). Among the main project partners are state and federal rural extension agencies, private companies interested in the carbon neutralisation market, companies that produce and commercialise ethanol and sugar, and other national and international electric power holding companies.

Example of an ecological corridor

A conceptual map was used to guide the creation of Brazil's largest reforestation corridor (Figure 2), which, after ten years of effort, links two main remnants of Atlantic Forest in the Pontal de Paranapanema region. This ecological corridor is approximately 7 km long with average width of 400 m. It was restored entirely on privately owned lands. It is protected by the Law for Protection of Native Vegetation, passed in 2012, with which the Brazilian National Congress revised the 'old forest code', as the previous version of the law was known. The 2012 law reaffirms the obligation of private landowners to conserve or restore permanent preservation areas and legal reserves on their properties.

Results

To date, approximately 1,800 ha of forest have been restored in Pontal do Paranapanema. This includes the 1,200 ha of the main ecological corridor, another 600 ha in five smaller corridors and 90 agroforestry stepping stones on rural properties. This project consolidates strategies that represent sustainable livelihood alternatives for communities of the land reform movement in Brazil, replicating good practices and policies in income generation and biodiversity conservation. At the policy level, IPÊ, together with other civil organisations in the region, are influencing policies that affect land use and conservation. By using scientific evidence, cooperating with new settlers and large landowners, and collaborating with state and federal agencies, the program is implementing a land-use framework that promotes sustainable agriculture and biodiversity conservation over the long term.

Figure 2. Some 2.4 million trees make up IPÊ's 1,200-ha ecological corridor connecting two main Atlantic Forest fragments, the largest in Brazil. © Instituto de Pesquisas Ecológicas

17. Connectivity, ecosystem services and Nature-based Solutions in land-use planning in Costa Rica

Félix Zumbado Morales and Jonathan Agüero Valverde, *Research Program in Sustainable Urban Development, University of Costa Rica*

Context and challenge

Costa Rica is a small nation of 51,000 km^2 that contains about 5% of global biodiversity. The sustainable management of biodiversity is one of the pillars of the work carried out by the country. Protected areas are the country's primary conservation strategy, playing a crucial role in the protection of ecosystems. Costa Rica's second most important conservation strategy is the ecological corridor program, managed by the Costa Rican government, but working hand in hand with communities through local ecological corridor committees. Municipal land management plans have emerged as a third tool complementing protected areas and ecological corridors. These management plans generate the guidelines necessary to allow human development activities to be carried out while maintaining sustainable landscapes, taking into consideration the comprehensive use of the regions. Protected areas and ecological corridors are incorporated into the land management plans; the same is true for the principles of ecosystem services and Nature-based Solutions as decision-making tools.

Key lesson

Costa Rica has a three-pronged approach to land conservation: protected areas, ecological corridors and sustainable management of the matrix; different levels of human use are allowed depending on the protection level.

Approach

Land management plans are a tool that local governments can use to generate regulations that complement protected areas and ecological corridors. These three land management tools are complementary and must be developed in an integrated fashion to achieve a systematic approach to planning. Management plans implement ecological corridors through tools such as the establishment of specific areas for focal species; the preservation of agricultural areas that function as biological, conservation and sustainable tourism corridors; the creation of buffer zones around protected

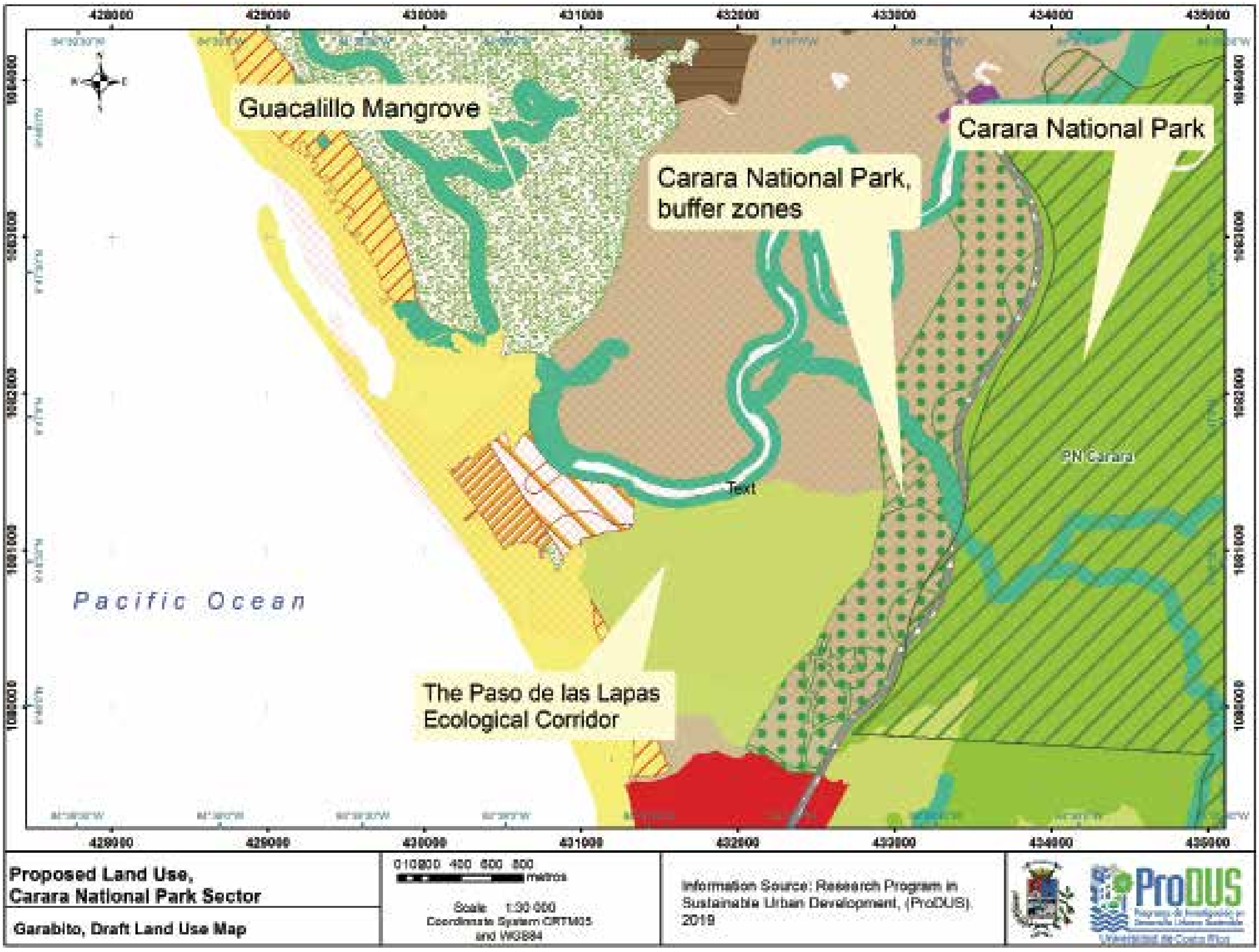


Figure 1. Proposed land uses in the region of Canton of Garabito containing the Paso de las Lapas Ecological Corridor © Research Program in Sustainable Urban Development (ProDUS) Universidad de Costa Rica

Carara National Park, Costa Rica © Adobe Stock

areas; and the zoning of aquifer recharge zones for the protection of water sources for local and regional populations. Through the University of Costa Rica's Sustainable Urban Development Research Program (UCR-ProDUS is the Spanish acronym), land management plans for more than a dozen municipalities have been developed, including the protected areas Corcovado National Park, Piedras Blancas National Park, Ballena Marine National Park, Juan Castro Blanco Water National Park and Carara National Park.

Example of an ecological corridor

UCR-ProDUS developed a land management plan for the Canton of Garabito, which contains the Paso de las Lapas Ecological Corridor (Figure 1). This ecological corridor encompasses 56,200 ha and connects protected areas in the mountains (La Cangraja National Park, Cerros de Turrubares protected area and Carara National Park) with coastal areas. The Paso de las Lapas Ecological Corridor was established in 2007 through an executive order. In Costa Rica, ecological corridors are not state conservation areas, but are a different conservation strategy promoted by the National System of Conservation Areas through the national program of ecological corridors. The ecological corridors connect protected areas, preserve water resources and protect biodiversity. The land plan establishes regulations that ensure the sustainable management of the region. Planning took into account the location of protected areas; the benefit of ecosystem services such as carbon capture, aquifer recharge zones protection and flood regulation; and the value of Nature-based Solutions such as national park buffer zones, river basin management and agricultural land protection. The land management plan strengthens the functionality of the ecological corridors and gives greater control over their management through the input of local governments. Buffer zones and proposed wildlife crossings are important elements of corridor management and implementation. In the land management plan for the Canton of Garabito, measures to protect the Paso de las Lapas Ecological Corridor include zoning of protected areas, low-intensity agriculture and ecotourism areas.

Results

Land management can be an ally of conservation and sustainable development. It can promote ecological connectivity by strengthening ecological corridors that link protected areas. Currently, the Paso de las Lapas land management plan is in the final phase of the approval process. The regulations of the land management plan can help to:

- Reduce conflicts between owners and the municipality;
- Protect ecological connectivity;
- Promote ecotourism and other low-intensity activities;
- Support the ecological corridor's conservation objectives;
- Restrict intensive uses such as residential and industrial development, and other incompatible land uses; and
- Protect fragile ecosystems such as wetlands and mountains.

18. The Jaguar Corridor Initiative: A range-wide species conservation strategy

Kathy Zeller, *Massachusetts Cooperative Fish & Wildlife Research Unit*

Context and challenge

Species conservation efforts are often conducted on discrete populations and are usually envisioned at small scales. Thinking about conservation throughout the entire range of a species allows us to broaden our perspective and identify species' needs across political and jurisdictional boundaries. This perspective also allows for the identification of large-scale patterns of threats and anthropogenic development.

Key lesson

Some large-scale visions for multi-country ecological networks focus on wide-ranging umbrella species such as the jaguar. Ecological corridors in these networks can encompass multiple land uses and different land ownership, from federal entities to individual landowners.

In 1999, the Wildlife Conservation Society and the Universidad Nacional Autonóma de México brought together jaguar (*Panthera onca*) experts to develop a range-wide research and conservation plan for the species. This effort identified 51 jaguar population centres from Mexico to Argentina (Sanderson et al., 2002). Shortly after this plan was developed, a genetic study provided evidence of widespread gene flow across jaguar range (Eizirik et al., 2001), indicating that these populations were still connected and that there was little evidence of geographic barriers to gene flow. These results inspired the Jaguar Corridor Initiative, an approach conceived by the late Dr. Alan Rabinowitz, to maintain connectivity and gene flow across jaguar range.

