

# Technical Guidelines for the Design and Management of Participatory Connectivity Conservation and Restoration Projects at the Landscape Scale in Latin America

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Tropical Agricultural Research and Higher Education Center (CATIE)  
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Photo: Olivier Chassot

## Introduction

In Latin America, loss, degradation, and fragmentation are principal threats to biodiversity and ecosystem services provision (WWF 2015). These processes contribute to the loss of ecosystems and species, isolation of populations, and present challenges to migration and dispersal of individuals across the landscape (Noss 1991, Hobbs 1993, Beier and Noss 1998, Bennett 1998).

Much biodiversity conservation undertaken in recent decades has not been able to reverse trends in biodiversity loss (WWF 2015). These processes have focused on preserving “critical” ecosystems, defined by their high rates of biodiversity and endemism on a continental scale. Today, nevertheless, the field recognizes that it is necessary to understand biodiversity conservation in a more systematic manner that must design interventions at local, regional, and continental scales. It is also necessary to integrate ecological, biological, social, economic, anthropological, and political factors (Herrera and Finegan 2008).



Protected areas represent one biodiversity conservation strategy that has been widely implemented across the globe. Nevertheless, owing to habitat fragmentation and degradation, complementary conservation and sustainable development strategies at the landscape scale are arising. This must be done while at the same time recognizing and reconciling objectives of both development and biodiversity conservation (Herrera and Finegan 2008).

One promising conservation and sustainable use tool to reestablish and maintain landscape connectivity are biological corridors. This strategy can also contribute to meeting national conservation goals, given that biological corridors can fulfill a strategic role in the conservation of representative biodiversity (Arias *et al.* 2008).

In Latin America, important efforts to conserve and restore connectivity have been occurring for decades. Almost all countries in the region have developed biological corridor initiatives, which require political support, stakeholder group involvement, and the active consideration of human wellbeing and sustainable development. More than a hundred biological corridors now exist in sixteen countries of which more than twenty involve the participation of three or more nations (Bennett and Mulongoy 2006).

One of these regional initiatives is the Mesoamerican Biological Corridor (MBC). The MBC started as a political goal conceived by the seven Central American countries and Mexico to generate a common good across the region. The corridor agenda was officially signed in 1997 during the Summit of the Presidents. This declaration defined the “MBC as a system of land use planning composed of natural protected areas of different management categories plus their interactions, organized and consolidated to offer a package of goods and environmental services, as much for Central American society as for the world, at the same time, offering opportunities to promote investment in conservation and the sustained use of resources” (translated

from Miller *et al.* 2001). The MBC is composed of existing and proposed protected areas for each participating country. The initiative also includes a complementary series of interconnecting zones between protected areas, the majority of which were selected based on their forestry uses (Miller *et al.* 2001).

This document recounts the authors’ experience in participatory conservation processes that seek terrestrial biodiversity connectivity. It synthesizes at least a decade of research and practice. Its documentation of this experience hopefully can contribute to the conservation and restoration of ecological connectivity in other parts of Latin America and the world. We further hope that these guidelines might be adapted to the biophysical, socio-economic, and institutional conditions of each site. Although related themes such as governance are discussed, this topic requires greater development. Nevertheless, it should be recognized that some countries (e.g., Costa Rica) have created policies, regulations, and incentives to improve governance (Lausche *et al.* 2013). The paper also presents a case study from Costa Rica (the San Juan-La Selva Corridor), which exemplifies the application of these guidelines and thus the process of constructing the corresponding ecological and governing institutions and public forums. The guidelines are complemented with a glossary, which provides the definition of key concepts related to conservation connectivity science.

This paper transcends a strictly ecological perspective of a biological corridor as proposed by various authors (e.g., Bennett 1998). These view the biological corridor as merely a linear habitat of various types that interconnects important habitat core areas in order to maintain wildlife populations. Although we preserve this focus, our experience shows that biological corridors can also serve as platforms for diverse stakeholder and institutional participation that seeks both conservation connectivity as well as sustainable development and human wellbeing.



Photo: Bernal Herrera-F.





Photo: Olivier Chassot

# Ecological Connectivity, Biological Corridors, and Community Participation: Fundamental Concepts

## Towards an Integrated Vision of Biodiversity Management

The discipline of conservation biology was born in the 1970s and has evolved into an emerging paradigm in science (Pickett *et al.* 1997). It integrates a diversity of scientific, practical, and traditional disciplines such as taxonomy, wildlife management, ecology, evolution, genetics, population biology, ecological restoration, forestry, veterinary medicine, horticulture, anthropology, geography, history, sociology, philosophy, law, and economics (Meffe and Carroll 1994, Primack *et al.* 2001, Primack 2002, Groom *et al.* 2006). Its objectives include (Primack *et al.* 2001, Groom *et al.* 2006)



- Research about human impacts on other living beings, communities, and ecosystems
- Prevention of habitat degradation and species extinction
- Restoration of ecosystems
- Reintroduction of populations
- Establishment of sustainable relationships between human communities and ecosystems



Photo: Bernal Herrera-F

Since its beginnings, conservation biology has evolved into an experimental and proactive discipline with a focus on patterns and processes at multiple scales (Poiani *et al.* 2000). Now, it considers the human being as an integral part of ecosystems, given that it continuously interacts with other inhabitants. It recognizes that local populations use natural resources to satisfy their needs and requires that natural resource managers assume a wider perspective with respect to natural resource and ecosystem management. Furthermore, it understands that the landscape responds to organisms' spatial needs (Meine *et al.* 2006). Conservation biology also seeks stronger inter-sectorial relations, for example, between science and policy, science and landscape management, and the mass media and the public (Pickett *et al.* 1997).

Conservation biology not only generates academic knowledge, but also allows pragmatic ecosystem management (Soulé 1986) by reducing threats that cause irreversible biodiversity loss, focusing especially on those sites with high levels of diversity and endemism (Primack 2002). It is, nevertheless, a discipline of crisis (Primack *et al.* 2001, Groom *et al.* 2006). Managers so often make conservation decisions under severe time pressures while working with governments, private sector, and the general public (Primack *et al.* 2001). Conservation biologists should maintain both rigor and depth with respect to biological studies and urgently integrate the social sciences in order to better respect and promote diverse biological and cultural communities. Only in this way can it guarantee biodiversity conservation and survival of human communities (Primack *et al.* 2001). In this sense, conservation

biology is similar to conservation science in which multiple disciplines interact in complex problem-solving that envelops the protection and sustainable use of biodiversity.