Approach

To model connectivity, we first updated the 1999 range-wide population data with new information and identified 90 important jaguar populations throughout the species' range,

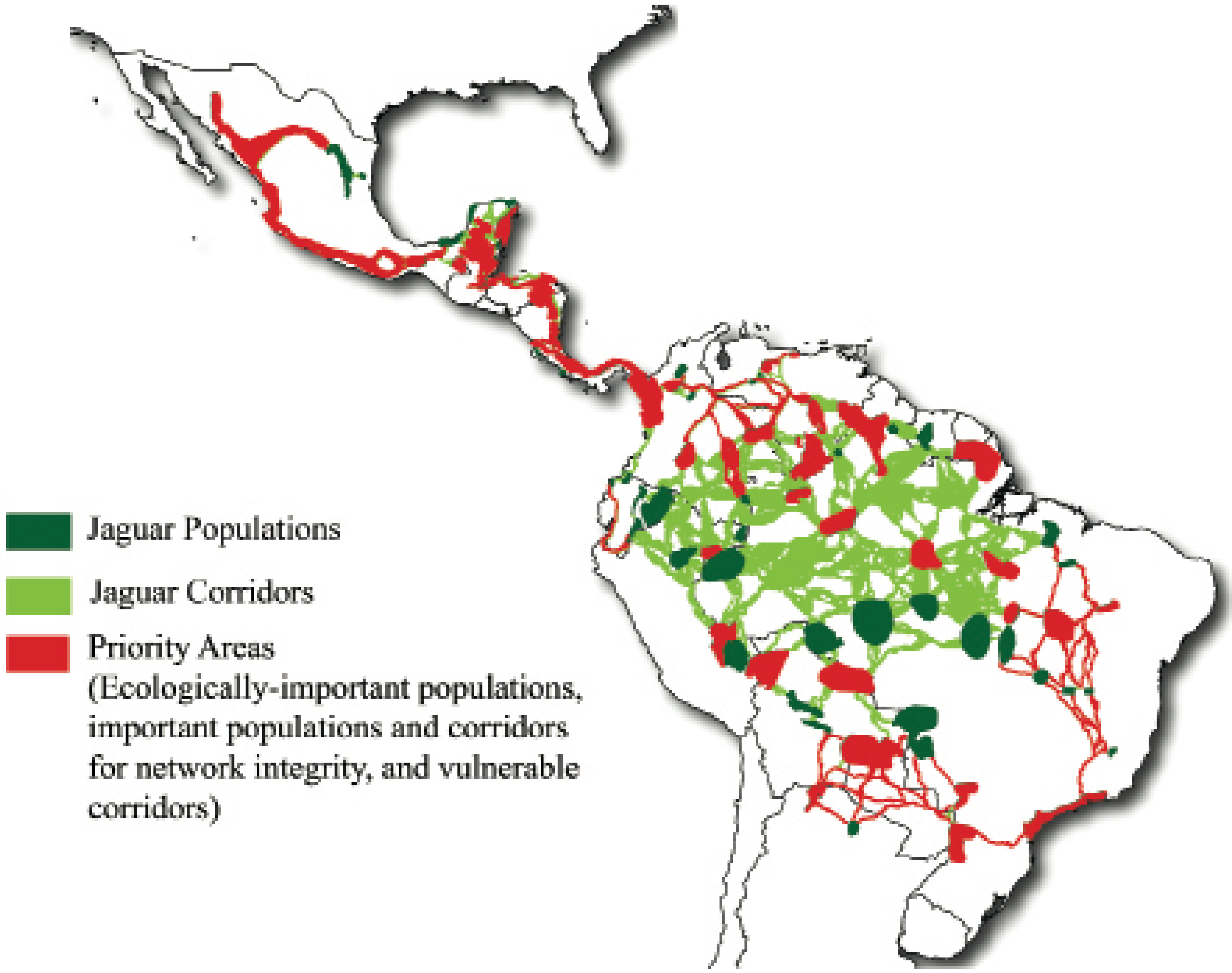
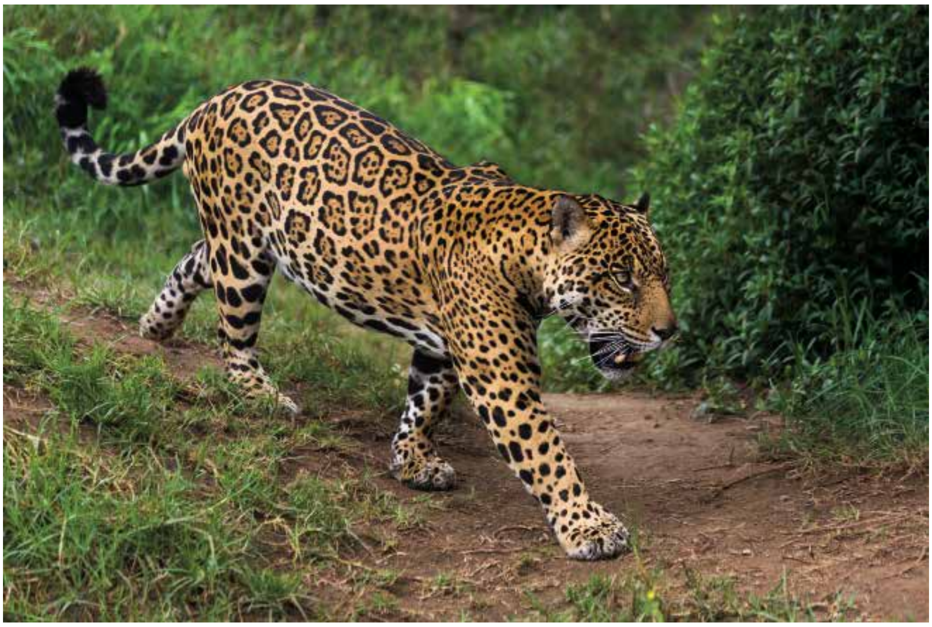


Figure 1. Jaguar populations and corridors across its range. Populations and ecological corridors were prioritised according to ecological importance, network integrity and vulnerability. They were combined to identify all priority areas across jaguar range. © Kathy Zeller



Jaguar (*Panthera onca*) © Adobe Stock

which measured 1.9 million km². We then invited 15 jaguar experts to assign cost or resistance values to six GIS layers known to affect jaguar movement. We combined these scored layers into a single resistance surface and modelled least-cost corridors between the 90 populations (Rabinowitz & Zeller, 2010). The resulting 182 corridors measured 2.6 million km² for a total conservation network of 4.5 million km² (Figure 1, previous page). When compared with the World Database on Protected Areas, 67% of the jaguar populations and 46% of the ecological corridors were under some form of protection.

In order to focus research and conservation efforts across this vast network, we prioritised jaguar populations and ecological corridors using three criteria: ecological importance, network importance and corridor vulnerability (Figure 1) (Zeller et al., 2013). We directed our field-based conservation efforts towards these prioritised areas.

Because the ecological corridors were identified with coarse-scaled GIS data and expert-derived resistance values, we wanted to validate the corridors before conducting site-based conservation activities. This was a challenge, however, because the corridors were often large and comprised numerous landowners. So we developed a rapid assessment, interview-based methodology that allowed us to estimate occupancy for jaguars and their main prey species in the corridors (Zeller et al., 2011; Petracca et al., 2017). All the corridors in Central America have now been validated and adjusted, and validation is currently being conducted in South America. Conservation work across the Jaguar Corridor Initiative is mostly led by the non-profit organisation Panthera (www.panthera.org).

Example of an ecological corridor

The Barbilla-Destierro Jaguar Corridor is located in Costa Rica and links the Talamanca Mountains in the south with the Central Volcanic Range in the north. The corridor, which contains myriad land uses, comprises private, municipal and federal lands. Conservation strategies from the federal to the individual landowner level have been implemented. Examples include:

- Incorporating the corridor into Costa Rica's National Program of Biological Corridors;
- Developing a local corridor council, which brings together landowners once a month to discuss and address threats and opportunities;
- Working with a hydroelectric company to direct its environmental mitigation and restoration projects toward areas that will enhance connectivity across the corridor;
- Training and establishing a Wild Cat Conflict Response Unit to investigate depredations on livestock and implement anti-predator strategies; and
- Providing science-based recommendations to development projects for maintaining connectivity across the corridor.

Results

The Jaguar Corridor Initiative has provided a conservation blueprint across the species' entire geographic range. Panthera is currently leading conservation efforts similar to those described for the Barbilla-Destierro Jaguar Corridor in 11 of the 18 countries where jaguars reside. Jaguar research is ongoing across the ecological network and corridor monitoring plans are being established. Support for the initiative has been steadily growing across jaguar range with the backing of numerous governments, landowners, corporations and scientists. With growing support, the vision of a connected and protected ecological network for jaguars from Mexico to Argentina hopefully will become reality.

Freshwater connectivity: Asia

19. Grassroots reserves have strong benefit for river ecosystems in the Salween River Basin

Aaron A. Koning, *Cornell University*

Context and challenge

In many low-income countries, people depend highly on inland fisheries for daily nutrition, creating strong incentives to access the resource regardless of regulations. Even in protected areas that contain human populations, hunting bans rarely extend in practice to fish. While national fishery regulations and guidelines exist in Thailand, in remote areas such as the Mae Ngao River, enforcement is difficult and rare. Due to their linear nature and the dependence of many sectors upon rivers and their waters, it is a challenge to create ecological corridors covering entire river basins or even individual rivers.

Approach

Throughout Southeast Asia, in response to perceived declines in fish populations, concerns for continued resource security, and encroachment from outsiders using illegal fishing gear (e.g. electric shocking), small no-take reserves on rivers have been created by local communities, established by non-governmental organisations or imposed by national governments. These small reserves are effectively the only management action for these intensive-harvest fisheries. In tributaries of the Salween River in north-western Thailand, ecological networks of small riverine reserves continue to grow, particularly among fishery-dependent communities where overharvest is common.

Example of an ecological corridor

One such ecological network is located in the Mae Ngao River Basin of north-western Thailand, which encompasses 1,000 km^2 and over 8,000 people among more than 70 villages (Figure 1). Over 25 years ago, the first community-created reserve was established following a meeting with a local NGO, which suggested creating small areas closed to fishing as a conservation measure. Initially, only one community took this action, but the practice has slowly spread since to include more than 50 others, which largely act independently and are unsupported by government or other outside entities. Communities individually determine reserve locations, sizes and penalties for non-compliance, which range from the equivalent of 15 USD to over 300 USD. Inside reserves, all harvest activities are prohibited, including harvest of snails and other aquatic invertebrates, which otherwise are commonly eaten, particularly during the extended dry season (November–May). Outside of reserves, harvest effort is high, using a variety of methods (e.g. gill nets, lines, traps, hand spears). Fishing effort often extends from the borders of the reserve for hundreds of meters both upstream and downstream, creating a gauntlet of nets and hooks for fish moving outside of protected areas. Several neighbouring communities have added additional regulations outside reserves, notably banning the use of diving masks in collecting snails and spearfishing. Spearfishing, particularly in the dry season when water temperatures are warm, the water is clear, and local schools are on break, is thought to have a large impact on populations of fish of all sizes.

Key lesson

Recognition and enforcement of river reserves by the local communities, which benefit local fisheries and enhance the health of the river system, is a significant first step to increasing in-stream connectivity in the Mae Ngao River in Thailand.

Results

There is no broader strategic planning among communities regarding the creation of reserves. In fact, there is a general lack of recognition even among community members of the number of reserves in existence throughout the Mae Ngao River Basin. Nevertheless, there are now 52 reserves that, basin-wide, cover 2% of all perennially flowing water, and form a network of protected areas within the larger river network. This network has been entirely created and enforced by individual communities.

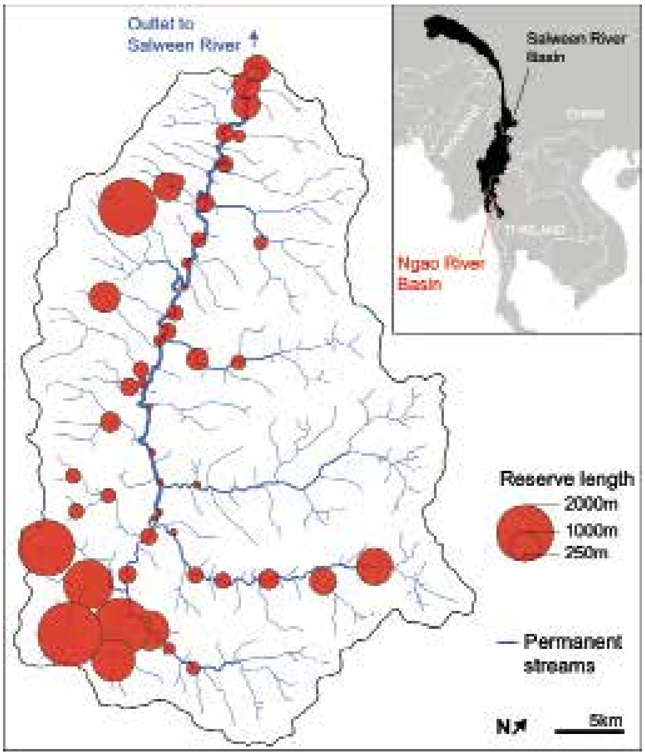


Figure 1. Ecological network of no-take reserves on the rivers in the Mae Ngao River Basin in north-western Thailand © Aaron A. Koning

Figure 2. In no-take reserves, large schools of fish can be seen from the riverbank. © Aaron A. Koning

However, intense fishing effort forms a large barrier to connectivity between and among reserves. Viewed at more local scales, though, individual reserves are typically long enough to connect habitats within the river network, including pools that are critical refugia for many species during dry season. In the rainy season, when river levels increase by up to 5 m from dry-season lows, fishing effort goes down and systemwide connectivity goes up, giving fish the opportunity to move for breeding.

Because of the disparity in harvest effort between reserves and other areas, the effects of the conservation action can be seen even from the river bank, where large schools of fish become points of interest for tourists and travellers in the area (Figure 2).

A comparison of 23 of these small reserves with adjacent fished areas showed gains in fish species richness, density and biomass commensurate with reported gains from marine reserves (Koning, 2018; 2019). Specifically, richness increased in reserves relative to fished areas by 27% and density by 124%, and biomass was 23 times higher on average. Although benefits were often observed only three to five years after a reserve was established, gains were sustained through time.

Community members regularly harvest large fish outside of reserves and credit fish movement out of reserves for such catches. It remains unclear whether reserves are sufficiently large to maintain populations over the long term and whether there is regular movement among reserves that would transfer critical genetic diversity among potentially isolated sub-populations. Given the seasonal fluctuations in the river, though, it seems likely that fish movement occurs during the rainy season.

The extent to which these small reserves are able to benefit local fish populations is all the more remarkable given that communities have largely acted independently without a broader coordination of effort. Next steps for this reserve network would be to work with communities, informed by the surveys conducted previously and the body of reserve design theory that has been developed for marine systems, to attempt to optimise reserves individually and collectively for maximum conservation and fishery benefits.

Freshwater connectivity: Europe

20. The ecological corridor Mura-Drava-Danube and future five-country biosphere reserve

Arno Mohl, *WWF Austria*
Ivana Korn Varga, *WWF Adria*
Emöke Györfi, *WWF Austria*

Key lesson
Conserving river connectivity can be achieved through a series of protected areas and a vision that prohibits dams and other developments that would impair the long-term connectivity of river systems, but promotes benefits that are compatible with connectivity.

Context and challenge

For a long time, large parts of the river landscapes along the former Iron Curtain between the Baltic Sea and the Black Sea in Europe remained largely unaffected by serious encroachments. With the end of Communism in Europe in the late 1980s and the subsequent enlargement of the EU eastward, these forgotten river paradises were catapulted into another age. Suddenly, they were in areas of human economic interest. On the one hand, this pressure has threatened to irreversibly destroy the last intact areas. On the other hand, new opportunities for cooperation in nature conservation and sustainable development have emerged. Transboundary Biosphere Reserves (TBRs) are an appropriate tool to tackle this major need for large-scale cross-border river protection, management and restoration. Current examples can be found on the lower reaches of Drava and Mura rivers and in the adjacent floodplains of the middle Danube River between Austria, Slovenia, Croatia, Hungary and Serbia (Mohl et al., 2009).

Approach

As borders between states are political rather than ecological, ecosystems often stretch across national boundaries, and may be subject to different, or even conflicting, management and land-use practices. TBRs provide a tool for common management. A TBR is an official recognition at the international level and by a UN institution, UNESCO, with the political will to cooperate in conservation and sustainable use through common management of a shared ecosystem (UNESCO, 2017). The initiative for the five-country Biosphere Reserve Mura-Drava-Danube between Austria, Croatia, Serbia, Slovenia and Hungary goes back to 1993. It has been developed as a counterproposal to emerging threats of new hydropower dam projects after the fall of the Iron Curtain and as a tool to connect and better protect all national river areas of the corridor under one international management framework (Schneider-Jacoby & Mohl, 2012).

Campaigning against large-scale water management and hydropower dam projects which were threatening the riverine area has been an important approach to achieve protection of this valuable ecosystem. The campaign has increased public and political awareness, created pressure on governments and triggered the establishment of 13 major protected areas, including the 88,000-ha regional park Drava-Mura in Croatia. Mostly part of the Natura 2000 network, these protected areas fall under several categories. Setting up an ecological network for conservation has laid the foundation for transboundary cooperation for harmonised conservation, integrated management and restoration within the future Biosphere Reserve Mura-Drava-Danube.

Since 1993, WWF, EuroNatur and local NGOs have been campaigning to protect the unique landscape of the three rivers in a five-country TBR (Figure 1). Increasingly, governments and NGOs cooperate to jointly achieve, stepwise, the TBR. They are establishing Europe's largest protected river corridor (700 km, 1,000,000 ha) through innovative cross-sector cooperation and harmonised sustainable regional development that also supports cross-border reconciliation (WWF, 2013). Once fully established, the biosphere reserve will form an ecological network for conservation that consists of core zones embedded in buffer zones and transitional zones.

Example of an ecological corridor

Spanning Austria, Croatia, Hungary, Serbia, and Slovenia, the lower courses of the Drava and Mura Rivers and related sections of the Danube are among Europe's most ecologically important riverine areas – the so-called Amazon of Europe. Despite numerous human-made changes in the past, this region hosts amazing biological diversity and is a hotspot of rare natural habitats, such as large softwood forests, wet meadows, river islands, gravel and sand banks, steep banks, side branches and oxbows (Figure 2).

The area is home to the highest density of breeding pairs of white-tailed eagles (*Haliaeetus albicilla*) in Continental Europe, and other endangered species such as the black stork (*Ciconia nigra*), beaver (*Castor fiber*), otter (*Lutra lutra*) and the nearly extinct ship sturgeon (*Acipenser nudiventris*). Many of the species are indicators of a natural river corridor, including the little tern (*Sternula albifrons*). Every year, more than 250,000 migratory waterfowl use the rivers to rest and feed. The largest and best-preserved floodplains and forests can be found around the confluence of the Danube and Drava, shared between Croatia, Hungary and Serbia. Most parts of this transboundary area are assigned to the core zone of the TBR. In addition to high levels of biodiversity, the river and floodplain areas are vital to the local communities. Local fishers rely upon the fish populations for their livelihoods. The extensive floodplains lower the risks from floods, secure favourable groundwater conditions and provide self-purification of water, which is essential for drinking water, forests and agriculture. People also enjoy recreational activities along the rivers by walking, swimming, fishing and canoeing (WWF Austria, 2014).

Results

Driven by the vision of establishment of the five-country TBR, major progress has been made over the past 30 years toward better protection and management of the river corridor:

- Thirteen major protected areas along the Mura, Drava and Danube, which are forming the TBR's backbone, have been established by the governments of the five countries.
- So far 270 km of natural river stretches have been successfully defended from being destroyed by large-scale water management and hydropower dam projects.
- In 2009, Croatia and Hungary signed a joint declaration to establish the TBR, followed in 2011 by a five-country ministerial declaration. In 2012, the riverine areas in Croatia and Hungary were granted biosphere reserve status, soon followed by those in Serbia (2017), Slovenia

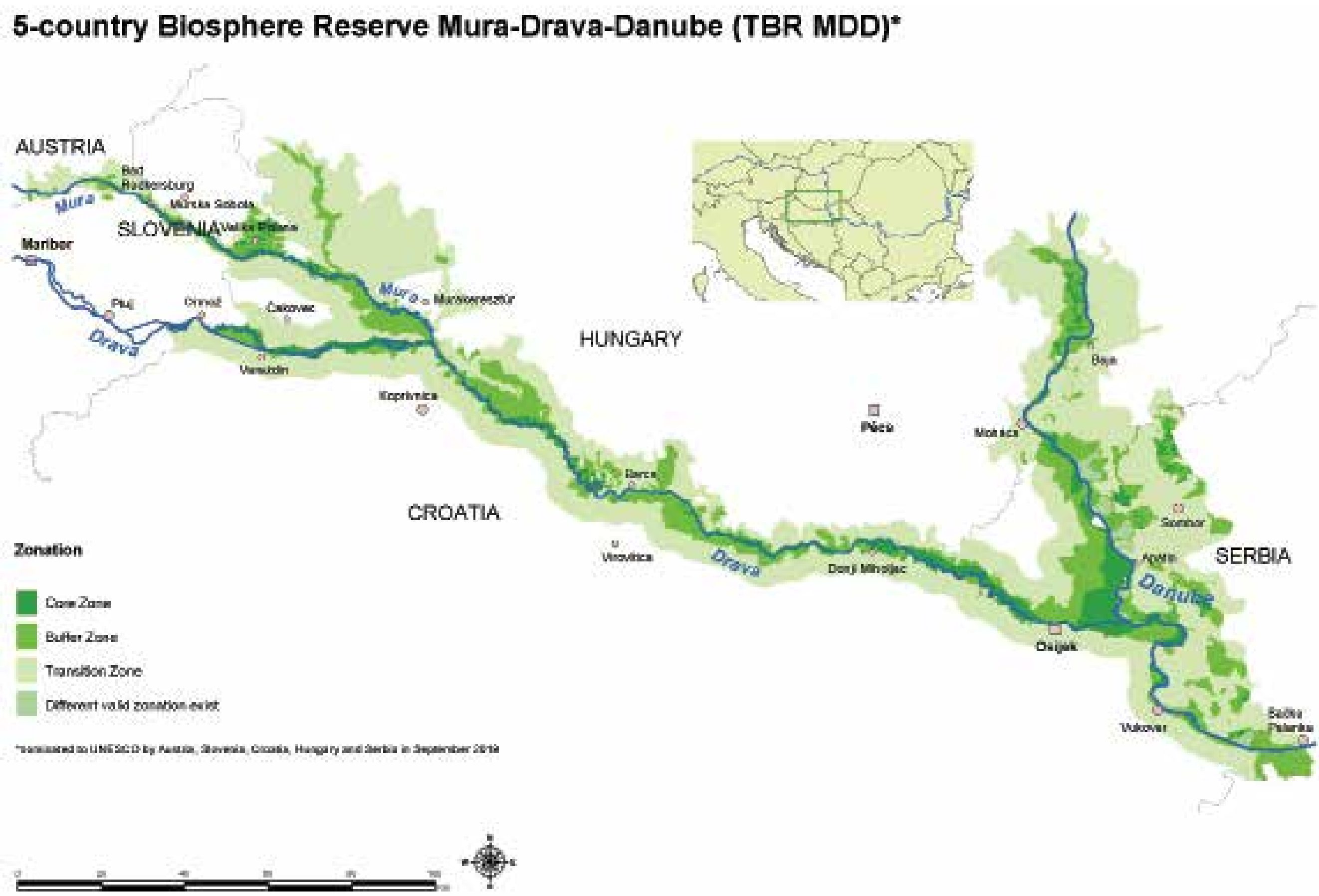


Figure 1. The future five-country UNESCO Biosphere Reserve Mura-Drava-Danube © World Wildlife Fund (WWF)

Figure 2. (left) Floodplains of the Danube in Croatia © Mario Romulic. (right) The Drava River in Croatia © Arno Mohl

Black stork (*Ciconia nigra*) © Adobe Stock

(2018) and Austria (2019). The strictly protected core and buffer zone, which consists of those 13 major protected areas, amounts to 280,000 ha. It is surrounded by 650,000 ha of transitional zone.