## Equilibrium Theory of Island Biogeography

The theories behind connectivity and conservation of biological corridors originate with the Equilibrium Theory of Island Biogeography first proposed by Robert MacArthur and Edward O. Wilson (1963, 1967). The theory posits that islands tend to support lower levels of biological diversity than comparable mainland areas. It further postulates that the number of species on an island tends toward an equilibrium between new species colonization rates and resident species extinction rates. Thus, the colonization rate depends on the degree of island isolation with respect to the mainland species source, while the extinction rate depends on the island's surface area (Bennett 1998, Primack *et al.* 2001).

Scientists have applied this theory to forest fragments to demonstrate the dynamic distribution of flora and fauna in habitat remnants as well as to recognize the ecological value of ecosystem patches (Harris 1984). Understanding the relationship between number of species and land area, one can estimate the number of species that will go extinct as a result of habitat destruction. For habitat conservation, then, this theory has promoted attempts to reduce species isolation by means of maintaining or

restoring habitat patches formed by stepping stones, or preferably, continuous corridors that facilitate species movement (Diamond 1975).

This theory does not take into consideration, nevertheless, the effects of patches on the overall territory, nor does it consider the contribution that other land uses might have on the “islands.” Thus, complementary theories are needed. These can be seen in the following sections.

## Metapopulation Theory

A metapopulation is a complex of temporarily related populations of the same species that changes due to dispersal and gene flow (Poiani *et al.* 2000). They occupy discrete yet interconnected habitat patches (Bennett 1998, Primack *et al.* 2001). Metapopulations are composed of subgroups or subpopulations that include both source and sink or satellite populations.

The source populations generally exist in favorable habitat that generates a surplus of individuals, while sinks or satellites are found in less favorable habitat in which population sizes cannot be maintained without immigration from sources (Poiani *et al.* 2000). The satellite populations can go extinct in unfavorable years, but, when conditions improve, are recolonized thanks to immigration from more permanent sources (Primack *et al.* 2001). Pulliam (1988, cited in Poiani *et al.* 2000) demonstrated that 10% of a source population can maintain 90% of sink populations.

## Landscape Ecology

Landscape ecology is an emerging paradigm and discipline that recognizes the need to practically and integrally manage habitat mosaics as complete landscapes, whether or not they are natural habitats or have been modified by humans (Fortin and Agrawal 2005). This discipline recognizes the dynamic nature of landscapes (Urban *et al.* 1987), prioritizes the study of spatial patterns within landscape mosaics in order to understand the effect of spatial patterns on ecological processes and community structure (Levin and Paine

1974, Wiens 1976, Risser *et al.* 1983), as well as temporal changes within the landscape matrix of habitat patches (Forman and Godron 1981, Forman and Godron 1986, Turner 1989, Legendre and Fortin 1989, Hansson *et al.* 1995).

A diversity of definitions describes the concept of *landscape*. Here, we follow Forman and Godron (1986) when we refer to a heterogeneous geographic area composed of interrelated groups of ecosystems that repeat across the same land area. Seen this way, landscape ecology is relevant for studying the ecological function of habitat patches and habitat management in environments that have suffered from anthropogenic intervention (Noss and Harris 1986). Besides, the application of this discipline implies an intrinsic acceptance that human beings are in fact landscape components (Barrett and Bohlen 1991, Bennett 2004).

## Protected Areas

Protected areas are defined as “a clearly defined geographical space, recognized, 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). They are areas of great importance for conservation and their effectiveness has been positive with respect to slowing deforestation and mitigating effects of climate change (SINAC 2007). Protected area objectives have been evolving from areas meant only for the enjoyment of society to areas that protect wild species (Dudley 2008).

The Convention on Biological Diversity (CBD) sees protected areas within the larger landscape context. Specifically, Article 8 mentions that “a protected area system or areas where special measures may need to be taken to conserve biological diversity will be established” (1992). As a result of this convention, an international political action framework has arisen to promote conservation and connectivity of biological corridors, including the creation and strengthening of interconnected networks that function as conservation areas (Poiani *et al.* 2000).



## Functional Areas for Biodiversity Conservation

Biodiversity conservation at multiple, spatial scales of biological organization requires an explicit identification and protection of ecosystems and indicator species in a particular geographic area, even though it may be difficult to determine the spatial needs of particular species as well as understanding some ecological processes (Goldstein 1999). In fact, biodiversity conservation requires the protection of these ecological processes associated with ecosystems and indicator species (McCullough 1996). Without such protection, an area cannot be considered functionally conserved (Pickett *et al.* 1992).

According to Poiani *et al.* (2000), a functional conservation area is one in which species, communities, and systems of particular interest and the ecological process that support them within their natural ranges of variability are maintained. More specifically, this area refers to the

amount of expected fluctuation in the patterns of diversity and ecological process under minimal or non-existent influence of human activity. Functional areas provide greater habitat diversity and populations both known and unknown species. They improve, as well, the efficiency and effectiveness of systems. By having a wide gamut of ecosystems and environmental gradients, these areas become potential areas to buffer global change.

Functional conservation areas seek to maintain the health of conservation targets over the long term (100–500 years). They should have, therefore, the ability to respond to natural and human induced environmental changes, taking into account patterns of both biotic and abiotic processes. These areas also consider the size, configuration, and other design parameters that relate to species, ecosystems, conservation targets, and ecological processes that support them (Poiani and Richter 2001). At the same time, because humans influence area functionality, ecological management and restoration are mainstays to retain functionality (Corrêa do Carmo *et al.* 2001).

Poiani and colleagues (2000) define three types of functional conservation areas classified according to management objectives and functional requirements of target species and ecosystems:

**Functional site:** Conserves a small number of ecological systems, communities, or species at one or two scales below regional; the conservation targets are relatively few and in general share similar ecological processes. Functional sites can be big or small, depending on the scale of the conservation targets and their ecological processes.

**Functional landscape:** Conserves a great number of ecological systems, communities, and species within their natural range of variability across all scales below the regional, which is to say, broad, intermediate, and local (Lambeck and Hobbs 2002). Given that conservation targets represent numerous ecological systems, communities, and known species, a functional landscape includes terrestrial, aquatic, and sometimes marine elements. In general, functional landscapes exist within a regime of multiple human land uses. The functional landscape concept then offers insights into

the modification of a protected areas system by considering conservation needs (Brandon 2002), which implies working within the land use planning processes of different political jurisdictions (Dengo *et al.* 1999).