- Triggered by the TBR, several projects co-funded by the EU are already being implemented across the five countries in the area, aiming to achieve better protection and sustainable development. Within the 'coop MDD' project, the protected area administrations of the Mura-Drava-Danube region have been cooperating since 2017 to jointly focus on common goals and trans-border nature protection measures. The 'Resilient riparian forests as ecological corridors in the Mura-Drava-Danube Biosphere Reserve' project started in June 2019, aiming at preservation and sustainable management of floodplain forests in the TBR. At the same time, the 'Amazon of Europe Bike Trail' ecotourism project started. Furthermore, river restoration is being implemented to create new natural habitats and recreational areas for people to truly experience the stunning landscape along the rivers.

Also in 2019, the dossier was prepared for the five-country TBR nomination, which will harmonise all existing biosphere reserves in the region under one international designation. The next step is for UNESCO to finalise and approve the nomination. Once officially designated, the five-country TBR should take steps to achieve a fully functional biosphere reserve in line with UNESCO requirements. This includes establishing a joint management structure and implementing a joint action plan and projects.

Further information: http://www.amazon-of-europe.com/
http://www.interreg-danube.eu/approved-projects/coop-mdd
http://www.interreg-danube.eu/approved-projects/refocus
http://www.interreg-danube.eu/approved-projects/amazon-of-europe-bike-trail

Freshwater connectivity: North and South America

21. Pacific salmon watersheds: Restoring lost connections

Lauren Law and Jonathan Moore, *Simon Fraser University*

Key lesson

Even in an otherwise protected watershed, dams impair connectivity of the headwaters to the ocean; dam removal can restore biotic and abiotic processes, as demonstrated in the Elwa River in the USA.

Context and challenge

Coastal watersheds that drain into the northern Pacific Ocean support populations of culturally and economically important migratory salmon. Pacific salmon are born and initially develop in freshwater environments and then migrate to the open ocean, where they forage and grow before returning to natal freshwaters to spawn. Across North America and Asia, 8% of high-value catchments that drain into the northern Pacific Ocean are at least partially protected, predominantly in areas that are higher in elevation and distant from the ocean (Pinsky et al., 2009). However, even if portions of catchments are protected, dams have fragmented many salmon systems. Dams, such as for hydroelectric production, may block or hinder salmon migration, alter hydrological regimes and modify downstream river habitat. As a result of the imperilled or extirpated status of many salmon populations (Gustafson et al., 2007), there have been substantial investments in conservation and recovery.

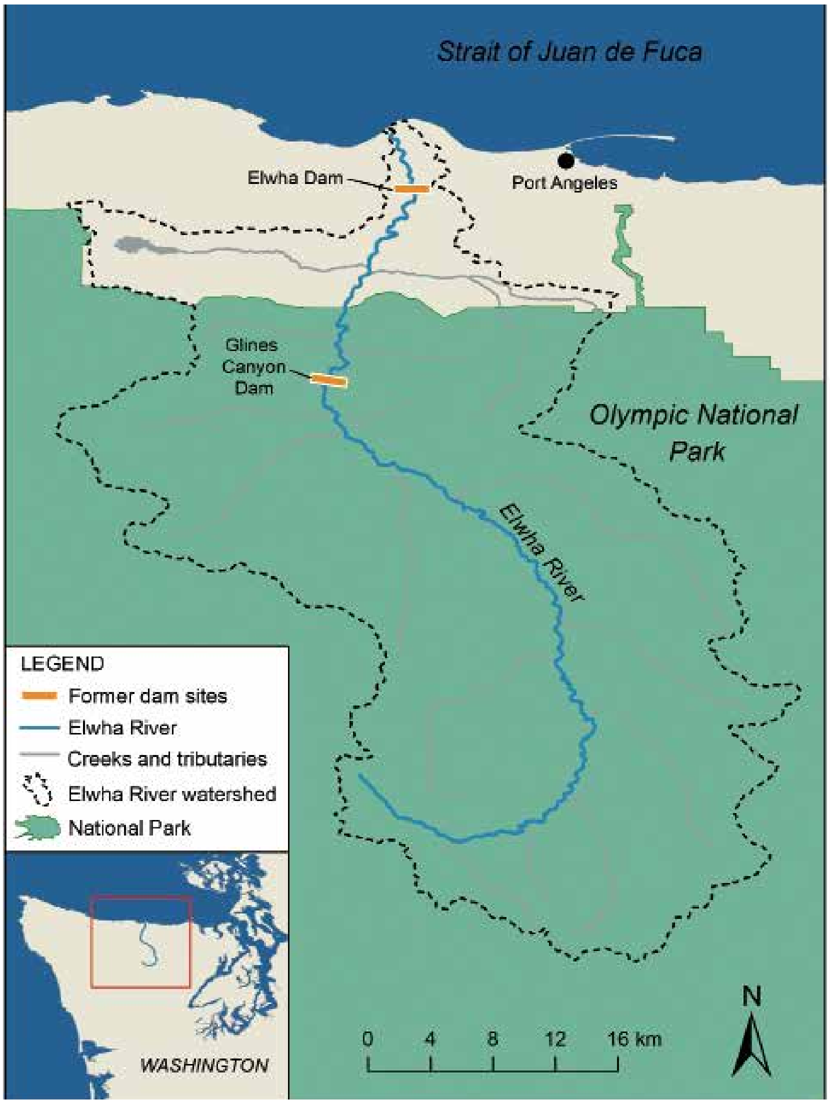


Figure 1. Elwha River watershed within Olympic National Park, Washington, USA. The removal of the Elwha Dam and Glines Canyon Dam restored connectivity between the upper and lower portions of the watershed. © Jonathan Moore

Chinook salmon (*Oncorhynchus tshawytscha*) © Adobe Stock

Approach

Over the last several decades, there has been increasing dam removal and mitigation to benefit salmon and other migratory fishes. Across the USA, more than 1,200 dams had been removed by 2017 (Bellmore et al., 2017). Dam removal generally occurs through a decentralised decision-making process involving numerous stakeholder groups, including federal agencies, state agencies, and private dam owners. Although some dam removals have been voluntary, many have been the result of legal proceedings that fall under the regulatory powers of the Federal Energy Regulatory Commission. Initial removal efforts were focused on older dam structures, which were too costly to maintain and no longer in compliance with modern safety standards. However, in recent years there has been a greater focus on dam removal for environmental protection and habitat restoration. In the USA, the Wild and Scenic River Act (1968) is a legal mandate to preserve rivers having exceptional natural, cultural and recreational values in a free-flowing state.

Example of an ecological corridor

In the USA, one of the largest dam removals that has restored connectivity in a protected salmon watershed was on the Elwha River. The vast majority of the 72-km-long river is within Olympic National Park in the state of Washington. Historically one of the most productive salmon rivers in the Pacific Northwest, the Elwha was disturbed in the early 1900s when two dams were constructed on it, disconnecting the protected upper portion of the watershed from the seascape that migratory salmon rely on. Migration of salmon was blocked, and the movement of sediment and woody debris was disrupted. The building of these large-scale dams led to a 90% reduction in fish populations, a loss of habitat connectivity and decline in habitat complexity (Pess et al., 2008).

In 1992, the Elwha River Ecosystem and Fisheries Restoration Act authorised the removal of the dams to restore the river ecosystem. The US National Park Service removed the dams in phases, starting with the removal of the smaller dam beginning in 2011 and eventually completing the removal of the larger dam in 2014.

Results

The removal of the Elwha River dams led to renewed riverine fluxes of sediments and large woody debris downstream that had been trapped in the dam reservoirs for nearly a century. Approximately 30 million tons of sediment were released, causing some 60 ha of river delta growth (Ritchie et al., 2018). The supply of sediment and large wood to the fluvial system restored channel morphology to its former complexity and resulted in increased river braiding, sediment-bar growth and pool filling.

Renewed connectivity of upstream protected habitat with the seascape in the Elwha River watershed is fostering the return of several salmon species (Chinook, *Oncorhynchus tshawytscha*; coho, *Oncorhynchus kisutch*; chum, *Oncorhynchus keta*; sockeye, *Oncorhynchus nerka*; and pink, *Oncorhynchus gorbuscha*) as well as anadromous trout (e.g. steelhead, *Oncorhynchus mykiss*; and bull, *Salvelinus confluentus*). Scientists have already observed record numbers of Chinook salmon returning to the Elwha, with high returns anticipated to follow for other species. About 30,000 Chinook and coho salmon and 270,000 pink salmon are expected to return annually. Salmon returns will eventually sustain local and regional fisheries.

The Elwha is one of many coastal catchments that has protected salmon habitat in its headwaters but whose connectivity to the seascape was severed. As illustrated by the Elwha project, dam removal and restoration of the free-flowing status of rivers can effectively connect protected headwaters with the seascapes on which migratory fishes such as salmon depend.

22. Fragmentation of riparian protections throughout catchments, Oregon, USA

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Brett Boisjolie, *Massachusetts Department of Conservation and Recreation*
Mary Santelmann, *College of Earth, Ocean and Atmospheric Sciences, Oregon State University*

Key lesson
Maintaining functional habitat can require policy protections and voluntary restoration efforts, both guided by science; monitoring and evaluation are critical to ensure that the actions will indeed result in the desired outcome.

Context and challenge

Lotic and lentic environments provide lateral connectivity to floodplain and riparian ecosystems. They can be passages for movement of aquatic organisms to and from headwater areas and marine environments, and are important components of global biogeochemical cycles (Butman & Raymond, 2011). Riparian environments also provide critical buffers between human land uses adjacent to the water's edge by filtering nutrients, retaining sediment and contributing biotic material that constitutes significant food inputs into freshwater food webs.

In many places, protection for freshwater taxa and their habitats is linked to the ribbon of riparian areas that flank rivers and lakes. Riparian protections, in turn, are often linked to land ownership, which changes along the length of a river, from its headwaters to the sea. However, this approach to conservation results in fragmented protections along the continuum of the river.

In coastal Oregon, USA, high-gradient headwater streams tend to be located within dense Douglas fir forest where the primary land use is timber harvesting. Downstream of these areas are low-gradient lowland areas that have been converted to agriculture, residential and urban development (Figure 1). Historically, these streams supported thriving

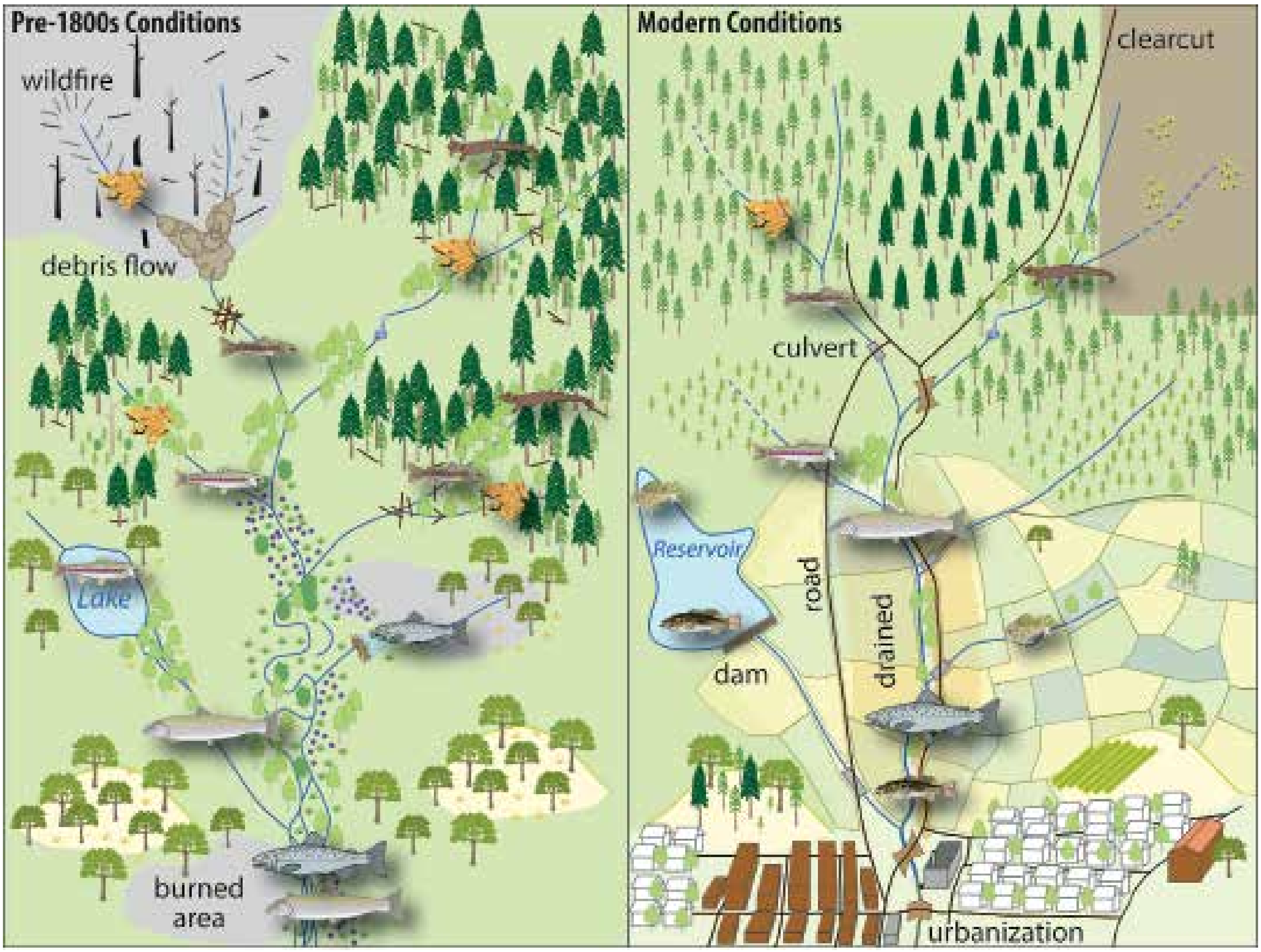

Figure 1. Historically, river systems of the Pacific Northwest connected a diverse array of freshwater and wetland habitats. Over time, development has reduced stream complexity and fragmented landscapes coincident with anthropogenic land uses such as agriculture, timber harvesting or residential development. Figure from Penaluna et al., 2017.

populations of anadromous salmonids that found spawning and rearing habitats throughout the connected corridors of the river network. The extensive floodplain of the Coquille River was a highly productive area for coho salmon (*Oncorhynchus kisutch*). However, this and other flat floodplains were colonised quickly by European settlers and continue to be used for agriculture.

In recent decades, migratory anadromous salmonids, including coho salmon, have been listed as 'threatened' or 'endangered' under the US Endangered Species Act, making them critical drivers of restoration and habitat protection. Millions of dollars of public funds have been spent on restoration intended to enhance the habitat and population-scale survival of this species. However, fish abundance continues to be lower than historical levels.

Approach

In coastal Oregon, riparian protection measures include a variety of approaches, from voluntary best management practices to legislated prescriptions (Boisjolie et al., 2017). The most rigorous protections are generally associated with extractive natural resource uses such as timber harvest or mining, while the least rigorous are linked with agricultural land uses. Policy approaches include prescriptive policies intended to eliminate pollution to waterways by specifying requirements for riparian areas and explicitly limiting certain management actions. For agricultural lands, outcome-based policy approaches are intended to minimise water pollution, allowing landowners discretion in land management so long as it does not negatively impact water quality standards. The efficacy of these approaches can be difficult to assess at a catchment scale. Prescriptive approaches may constrict

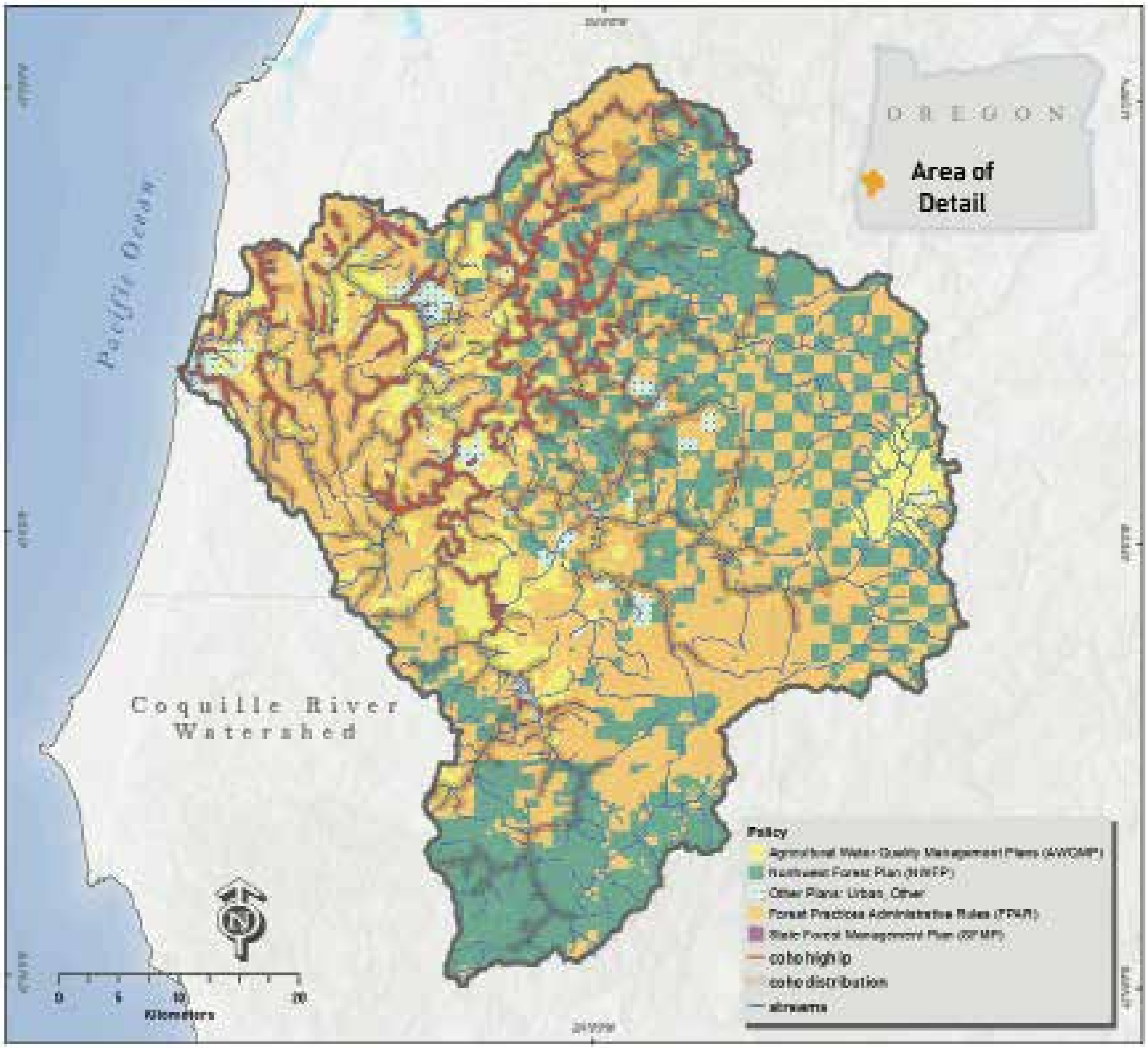

Figure 2. Coho salmon in the Coquille River Basin have historically utilised low-gradient floodplain areas. On the modern landscape, these areas are often associated with agricultural land uses. © Rebecca L. Flitcroft

Juvenile coho salmon (*Oncorhynchus kisutch*) © Adobe Stock

dynamic ecosystems to meet an ideal target condition, while outcome-based policies and a reliance on voluntary efforts can create gaps in protective efforts.

Protective efforts influence habitat conditions in time and space. Consequently, the variability in protective efforts has strong implications for the conservation of riparian ecological corridors. Overcoming fragmented riparian protections can be aided by:

- Legislative efforts;
- Restoration incentives;
- Collaborative restoration projects;
- Conservation designations;
- Technical assistance; and
- The formulation of collaborative governance bodies to address habitat and/or ecosystem degradation.

Understanding the extent of variable protective efforts can inform multi-agency policy responses for species recovery or conservation priorities. Developing an understanding of the mosaic of protective efforts can help identify and quantify gaps in them.

Example of an ecological corridor

For the Coquille River system, maps of riparian policy protections were overlaid with the distribution of coho salmon and areas of high intrinsic potential to support them (Figure 2). The maps show that the majority of riparian areas within the distribution of this fish are managed for agriculture, followed by timber harvesting. Further, areas with high intrinsic potential to support coho salmon are mostly located in agricultural areas. This shows a mismatch between riparian protection of coho salmon streams (which is determined by land ownership) and the location of habitats appropriate for different life stages of these highly migratory fish (which is determined by the hydro-geomorphic context of the river).

Results

Policies intended to protect riparian areas and coho salmon are more specific and enforceable in areas these fishes are less likely to occupy (Boisjolie et al., 2019). This gap in protections has led to the development of voluntary incentives for stream restoration actions and the management of working lands in the Coquille Basin. By mapping protections, their fragmentation along the continuum of the river network can be identified, allowing for targeted restoration or additional protection work. Tracking the effects of voluntary riparian protections, prescribed protections, voluntary approaches to stream restoration and collaborative landscape management are critical in evaluating the success of freshwater recovery throughout the river network. A broader perspective on identifying and quantifying fragmentation, as well as connectivity, is necessary if protections are to be effective for highly migratory fishes that must access habitats throughout a river system.

23. Protection of the free-flowing Bita River

Jose Saulo Usma and Cesar Suarez, *WWF Colombia*
Fernando Trujillo, *Omacha Foundation*
Michele Thieme, *WWF-US*

Key lesson
Management agreements within this Ramsar site are important to maintain connectivity for both freshwater and terrestrial species by managing activities in the watershed such as sport-fishing and agriculture.

Context and challenge

The Bita River in Colombia is 520 km long and its basin covers about 822,000 ha (Figures 1, 2). The river begins as a small, spring-fed stream in the middle of the llanos, a network of grasslands and seasonally flooded plains. The river meanders freely through this important and unique ecosystem, creating deep lagoons and beautiful beaches, until it reaches the Orinoco River. Along its path, the still-free-flowing Bita River supports rich biodiversity: freshwater fish, turtles (*Podonecmis* spp.) and crocodiles (*Crocodylus* spp.), river dolphins (*Inia geoffrensis*), jaguars (*Panthera onca*), tapirs (*Tapirus terrestris*), otters, and many other mammals, reptiles and birds.