**Functional network:** Integrates functional sites and landscapes designed to conserve regional species at a finer scale. The distribution of functional sites and landscapes that compose networks can be contiguous or link one or more regions. Functional networks contribute to species conservation whose distribution covers various ecoregions. In functional networks, it is important to consider the size of protected wild areas and their geographic location in such a manner as to ensure the viability of populations (Powell *et al.* 2002, Terborgh and van Schaik 2002). It is also important to consider the representativeness of ecosystem units with the same in order to achieve landscape heterogeneity (Grumbine 1994).

Aside from these characteristics, factors such as the mosaic context, connectivity of forest patches, and buffer zones are also important (Meffe and Carroll 1994). Thus, protected area networks play a very important role (Lovejoy 2006).

## Fragmentation Processes and Biodiversity Impact

Fragmentation divides continuous areas of natural habitat into smaller resource patches that remain separated from each other, particularly due to changes in land use and conversion into agricultural and urban lands (Fahrig 2003). It is a dynamic process characterized by notable changes in habitat patterns within a given period of time (Bennett 2004). Important attributes of the fragments or patches include density, distance, size, form, aggregation (spatial distribution), and boundaries (Lord and Norton 1990).

The fragmentation process involves a general habitat loss across a landscape, reduction in size of habitat patches, and isolation of habitats such as forest remnants, forests managed for production, natural forests, secondary forests, and gallery or riparian forests (Schelhas and Greenberg 1996, Bennett 2004, Lindenmayer and Fischer 2006).

Ecosystem fragmentation provokes diverse impacts on the biota (Saunders *et al.* 1991, Laurance *et al.* 2002). The most significant effect of forest fragmentation is the reduction and extinction of wild populations at the patch, local, and landscape scales (Levin and Paine 1974, Jordan 1986, Franklin and Forman 1987, Collado and Dellafiore 2002, Kattan 2002, Gallego and Finegan 2004, Laurance *et al.* 2002, Laurance and Vasconcelos 2004, Santos and Telleria 2006, Haddad and Tewksbury 2006).

Human activity constantly affects fragmented landscapes, complicating expansion of protected area networks (Lindenmayer and Fischer 2006). Such expansion can facilitate that some species find each other between patches, even if they cannot in natural protected areas (Schelhas and Greenberg 1996). It is important, therefore, to consider an entire landscape and not manage protected areas as isolated, disconnected elements (Saunders *et al.* 1991). It should be recognized that within the mosaic of different types of agricultural landscapes, important ecological functions can still be maintained (Gascon *et al.* 2004, Bennett *et al.* 2006).

For example, forest fragments can be of great ecological and economic importance; for this reason, it is necessary to implement actions that offer incentives for conservation and effective management (Kattan and Álvarez 1996) as well as natural or assisted restoration (Viana *et al.* 1997, Lamb *et al.* 1997, Guariguata and Ostertag 2002). These actions contribute to linking different landscape fragments (Poffenberger 1996, Guindon and Palminteri 1996). Also it is important that planning processes recognize agroforestry activities within protected area buffer zones (Schroth *et al.* 2004).



Photo: Bernal Herrera-F.



Habitat patches contribute positively to the maintenance of basic ecological functions throughout a conservation landscape marked by human settlements (Browder 1996, Nepstad *et al.* 1996). Some authors, nevertheless, disagree with the assertion (Bierregaard and Dale 1996). In tropical regions where the process of forest cover loss has been severe, patches can serve as seed banks, as sources of seed dispersal (Guariguata *et al.* 2000), as buffer zones for intact forest blocks, offering resources to a great number of organisms that move along the landscape as well as refuges for local or long-distance migratory organisms (Greenberg 1996, Bennett 2004).

Natural ecosystems are composed of habitats that vary in time and space with respect to their quality and potential use by fauna. These follow their own natural rhythms that link them with local populations, independent of the fragmentation and integrity of habitat, forming metapopulations at the regional scale (Wiens 1976, Hanski 1989, Hanski and Gilpin 1991, Opdam 1991). In this sense, species move from one significant stretch of habitat toward local populations in small habitat patches (from core to satellite areas), or move permanently between habitat patches until, due to a lack of connectivity, local populations go extinct (irregular population model).

The problem of ecosystem fragmentation requires a holistic solution in terms of managing wildlife, partly based on the theory of metapopulations (McCullough 1996). Fragmentation compels various organisms previously extant in continuously connected habitats to survive as subpopulations in natural ecosystem

remnants (Lefkovitch and Fahrig 1985, Hanski and Gilpin 1991, McCullough 1996, Moilanen and Hanski 2006) and to move among natural ecosystem patches (Dale *et al.* 1994). On the other hand, fragmentation exposes existing organisms in forest ecosystems to the border effect (Lovejoy *et al.* 1986), subject to increases in light levels, invasion by organisms from open areas (Laurance *et al.* 1985), aeolic drying (Laurance 1997), and changes in vegetative communities (Lovejoy *et al.* 1997, Lezcano *et al.* 2002, Lindenmayer and Fischer 2006).

How organisms respond to fragmentation depends in great measure on their degree of ecological specialization, body size, and movement patterns (Kellman *et al.* 1996, Tewksbury *et al.* 2006). Many ecological processes by which organisms may suffer border effect impacts (natural or provoked) have not yet been studied (Harris 1988); some research, nonetheless, points to the decline of faunal richness and abundance (Willis 1974, Ernst *et al.* 2006, Lees and Peres 2006). They also note long-term effects in the pollination of plant species dependent on organisms that cannot move between patches (Murcia 1996, Manning *et al.* 2006, Hanson *et al.* 2007, Hanson *et al.* 2008), especially in places with high biodiversity levels and where plants and trees are subject to major occurrences of decline or extinction due to a lack of specialized pollinators (Vamosi *et al.* 2006). Cramer and colleagues (2007) have demonstrated how tree species whose seeds are dispersed by animals of medium and large size, suffer greater difficulty in dispersing their own genes in fragmented landscapes. Fragmentation and its ecological implications are complex and require a major effort in applied research (Crome 1997).



Photo: Olivier Chassot



Although protected areas and other habitat cores continue to be the most effective biodiversity conservation strategy, in the context of fragmented landscapes, these can be small and isolated (Sánchez-Azofeira *et al.* 2003). For this reason, their conservation contribution may be limited but relevant (Ranganathan and Daily 2008). Also because of this limitation, biological corridors can become opportunities for the maintenance of residual biodiversity in these fragmented landscapes (Vandermeer *et al.* 2008). Similar to the design of biological corridors, agroecological and silvopastoral systems, for example, can play a very important role in biodiversity conservation, and, in fact, represent a unique opportunity in some Mesoamerican landscapes (Harvey and Sáenz 2008).