Despite Colombia's wealth in natural assets, research has revealed that the llanos are one of the most under-protected ecosystems in the country. The country's ecosystems are increasingly under pressure from extractive industries, livestock grazing, large timber plantations and urbanisation. Additionally, the connectivity afforded by the Bita River allows migration of freshwater fish and seasonal movements of dolphins, both of which are critical for local livelihoods, including sustainable tourism, birdwatching and sport fishing.

Approach

The Alliance for the Bita River was created in 2014 and is composed of the Omacha Foundation, the Alexander von Humboldt Research Institute for Biological Resources, Corporinoquia, the Vichada Government, the Colombian Navy, Colombia's National Parks, the Palmarito Foundation, the Orinoco Foundation, La Pedregoza Corporation, and WWF. Since then, the alliance, fishers, tourism

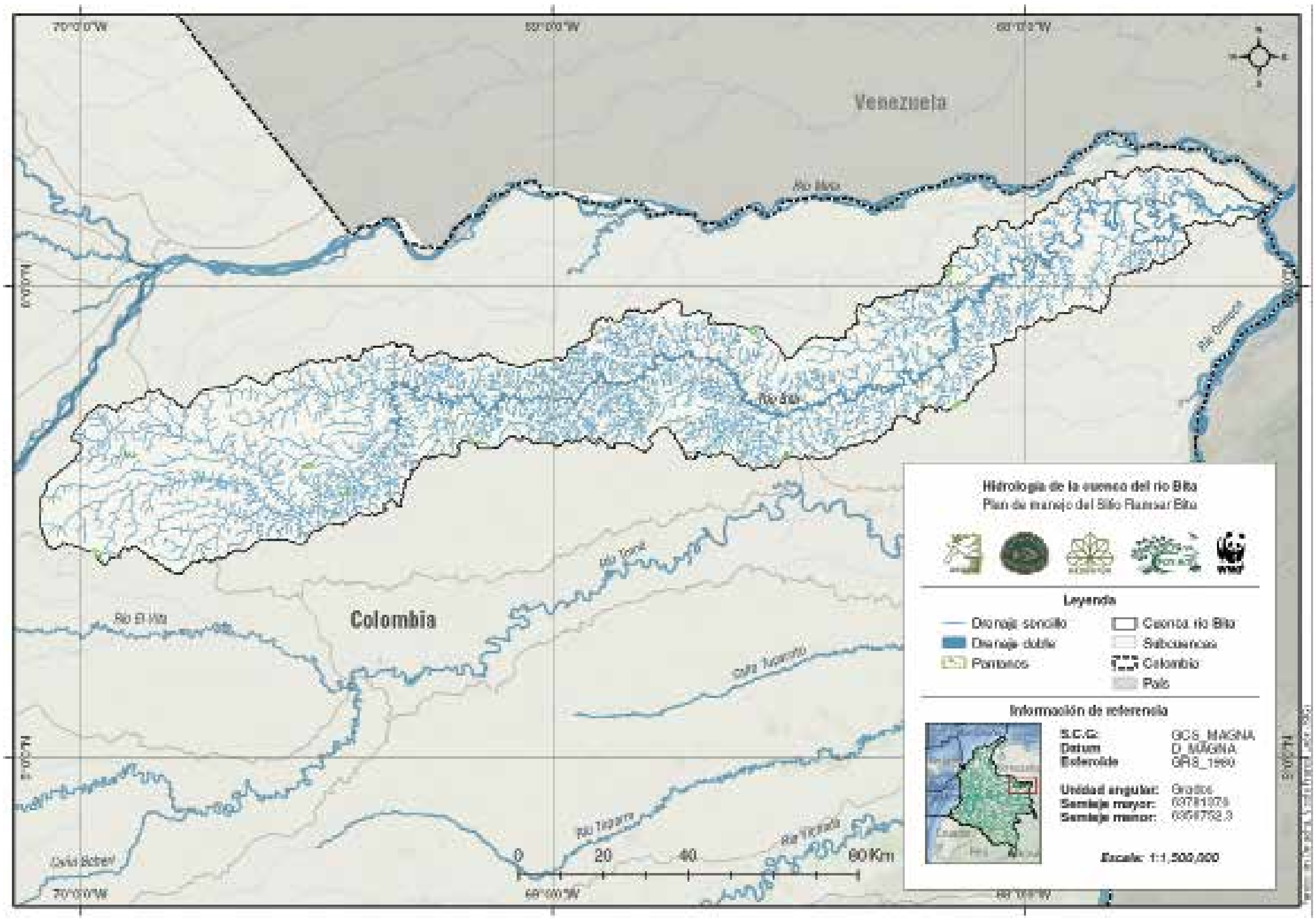

Figure 1. The Bita River Ramsar site in Colombia © Omacha Foundation, Courtesy Fernando Trujillo

Figure 2. Aerial view of the Bita River landscape © Omacha Foundation, Courtesy Fernando Trujillo

representatives, social and environmental organisations, scientists and local people have all been working together to protect the Bita.

To advance conversations about legally protecting the Bita, the alliance hosted a series of workshops with local stakeholders to understand the connections among various activities (such as agriculture and sustainable tourism) and protection. After better understanding the cause-and-effect relationships of these multi-sector activities, the group developed a decision-making framework that uses quantitative data to demonstrate the impacts of certain actions. This framework helped the government, the alliance and other partners choose the best actions to take to conserve the Bita River while meeting the needs of stakeholders.

Example of an ecological corridor

The free-flowing Bita River supports movement and migration of many species, including the following:

- River dolphins: The Bita has one of the best populations of river dolphins thanks to its proximity to the Meta and Orinoco rivers, which supply food (fish) for the dolphins and key habitats for their reproduction.
- Migratory fish: The different types of water and the longitudinal and lateral connectivity between the Bita (black waters), Meta (white waters), and Orinoco (mixed waters) and their wetlands favour the reproduction of many migratory species.
- Tapirs, jaguars, and pumas: It is estimated that 600–700 tapirs, 60–70 jaguars and 100–120 pumas (*Puma concolor*) live in the Bita River Basin thanks to the ecological integrity of its forests and wetlands.
- Other species: The river corridor will support the conservation of other species such as peacock bass (*Cichla* spp.), freshwater stingrays (*Potamotrygon* spp.), giant otters (*Pteronura brasiliensis*), and river turtles.

Results

On June 23, 2018, the Bita River was added to the List of Wetlands of International Importance of the Ramsar Convention. It is the largest Ramsar site in Colombia and one of the first anywhere to protect an entire free-flowing river and its basin (822,600 ha). Since the declaration, a management plan has been developed for the Ramsar site by the Omacha Foundation, Orinoquia Foundation, National University of Colombia, and RESNATUR (a private nature reserve network).

The management plan details actions to conserve and sustainably use the Bita's fisheries because the river is the epicentre for sport fishing in Colombia and important for the ornamental fish trade. Additionally, an agreement has been made to create within the Ramsar site an ecological corridor (228,000 ha) that connects the Upper and Middle Bita rivers and allows movement of 34 species of medium- and large-sized mammals including tapir, jaguar, puma, river dolphins, otters and migratory fishes. Among others, the agreement was signed between the Ministry of Environment, the Omacha Foundation, the Project Design Developers-Folgers Inc., the Tapirs Specialist Group of IUCN SCC, the forestry sector, and the farmers who are located within the ecological corridor in the Ramsar site. These parties committed to undertake sustainable agricultural practices and livestock production, forestry and responsible fruit production within the corridor and support the monitoring of flagship wildlife populations.

Marine connectivity: Australia

24. The Great Barrier Reef: Systematically protecting connectivity without connectivity data

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Jon C. Day, *ARC Centre of Excellence for Coral Reef Studies, James Cook University, Australia*

Key lesson

In barrier reef systems, placement of protected areas and management of activities in buffer zones can promote stepping-stone connectivity, thus maintaining larval movements, migrations from inshore to offshore habitats, and movements of adult benthic and pelagic organisms.

Context and challenge

Australia's Great Barrier Reef (GBR) is the world's largest coral reef ecosystem, and one of the country's most important ecological and economic assets. Most of the GBR is enclosed within the Great Barrier Reef Marine Park (GBRMP), a multiple-use marine park comprising eight different usage zones (Figure 1), with one-third zoned no-take. The Australian government, acting primarily through the GBRMP Authority, is responsible for management, undertaken in conjunction with other federal and Queensland agencies, Indigenous Traditional owners and various other stakeholders.

Although the GBRMP was originally created to protect the reef from mining exploration, its coral reefs are now mainly threatened by recurrent bleaching, cyclones and outbreaks of crown-of-thorns starfish. Large areas, particularly the inshore and northern reefs, have lost large proportions of their live coral cover in recent years. Secondary threats include adverse water quality, unsustainable fishing, dredging and coastal development. Despite these pressures, the condition of the GBR is good compared with that of many other reef systems globally.

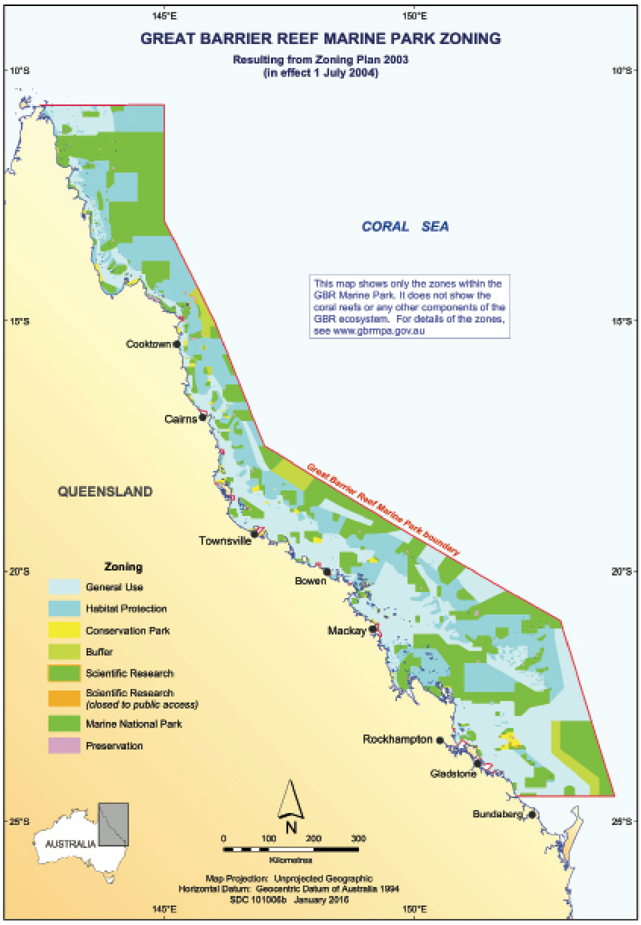

Figure 1. Current zoning for Great Barrier Reef Marine Park (resulting from the 2003 Zoning Plan, in effect since 1 July 2004). Map supplied by Spatial Data Centre, Great Barrier Reef Marine Park Authority, © Commonwealth of Australia (GBRMPA).