## Ecological Connectivity

Connectivity is a fundamental landscape attribute (Taylor *et al.* 1993). It is a term commonly used in the literature about landscape change and conservation practice, and generally refers to the level of ease by which an organism moves across specific landscape features (Pulsford *et al.* 2015). Connectivity describes “to what point does the landscape facilitate or impede movement between parcels with resources” (Bennett 2004) and more precisely which landscapes contribute to or not the movement of individuals between patches in search of resources (Taylor *et al.* 1993). In this way, landscapes exist with high connectivity given that individuals of a given species enjoy freedom to move between habitats, meanwhile landscapes of low connectivity do not facilitate such free passage, instead, limit their progress. Movement patterns between patches can be daily or temporary. Crome (1997) — alluding to a debate that divides the scientific community — warns against the belief that very small or isolated patches have no importance. What one should understand here, nevertheless, is that natural fragments constitute the minimum that must be preserved.

Biological corridors — such as those in Mesoamerica — are management tools to conserve connectivity (Worboys 2010). Gilbert-Norton *et al.* (2010) in a meta-analysis of 78 connectivity studies found that in those biologically

connected patches, species movement was 50% greater than in those fragments that were not connected by corridors. According to these same authors, corridors proved important for the movement of both vertebrates and invertebrates, except for birds. Nevertheless, corridors do not always result in greater ease of travel. That rather depends on existing land coverage and the perspective of a given organism. Sometimes corridors can also be barriers (Hilty *et al.* 2006, Anderson and Jenkins 2006). For this the mosaic context and ecosystem links are fundamental to ensure efficiency of ecological connectivity (Schelhas and Greenberg 1996, Crome 1997, Bierregaard and Stoufer 1997, Bennett *et al.* 2006), as well as each organism’s behavior with respect to corridor use (Soulé 1991, Bélisle 2005, Sanderson *et al.* 2006, Fagan and Calabrese 2006).

Biological corridors improve natural habitat quality and diversity in the landscape in order that the entire spectrum of native species can move among natural landscape areas (Noss 1991). Connectivity networks maintain and reestablish among ecosystem fragments separated by human interventions (Forman and Godron 1981, Bruinderink *et al.* 2003), permitting free movement of organisms from one patch to another (Dobson *et al.* 1999). Also implementation frameworks for biological corridors favor biological diversity and natural landscape resources by applying principles of conservation planning combined with information about the needs of filling conservation gaps in order to preserve natural communities (Hector *et al.* 2000).

Conservation connectivity theory, within landscape ecology and conservation biology, holds that connectivity can mitigate some climate change-caused collateral effects on species movement (Noss 1991, Hay 1991, Dobson *et al.* 1999, Thomas *et al.* 2006). Connectivity thus fulfills two functions: 1) regulation of movement in order that subpopulations can maintain minimally viable genetic diversity (Soulé 1991, Britten and Baker 2002, Frankham 2006); 2) facilitation of dispersal among home ranges and migration or colonization routes (Harrison 1992, Dobson *et al.* 1999). Finally, connectivity can occur at the patch, local, landscape, regional, or continental scale (Taylor *et al.* 2006).

On the other hand, there exist two principal components that influence connectivity: structural and functional. The structural component can be evaluated by way of landscape attributes such as density and complexity. Spatial distribution of different types of landscape habitats can be influenced by an suitable continuation of habitat, distance between one habitat patch and another, and finally the existence of alternative means whether corridors or the landscape matrix (Bennett 2004, Uezu *et al.* 2005).

Functional connectivity refers to habitat patch connection and its related populations by means of dispersal; it allows for dispersal of individuals among different patches (With *et al.* 1999). For this reason, functional connectivity evinces an individual's ability to move across a landscape. This movement is modulated by the interaction between the particularities of a species' movement and physical landscape structures (Bennett 2004, Stevens *et al.* 2004, With *et al.* 1999).

The interaction between landscape behavior and structure depends on two characteristics: 1) patch viscosity or the degree to which a landscape permits or impedes individuals from displacing across a landscape, and 2) permeability across a patch border, or the probability of crossing a border between different landscape features (Stevens *et al.* 2004). Similarly, it is important to consider the landscape scale in which a species moves, its habitat requirements, degree of habitat specialization, tolerance to environmental change, life phase, and time needed to disperse, as well as its response to predators and competitors (Bennett 2004). Thus, when an organism can cross gaps of inappropriate habitat, it perceives patches as connected, even when they are not continuous (With and King 1999).

It is important to recognize that landscapes contribute in different ways to different species. A landscape could provide high connectivity for one species and low for another (Bennett 2004). Thus, when one analyzes connectivity, he or she must consider management objectives and evaluate it on the species and community levels (Soulé 1991, De Campos and Finegan 2003, Bennett *et al.* 2006). It is important, then, to define a dispersal threshold in accordance with organisms' needs, given that they do not always correspond to other ecological thresholds (With 2002). Also ecological changes induced by climate change can impact conservation objectives and landscape connectivity (Pearson 2006, Chester and Hilty 2010).

## Importance of Public Participation in Biodiversity Conservation

Much evidence supports that the more stakeholder participation in conservation, the greater achievement of positive biodiversity impacts in the long run (Persha *et al.* 2001, Pretty and Smith 2004). Factors such as social cohesion between people, organized groups, and social networks, valuation of knowledge, incorporation of that knowledge into planning processes, and the implementation of biodiversity conservation activities all influence



Photo: Bernal Herrera-F.

conservation (Pretty and Smith 2004). Trusting relationships, reciprocity, fairness, norms, and sanctions constitute social capital necessary to mold individual action to achieve positive results for biodiversity. In this sense, when social capital rates highly, a social learning process becomes possible because participation in groups and networks catalyze conservation processes (Pretty y Smith 2004). To explicitly include social considerations into the design and management of biodiversity conservation makes corridors more adapted to biophysical and socioeconomic conditions (Ban *et al.* 2013). The integration of local human values, beliefs, necessities, and perspectives into the planning process increases implementation, because the conservation processes themselves embody those very local needs, interests, and visions.

Community-level biodiversity conservation complements protected areas systems with different objectives. It is an effective strategy that achieves conservation objectives at the species level (e.g. Muench and Martínez-Ramos 2016). Active community-based biodiversity management has been shown to be effective for tropical forest conservation (e.g. Grogan *et al.* 2016).

The search for participatory mechanisms that fuses local actors and conservation objectives, therefore, is necessary to reconcile conservation and development, as well as integrate biodiversity into community development.

## Biological Corridors Promote Public Involvement in Conservation and Sustainable Development

Biological corridors have evolved since the 1970s when promoters viewed them as vegetation connecting habitat patches (Bennett 1998). Later they were conceived as a limited space that connected landscape elements in order to guarantee the flow of species between different landscape patches, whether natural or modified.

This function contributed to biodiversity conservation and ecological-evolutionary processes of species, making lands productive again, and the economic valuation of biodiversity services and goods (Rojas and Chavarría 2005).

The current understanding of a biological corridor holds that it should not only contribute to biodiversity conservation and maintenance of ecosystem services, but also sustainable development. It does this by improving quality of life of communities that depend on biodiversity. Alternatively, they are also biodiversity management units integrating land use management, water, and other resources in order that they become more sustainable over time. Thus, they are managed landscapes that promote connectivity in order to continue ecological processes at the landscape level. The role of humans is fundamental to this process (Herrera-F 2010).

In this paper, we define a biological corridor as a geographic region composed of core and interconnecting areas that, within different spatial configurations, maximizes and ensures connectivity of this region. It also constitutes a space for public participation to define objectives for the rational use of biodiversity that maintain ecological processes that sustain biodiversity, related ecosystem services, and the benefits that these generate for local communities and society in general (Herrera-F 2010). In terms of ecological function, this definition is compatible with that of functional biodiversity conservation areas at the landscape scale as proposed by Poiani and Richter (2001).

Thus, the biological corridor is a functional territorial unit that favors biodiversity conservation and simultaneously generates benefits for local communities (Perrons 2013). The establishment of biological corridors, nevertheless, is complex. But if created, they contribute to biodiversity conservation, environmental land use planning, and ecological integrity of conservation targets by controlling threats. This is especially true when different actors participate in the process, strengthening sustainable development and human wellbeing (Canet-Desanti *et al.* 2008, Chassot *et al.* 2013).



In order that conservation practice be effective, the following objectives should be considered (ICF 2011):

- Maintenance of ecological integrity and population viability as well as the provision of ecosystem services, including the potential mitigation of climate change.
- Mitigation and control of the principal sources of pressure on biodiversity and ecosystems services.
- Capacity to manage land uses and knowledge at different scales of social organization (local, regional, national) in order to achieve conservation and development objectives, including financial sustainability.
- Mechanisms that ensure public participation and governance at sufficient scale as to define measures to monitor progress toward meeting objectives.

### **Box 1. An example of design and management of a successful participative connectivity initiative in Costa Rica: the San Juan – La Selva Biological Corridor (general description)**

The Great Green Macaw Research and Conservation Project was launched in 1994 to study the biology of the Great Green Macaw (*Ara ambiguus*) in northern Costa Rica. The project's first-year findings indicated that the population was in decline. The endangered Great Green Macaw has a limited distribution along the Atlantic wet lowlands of Central America, from southern Honduras to northern Colombia, with a small isolated population in the Pacific near Esmeraldas and Guayaquil, Ecuador. In Costa Rica, this species is currently limited to approximately 600 km<sup>2</sup> of tropical very wet forest bordering Nicaragua. It is highly dependent on the almond tree (*Dipteryx panamensis*) both for feeding and nesting.

The survival of the Great Green Macaw depends on the availability of intact forest habitat. For this reason, together with local and national stakeholders, the Great Green Macaw Project proposed in 1998 a conservation plan based on data generated by a multi-year telemetry study to protect enough habitat to maintain a small, viable breeding population in Costa Rica. This integral conservation plan became known as the San Juan-La Selva Biological Corridor. Within this framework, the 54,000 ha Maquenque National Wildlife Refuge was created in 2005, covering the breeding range of the Great Green Macaw (Chassot and Monge-Arias 2012). From an estimated 210 individuals in 1994, the population has increased to more than 350 in 2015. This increase correlates with conservation actions undertaken since 1994 in order to protect the habitat of this magnificent bird.



Photo: Bernal Herrera-F.





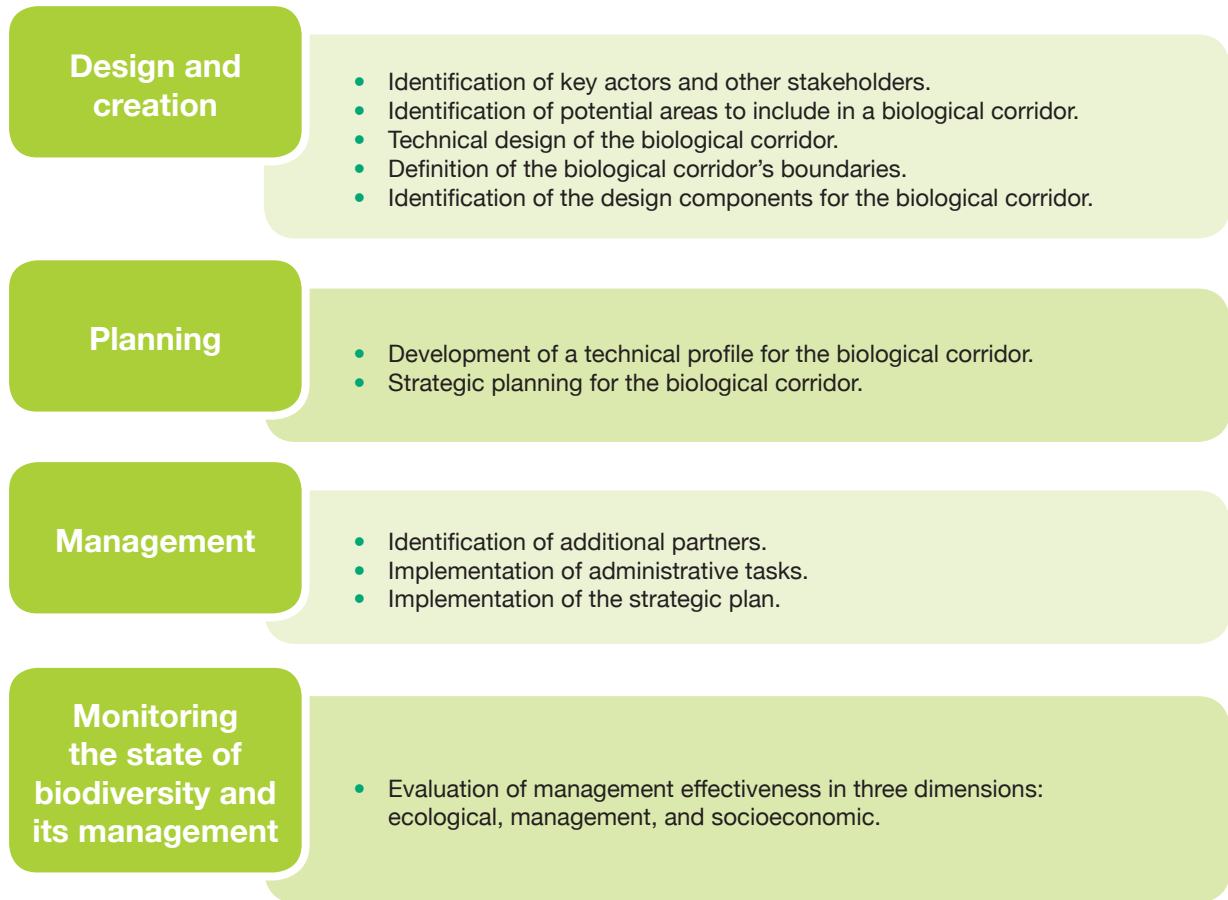
Photo: Bernal Herrera-F.