Approach

Conservation of the GBR's coral habitat requires three types of connectivity to be protected. The first, and most important, is larval connectivity: most organisms on reefs have an obligate pelagic larval dispersive phase making connectivity a constant demographic necessity. Oceanic currents create spatiotemporally complex larval connectivity patterns that drive population dynamics on the GBR. These connectivity patterns are similar to terrestrial ecological corridors, but the dispersing organisms are not exposed to threats during dispersal, and so marine ecological corridors do not require protection. Instead, conservation outcomes are enhanced by networks of marine reserves that exchange large amounts of larvae, while fishery outcomes are improved when no-take zones are connected to fished areas. The second form of connectivity is ontogenetic migration, typically where species spend their early life-stages in estuarine/inshore habitats, before migrating offshore as adults; Figure 2 shows one example. The third is small-scale movement of adults for foraging or reproducing. Most coral reef species are benthic-associated, and so these movements occur at within-reef scales. However, pelagic species can undertake longer-distance adult movements between reefs.

The GBRMP was substantially rezoned and expanded in 2003, based on systematic planning principles. Eleven biophysical operating principles (BOPs) (GBRMPA, 2002) were devised to protect representative examples of each of the GBR's 70 bioregions (30 reef habitat; 40 non-reef) (Fernandes et al., 2005). The maintenance of connectivity was also an explicit goal of the marine park – both the total size of the no-take marine reserves and their individual locations were taken into account. As an overarching goal, BOP 9 recommended that no-take zones be chosen to maintain connectivity across the GBR. However, minimal data about connectivity were available at the time of the rezoning, and so several of the

BOPs were designed to prioritise potential proxies for each form of connectivity. BOPs 1 and 2 aimed to protect larval connectivity, particularly self-recruitment. For example, BOP 2 recommended that no-take zones be as large as possible, motivated by models indicating self-recruitment increased with reserve dimensions. BOP 4 recommended that no-take zones include whole reefs where possible, to protect connectivity for foraging and migrating adults.

Results

Little information on connectivity was available for the 2003 rezoning, so proxies were used to design networks of no-take zones that would ensure the exchange of larvae between them, as well as the export of larvae to fished areas. Recent empirical studies and biophysical modelling demonstrate that this approach was successful to some extent, with larval dispersal connecting no-take zones at a range of scales, from local self-recruitment (Harrison et al., 2012) to consistent bi-directional exchanges of over 250 km (Williamson et al., 2016; Bode et al., 2019).

There are three possible reasons why a network of no-take zones that was not designed with explicit connectivity data was nevertheless able to achieve connectivity outcomes. First, the GBRMP contains a very large proportion of effective no-take zones (33% of the entire area). We would generally expect that higher levels of protection will achieve superior connectivity outcomes. Second, explicit connectivity proxies form the basis of several BOPs, and these likely improved connectivity outcomes beyond the simple null expectation.

The final reason is less obvious. The GBRMP is a global exemplar of a systematically planned network. Several BOPs (specifically 5 and 7) aimed to create a 'representative' network, with no-take zones distributed across bioregions, latitudes and cross-shelf position. While these goals do not mention connectivity, evidence suggests that representiveness allows no-take networks to effectively protect previously unknown biodiversity features (e.g. mesophotic reefs, as in Bridge et al., 2016). It is entirely possible that representativeness principles are also responsible for the protection of connectivity in the GBR.

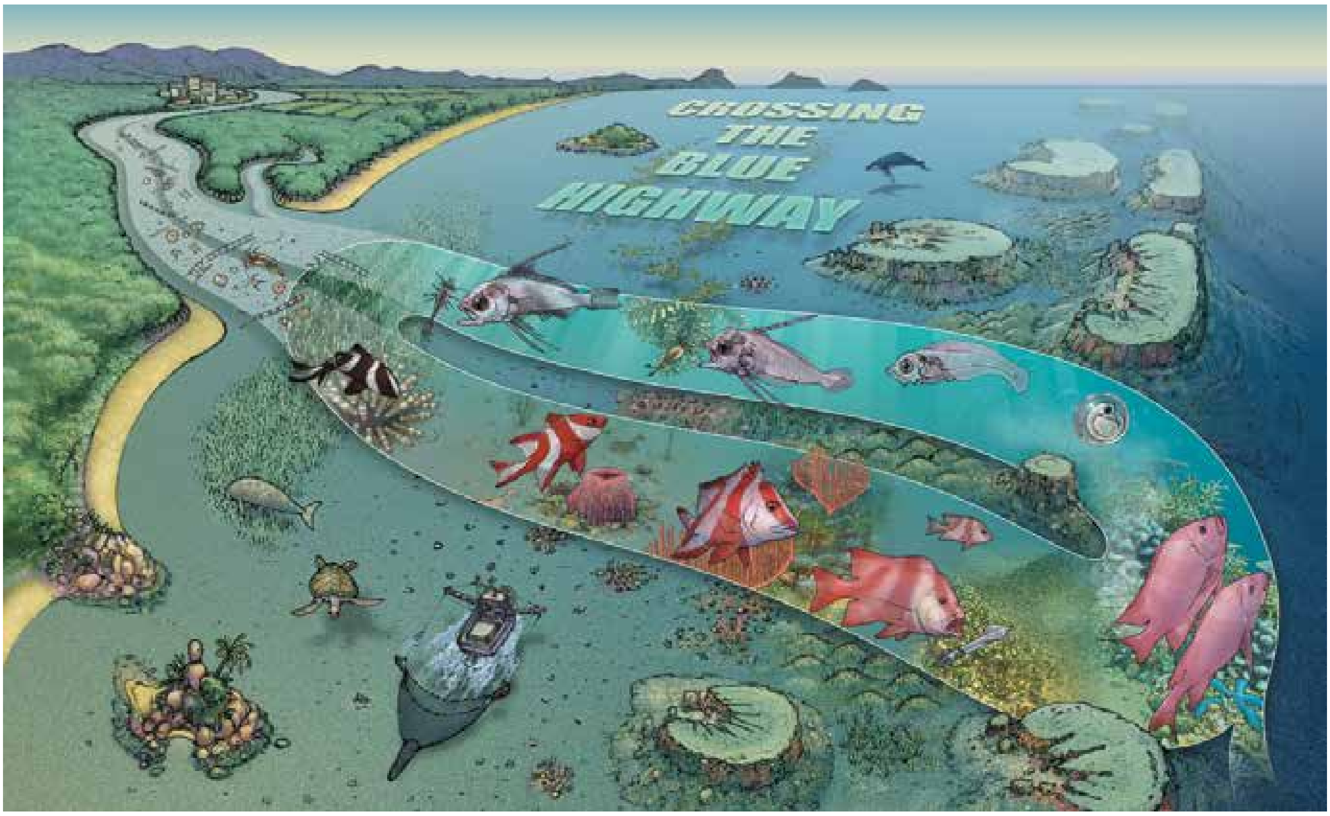

Figure 2. 'Crossing the Blue Highway': The red emperor (*Lutjanus sebae*) spends different stages of its life cycle utilising different habitats across the GBR. © Russell Kelley/Australian Coral Reef Society, http://www.russellkelley.info/print/the-blue-highway/

Marine connectivity: North America

25. Northern Channel Islands: Connectivity across a network of marine protected areas contributes to positive population and ecosystem consequences

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Mark Carr, *Department of Ecology and Evolutionary Biology, University of California Santa Cruz*
J. Wilson White, *Coastal Oregon Marine Experiment Station, Oregon State University*

Key lesson
The creation of an ecological network of marine protected areas has helped to restore species, increased connectivity and made the network more robust to invasive species.

Context and challenge

Temperate coastal marine ecosystems produce a diversity of ecosystem services, including the support of recreationally and commercially important fisheries, economically important ecotourism and other cultural values. One temperate marine ecosystem of particular importance is kelp forests, which support some of the most species-rich and productive ecosystems on Earth. They are subjected to a host of human impacts, particularly from fisheries, invasive species, and various manifestations of global climate change.

Approach

In 1998, a group of fishers, managers and other citizens in southern California, USA, was concerned about declining resources such as abalone, lobsters and rockfishes in nearshore ecosystems, including kelp forests. This group approached the California Fish and Game Commission with a proposal to set aside areas for protection in the northern Channel Islands, a chain of four islands north-west of Los Angeles and separated from the mainland by the Santa Barbara Channel. In 2003, following a multi-year public process, the state of California, in collaboration with Channel Islands National Park (CINP), created 13 marine protected areas (MPAs) within state and national park waters. In 2007, the National Oceanic and Atmospheric Administration extended eight of these MPAs into Channel Islands National Marine Sanctuary (CINMS) waters (Figure 1). Thus, the MPAs encompass both state and federally managed waters. The objectives of the MPAs were to help restore biodiversity, ecosystem health and fisheries species by protecting marine life and habitats. Extending from the intertidal zone to depths of 1,400 m, the MPAs encompass a diversity of ecosystems, distinguished by seafloor type (rock versus sand) and depth.

Today's Channel Islands MPA network has a large number of overlapping agency jurisdictions. Eleven federal, state and local agencies have some jurisdiction in the planning region. While both CINMS and CINP overlap around the northern Channel Islands, neither agency regulates commercial or recreational fishing. The California Department of Fish and

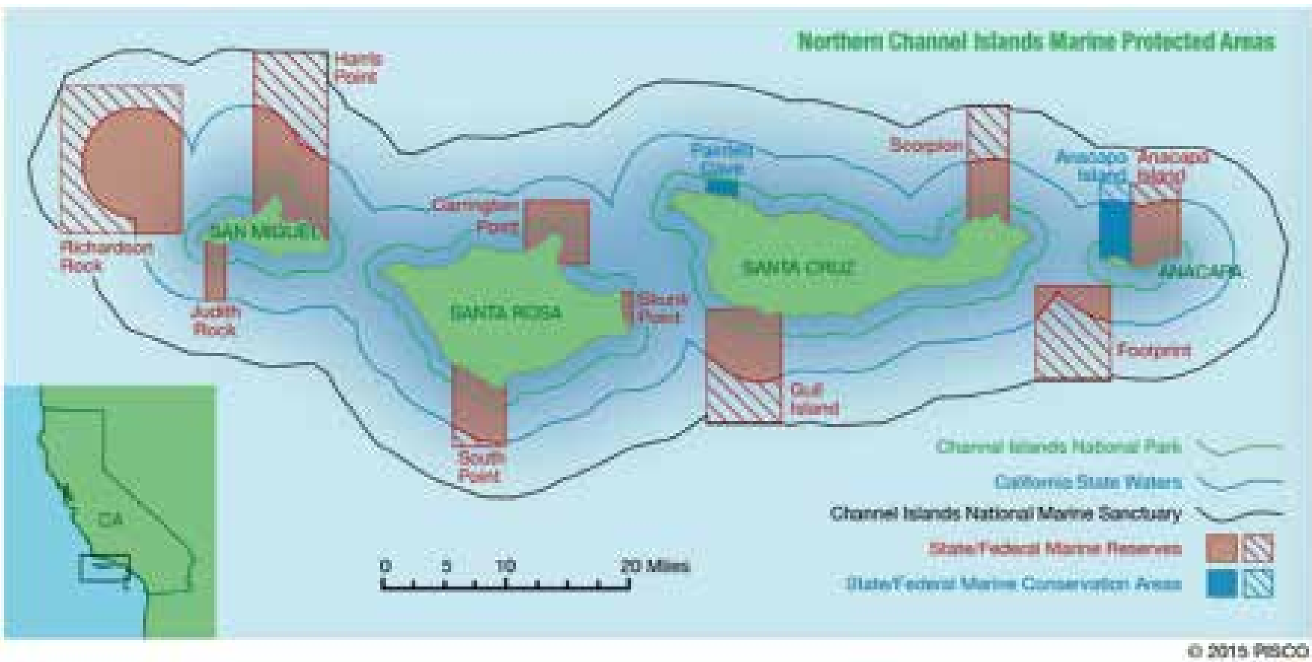

Figure 1. Map of the distribution of marine protected areas across the Northern Channel Islands archipelago off the coast of southern California, USA (see inset). Map indicates the jurisdictional ranges of state and federal institutions and the two types of protected areas (marine reserves and marine conservation areas) © The Partnership for Interdisciplinary Studies of Coastal Oceans

Kelp forest © Adobe Stock

Wildlife manages all fisheries in state waters (within 5.6 km of the shore), while the California Fish and Game Commission (an appointed body) has authority to set all state fishery regulations, including the creation of MPAs.