## Technical Guidelines for the Design, Creation, and Management of Biological Corridors

The process for the design and management of biological corridors has four stages: 1) design and establishment, 2) planning, 3) management, and 4) monitoring the state of biodiversity and management (Figure 1).

Initial steps of the first stage include the identification of key actors, potential areas to include in a biological corridor, and its boundaries. The second stage consists of developing a technical profile for the corridor, including a strategic planning process within which the biological corridor will be managed (Canet-Desanti 2007). In the third stage, the implementation of the strategic plan begins, including the continued inclusion of new partners and carrying out corridor management tasks. Last, monitoring measures both the state of biodiversity as well as that of management of the biological corridor (Canet-Desanti et al. 2008).





**Figure 1.** Technical guidelines for the design and management of biological corridors

In the following sections, we describe each step for the design, strategic planning, management, and monitoring the state of biodiversity and management in biological corridors.

## Design and Creation

To establish a biological corridor, it is necessary to identify areas important for the maintenance of biodiversity as well as local management opportunities and processes. This stage is fundamental, since it involves identifying the landscape of interest, conservation objectives, and a first stakeholder map of the future corridor, as well as key management issues (Chassot *et al.* 2013).

### Identification of Key Stakeholders

Given that a biological corridor should be a participatory and inclusive entity, managers must identify key actors, partners, and other stakeholders. They can come from public or private institutions, communities, NGOs, academia, among others. Multiple actors increase the diversity of perspectives that comes to bear on decisions as well as heightens understanding of expectations and the role that local people could play within the biological corridor initiative. Additionally, their involvement may reveal other conservation efforts within the proposed zone. It is also important to discover an organization with the potential to take the lead in managing the biological corridor (Canet-Desanti 2007).

## Identification of Potential Areas for the Creation of the Biological Corridor

Potential areas within a proposed biological corridor include public or private protected areas which could serve as core conservation areas. Other areas may also contribute to landscape connectivity as well as contain key flora and fauna. This process also analyzes threats to the identified areas (Chassot *et al.* 2013).

## Technical Design

Although there is no single formula for designing biological corridors, the ultimate goal is to re-establish or maintain connection between isolated ecosystem patches (Canet-Desanti *et al.* 2012). Nevertheless,

multiple other interests converge within these initiatives that demand attention when designing a strategy (Canet-Desanti 2007), including land use changes within the landscape (Chassot *et al.* 2010). Some aspects to consider in the biological corridor design stage include (SINAC 2008):

- Presence of protected areas to serve as core conservation areas.
- Presence of a mosaic with a favorable proportion of natural vegetative coverage necessary to re-establish connectivity.
- Concept of watershed management.
- Migratory patterns of target conservation species.
- Presence of important conservation sites.
- Utilization of natural boundaries (rivers, water bodies, watersheds, mountains, continental divides)

### Box 2. Stakeholder Identification

In mid-2001, the Great Green Macaw Research and Conservation Project, Tropical Science Center (TSC), Costa Rica-Mesoamerican Biological Corridor, Organization for Tropical Studies, and the Wildlife Conservation Society created the first core area of the San Juan-La Selva Biological Corridor. The Local Committee has since created annual operation plans. Organizations such as the MBC, GTZ, UNDP, and the Costa Rica-Canada Fund have made small donations to finance some early actions to set up the biological corridor. The corridor was created formally, without an institutional presence or incorporation into the structure of the Ministry of Environment and Energy. This allowed a more agile, direct, and consensus-based decision making. Thirteen organizations working in the area joined together at the Workshop to Create the Executive Committee of the San Juan La Selva Biological Corridor, (23 November 2001, Tirimbina, Sarapiquí). They were all interested in contributing to the corridor's implementation.

Their first act was to sign a symbolic, philosophical declaration of commitment. Since, new organizations have joined, strengthening activities in the biological corridor. Each has assumed specific responsibilities to achieve the objectives. From the beginning, the TSC managed the corridor's funds. Each organization has implemented a transparency policy with respect to all aspects of financial, administrative, and programmatic management (Villate *et al.* 2010).

The alliance chose the Great Green Macaw as the flagship species of the biological corridor. This charismatic megafauna enjoys the support of many people at the same time calling attention to its conservation objectives. It has also been the standard-bearer for awareness campaigns and fundraising among communities and institutions. The Great Green Macaw is the pride of the communities within the biological corridor.

One success factor has been TSC's office support. Little by little the growth of salaries of those charged with corridor management has sustained the initiative. The Local Committee has been open to all those interested in participating. There are no exclusive requirements for aspiring entrants aside from attending at least three meetings to confirm interest. After this requirement has been met, the institution submits a letter of interest in order to become a formal member.



- We recommend that planners include as wide an altitudinal gradient as possible to allow flora and fauna to adapt to climate change. They should also include forest ecosystem patches with a high ecological integrity, incorporating representative biodiversity elements, and greater ecosystem heterogeneity in the biological corridor (Heller and Zavaleta 2009).

## Definition of Biological Corridor Boundaries

In order to define a corridor's boundaries, one should consider the principal objective of structural connectivity. This outcome requires understanding of land use coverage, ecosystems, movement patterns for conservation targets, etc. Also we recommend the consideration of other ecological criteria such as size, ecosystem form, and socioeconomic criteria such as water sources and zones of influence for human settlements. These all help to define corridor boundaries (Canet-Desanti 2007).

## Components for the Design of Biological Corridors

Some criteria commonly used for the design of biological corridors are biophysical, political, social, economic, and land use management-related (Canet-Desanti 2007, SINAC 2008, González-Maya *et al.* 2010, Chassot *et al.* 2013). Herrera-F (2010) details the extent to which different components should be considered in the design of biological corridors:

**Biophysical and Ecological:** Biophysical data are fundamental to evaluating conservation impacts. Within this component are public and private protected areas of any management category; potential conservation sites; natural and transformed ecosystems that contribute to connectivity; sites or ecosystems of cultural importance; flora and fauna of note; or groundwater recharge areas. This category further includes geomorphological, topographic, edaphological, hydrological, and climatic characteristics within the corridor (Herrera-F 2010).

**Political and institutional:** This component refers to formal mechanisms for public involvement in planning processes, management, and evaluation; land use planning and governance in the area; also the legal and institutional framework (Herrera-F 2010).

**Socioeconomic:** This aspect includes different levels of social organization that occur in sustainable development and management, ecosystem and biodiversity services that benefit local communities and society, as well as opportunities and challenges for sustainable community development (Herrera-F 2010).

**Financial:** This refers to fundraising mechanisms and strategies to sustain long-term activities necessary to meet conservation and development objectives (Herrera-F 2010).

**Establishment of ecological networks of connectivity:** An ecological connectivity network is a spatial structure that links core areas and whose coordinates are defined by routes of least resistance for the movement of organisms (Ramos and Finegan 2007). Defining ecological networks first requires establishing network objectives based on models that identify optimal routes for connectivity (Céspedes *et al.* 2008). Ecological connectivity networks arise from the subjective evaluation of experts, but must also consider stakeholder input (Chassot 2010).

One procedure that has been widely used, at least in the context of research and development of new techniques led by CATIE, is to use algorithms with GIS combined with ecological theory and landscape ecology (e.g. Ramos and Finegan 2007, Céspedes *et al.* 2008).

Specifically, the procedure models networks of structural connectivity using three components proposed by Hctor *et al.* (2000) and Céspedes *et al.* (2008):

1. Identification of protected areas and priority habitat core areas for conservation that are not protected within the national protected area system.
2. Establishment of levels of difficulty for wild species to move through the entire intermediary area between protected areas which have been identified as target areas.

### Box 3. Technical Design of the San Juan-La Selva Biological Corridor

To design the San Juan La Selva Biological Corridor, planners studied geospatial data about Great Green Macaw nesting and migration patterns. Other factors included forest cover and fragmentation, natural boundaries (such as waterways), altitudinal range and groundwater recharge areas. Over time, they added to the map areas that responded to other needs such as those of community groups to form part of the biological corridor and connectivity proposals from the Costa Rican government, among others.

Part of the corridor's consolidation included the classification of land into three levels of public and private lands: a central protected area (Maquenque National Wildlife Refuge); a series of core areas (Tiricias-Crucitas, Astilleros-Sardinal and Arrependidos), or other priority areas that can serve as bridges for species that have extensive ranges; the corridor matrix which surrounds the central and core areas. This zoning protects the entirety of native species and fulfills the basic connectivity functions of the biological corridor, at the same time maximizing sustainable forest uses and benefits that come from environmental services.

**1. Principal protected area.** The principal protected area, the heart of biodiversity protection, is the Maquenque National Wildlife Refuge, a public property available only for non-consumptive uses. These uses include ecotourism, education, scientific research, and environmental services. Its management is defined based on its commitment to local communities. These areas remain in a natural state in order to protect species that depend on large native forest habitat blocks. The Refuge is closed to hunting, cutting, mining, and road construction, and provides, by way of ecosystem service payments, incentives for property owners to protect their forests.

**2. Core areas.** The corridor's core areas are blocks adjacent to the Refuge along the San Juan River (Tiricias-Crucitas) and two areas dispersed along the corridor's length (Cerros Astilleros-Loma Sardinal and Cerros Arrependidos). These areas enjoy high strategic value in terms of biodiversity, maintained by regulated land use. The strategic location of these two areas allow them to provide connectivity for species that require large home ranges in the Central Volcanic Mountain Range Conservation Area and the Indio-Maíz Biological Reserve in Nicaragua.

**3. Corridor Matrix.** The matrix is an extensive private land area: it extends 35 km from the Central Volcanic Mountain Range to the Nicaraguan border (excluding principal and core areas) and forms the primary basis for preserving the corridor's continuity. In this zone, management focuses on compatible economic uses including environmental services, plantations with native species, and ecotourism. Focused on low-impact human use, this part of the corridor allows the continued dispersal of native species.

3. Modeling of a network of connectivity integrated with priority core conservation areas across routes of lower displacement difficulty.

The identification of **core areas** uses among its principal criteria those sites that contain high species richness and offer a higher quality habitat, mainly protected areas and larger patches of ecosystem. Also criteria are used that describe the fragment shape, given the relationship between progressive degradation associated with border effects (Bennett 1998).

The **levels of displacement difficulty** that represent ecological connectivity are estimated based on different types of soils and human activities that take place there. The model assumes that the most difficult movement arises in those areas where the existing coverage or human activities differ most from natural conditions. For example, areas with high population density or high levels of vehicular traffic are those that make displacement most difficult; meanwhile areas with unaltered natural cover or very low population density imply the least difficulty.



In the model, difficulty values are determined based on four factors: land use, river networks, population density, and highway networks. The calculation of difficulty level for each of the variables is determined by the application of expert opinion and available ecological knowledge (Céspedes *et al.* 2008).

The **spatial modeling of connectivity routes** uses available algorithms in GIS and whose routine optimizes connectivity consistent with a series of criteria based on the movement resistance model. The spatial analysis generates a surface cost, using a point of origin and movement difficulty values for each unit in the matrix. The tracing of connectivity routes arises from a general rule that establishes that “any line necessarily should connect two protected areas which in turn represent core areas of biodiversity dispersal” (translated from Arias *et al.* 2008).