Examples of ecological corridors

Though not originally designed as a network of MPAs connected to one another by the dispersal of young (i.e., fish and invertebrate larvae), subsequent analyses of oceanographic currents and larval dispersal patterns indicated that young generated in the MPAs very likely are transported to and contribute to the replenishment of populations and communities in other MPAs, thus forming a *de facto* network. The primary way ecological corridors have been analysed is by simulating the movement of larvae using numerical ocean circulation models that describe currents in the region. For example, Watson et al. (2010) simulated the movement of larvae of two important fishery species – kelp bass (*Paralabrax clathratus*) and kelp rockfish (*Sebastes atrovirens*) – to and from sites throughout southern California, including the Channel Islands MPAs. The simulations calculated the probability of larvae travelling from one location to another; the authors then multiplied those probabilities by estimates of the spawning biomass at each location to predict how many larvae travelled along each potential ecological corridor. The analysis showed that kelp bass larvae produced inside MPAs on Santa Cruz and Anacapa islands likely disperse to other MPAs in the network and to fished areas; the same was true of kelp rockfish larvae produced in MPAs on San Miguel Island (Figure 2). Thus, the MPAs are linked by ecological corridors, but different corridors are used by different species, depending on habitat. In this case, kelp bass prefer the warmer water of the eastern islands while kelp rockfish prefer the cooler western waters.

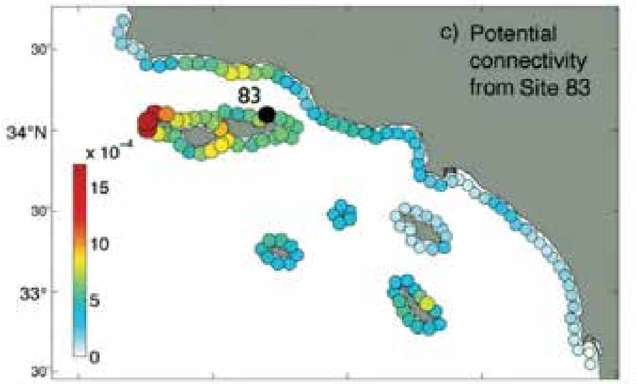

Figure 2. Predicted dispersal of larval kelp bass using an ocean circulation model of the Southern California Bight (Watson et al., 2010). Each coloured circle corresponds to a spatial node (site) in the model from which simulated larvae could be released and to which they can settle. In this example, the connectivity from Site 83 (which overlaps with the Scorpion State Marine Reserve on Santa Cruz Island) is shown. The colour of each dot represents the relative number of larvae that travel along the ocean corridor from Scorpion to the other sites (the numerical values are expressed as a proportion of the total number of larvae released from all sites in the simulation). Thus, there are strong connections to the other MPAs in the Channel Islands, as well as to non-MPA sites.

Results

The ecological network of MPAs implemented in the Channel Islands region contains 21% of the CINMS waters in 11 state marine reserves (no commercial or recreational fishing allowed) and two conservation areas (where some types of fishing are allowed). Following a decade of protection, monitoring of nearshore kelp forests in the Channel Islands MPAs showed increases in the biomass of targeted fish species inside the MPAs relative to fished areas. While the biomass did not increase spectacularly, the dramatic declines that were predicted by some models as a result of potential displacement and compaction of fishing effort did not take place either. More recently, protection of higher-level predators within older, fully protected areas has been shown to prevent invasion of a non-native macroalgae.

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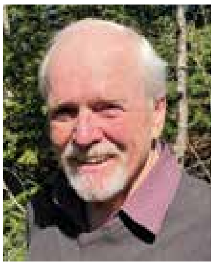
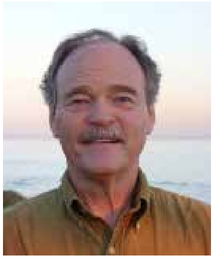
Annika Keeley PhD is a wildlife ecologist with expertise in ecological connectivity science. She has published several scientific research articles on aspects of ecological corridors, ecosystem science, and animal behavior. As a postdoctoral scholar at the University of California, Berkeley, she systematically reviewed the literature on the intersection of connectivity and climate change science and explored the challenges and opportunities for implementing connectivity in California and around the world. She is currently a scientist with the Delta Stewardship Council in California where she promotes science-based adaptive management and synthesises and communicates scientific information, including on estuarine connectivity, to policy- and decision makers.



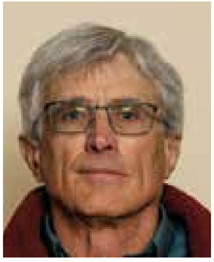
Stephen Woodley PhD has worked in environmental conservation as a field biologist, researcher, consultant, University Research Centre Director, and first Chief Scientist for Parks Canada. In 2011, Stephen began working as Senior Advisor to the Global Protected Areas Program of the IUCN and continues that work as Vice Chair for Science and Biodiversity of IUCN's World Commission on Protected Areas. The work focus is to understand the role of protected areas as solutions to the current global conservation challenges.

Barbara Lausche JD is an international environmental law and policy advisor with more than 30 years in conservation law and policy, nationally and internationally. Since 2010, she has served as Director of the Marine Policy Institute (MPI), Mote Marine Laboratory, Florida. As an active member of the IUCN World Commission on Environmental Law and WCPA, she began working with the project early on as part of Graeme Worboys' team, focusing on governance, law, policy, and marine content. Among publications relevant for this project are the IUCN *Guidelines on Protected Areas Legislation* (2011), and *The Legal Aspects of Connectivity Conservation, A Concept Paper* (coauthor, 2013). In 2019, she was appointed Chair of the IUCN WCPA-CCSG Marine Connectivity Working Group, comprising some 80 marine professionals worldwide. Prior positions have included senior staff at the World Bank, World Wildlife Fund-US and numerous legal drafting consultancies in developing countries.

Harvey Locke JD is a conservationist, writer and photographer who is a recognised global leader in the field of parks, wilderness and large landscape conservation, based in Banff National Park, Canada. He is co-founder of both the Yellowstone to Yukon Conservation Initiative and the global Nature Needs Half Movement and serves as Chair of the IUCN World Commission on Protected Areas Beyond the Aichi Targets Task Force. He also served as President of the Wildlands Project, the first continental-scale effort to promote connectivity, and has been involved since IUCN WCPA began its work on connectivity in the 1990s.



Mark Carr PhD is a professor of marine ecology in the Department of Ecology and Evolutionary Biology at the University of California, Santa Cruz (UCSC). He and his lab study the basic and applied ecology of coastal marine species and ecosystems. His research informs marine fisheries management and conservation, including ecosystem-based management, the design and evaluation of marine protected areas (MPAs) and climate change. Dr. Carr was co-chair of the Science Advisory Team to California's Marine Life Protection Act for the state's network of MPAs. He conducts studies of the network's conservation consequences. He was the science advisor on the US Marine Protected Area Federal Advisory Committee and is a member and past co-chair of the Science Advisory Team for California's Ocean Protection Council. He is a founding faculty member of the Coastal Science and Policy graduate program at UCSC.



Ian Pulsford MSc is a founding Director of Great Eastern Ranges Ltd. Ian has over 37 years' experience in the conservation of natural and cultural heritage including the assessment, selection, design and management of protected areas. In 2006, he and Graeme Worboys proposed to the New South Wales Government the establishment of the Great Eastern Ranges connectivity corridor, Australia's first continental-scale conservation corridor. He was the founding Manager of the corridor initiative from 2007–2010. He is a member of the IUCN WCPA Connectivity Conservation Specialist Group and has served on various Government advisory committees, including an expert scientific panel advising the Australian Government on the proposed Australian National Wildlife Corridors Plan. Ian has been a co-editor or lead co-author on two books: *Linking Australia's Landscapes* (2013), and *Protected Area Governance and Management* (2015).

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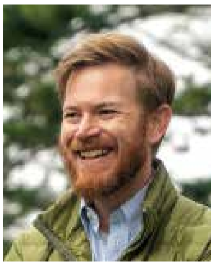
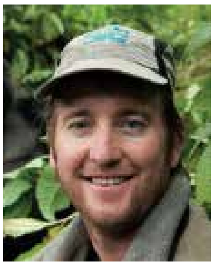


J. Wilson White PhD is Assistant Professor of Nearshore Fisheries Oceanography at the Coastal Oregon Marine Experiment Station at Oregon State University. Will's research links statistical and dynamic models to empirical datasets, often seeking to detect subtle patterns in noisy data. His research topics span the pelagic dispersal of marine larvae, planning and adaptive management of marine protected areas, behavioral ecology and population dynamics. His expert testimony has been used in cases argued before the US Supreme Court, and he has informed fishery management and reserve planning processes in multiple US states and Canada. Will has coauthored more than 80 peer-reviewed journal articles and the book *Population Dynamics for Conservation,* and he is co-Editor-in-Chief of the *Journal of Experimental Marine Biology and Ecology.* He holds a PhD in Ecology, Evolution and Marine Biology from the University of California Santa Barbara.

David Theobald PhD heads the EXP initiative at Conservation Planning Technologies. He has worked for nearly 30 years as a landscape ecologist and geographer to assess the patterns and trends of land use that emerge from socio-ecological systems operating at global to local scales. Dave applies his experience and expertise to inform connectivity and permeability modeling, conservation planning and proposed policy changes on natural resource sustainability and landscape vulnerability assessments. He has used visualisations of landscape dynamics to compel policy makers, land managers and the general public to conserve lands and waters. Through exercising collaborations, creating tools and placing network science within a geographic context, Dave envisions a world of permeable and regenerative landscapes.

Jessica Levine MSc MCP is Conserving Land and Water Strategy Lead for Nature United, the Canadian affiliate of The Nature Conservancy, and Coordinator of the Staying Connected Initiative, a binational public–private partnership working to sustain landscape connectivity in the Northern Appalachian–Acadian region of the USA and Canada. She serves on the Executive Committee of the Network for Landscape Conservation and Canada's Pathway to Target 1 Connectivity Working Group. Prior to joining Nature United, Jessica managed local and international environmental partnerships across North America, coordinated biodiversity research among Quebec universities, oversaw youth environmental education programs in California and directed volunteer programs across Latin America. Jessica has a BA in Human Biology from Stanford University as well as an MS in Energy and Resources and an MCP in City and Regional Planning, both from UC Berkeley.

Melly Reuling MSc has worked to connect key conservation landscapes on multiple continents for more than three decades. Trained as a wildlife ecologist, Melly started her career working on elephant conservation in East Africa where she studied corridors linking iconic protected areas of northern Tanzania. After more than 25 years in Tanzania, she moved to Bozeman, Montana, USA, and is now the Vice President of Programs at the Center for Large Landscape Conservation. Having spent time in all aspects of conservation – government, non-government, wilderness education and tourism – Melly firmly feels that the key to connecting landscapes is successfully connecting different types of people and communities.



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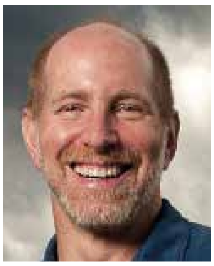

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