## Establishing a Biological Corridor Management Regime

The success of a biological corridor depends in great measure on its local committee (Villate *et al.* 2010). It is therefore necessary to define a group of people, institutions, and other stakeholders to manage the corridor. In order to achieve sustainability and objectives, we recommend that this multi-sector group have multiple levels of involvement (Canet-Desanti 2007, SINAC 2008, Chassot *et al.* 2013).

Once the group has been identified, it is important to establish an institutional management structure including responsibilities of each local committee member. Such members should change and the constant involvement of people and institutions will facilitate the initiative’s continuance. Wide stakeholder participation balances out diverse interests with respect to the use and conservation of natural resources within the biological corridor (Canet-Desanti 2007). In order that the local committee function more efficiently, we recommend that there be a coordinator to follow up on proposed activities and responsibilities by the local committee (Canet-Desanti *et al.* 2012).

The local committee’s functions must be defined. Some of the most important include the following: managing the biological corridor implies designing and managing administrative processes; financial management and that of all kinds of resources requires not only accounting procedures but also fundraising; strategic planning is another fundamental function as well as promotions and outreach; last, the local committee must monitor and analyze much information.

## Strategic and Operational Planning

Biological corridor planning is based on the accumulated experience of strategic planning and more recently on the adaptive management focus (CMP 2013). Methodologically, the Open Standards for Biodiversity Conservation (CMP 2013) is apt for planning biological corridors.

Samayoa (2014) presents five principles that guide biological corridor planning:

**Principle 1:** Biological corridor planning focuses on maintaining ecological integrity at the landscape scale in order to develop ecological processes and provide ecosystem services to improve human wellbeing.

**Principle 2:** High priority actions focus on the mitigation and control of principal sources of pressure and threats to conservation targets.

**Principle 3:** From design to implementation, planning demonstrates a high capacity for land management and knowledge including financial mechanisms that ensure sustainability.

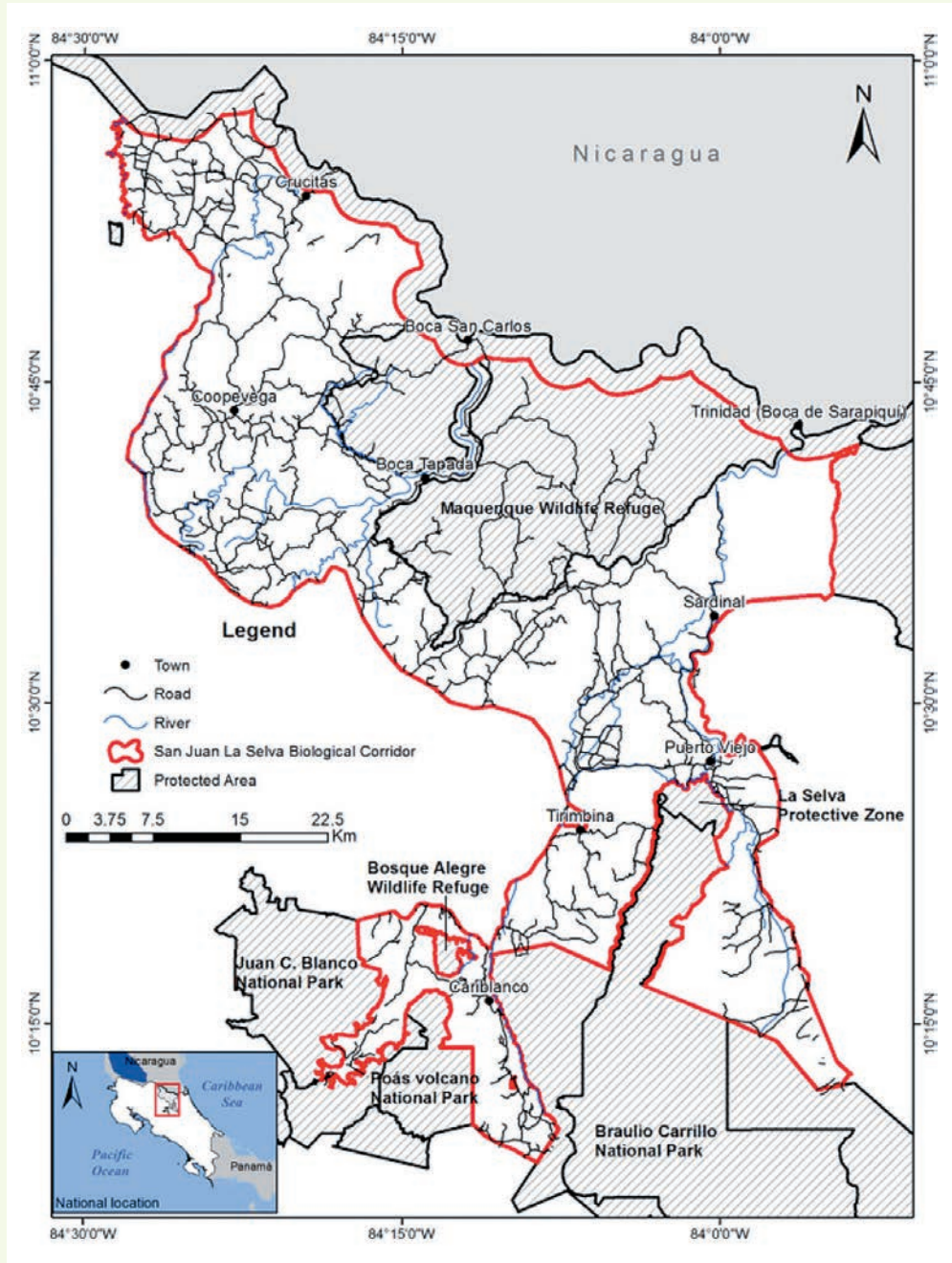
**Principle 4:** There are mechanisms that ensure public participation at a scale necessary to implement actions.

**Principle 5:** Monitoring and evaluation generate lessons learned to adjust objectives as necessary.

The following are general components of strategic planning for these conservation and sustainable development regimes.

### Box 4. Spatial Design of the San Juan La Selva Biological Corridor, Costa Rica.

This corridor connects tropical humid low-land forest patches of existing protected areas and priority core habitat on private property.





## Biological Corridor Technical Profile

A first step in implementing a biological corridor is the development of a corridor's technical profile (SINAC 2008). This profile synthesizes land use information in order to support better decision making. The profile highlights the corridor's importance, the resources it contains, its contextual tendencies, and some aspects to consider in the short-, medium-, and long-term. This information identifies threats and opportunities in developing the corridor (SINAC 2008, Canet-Desanti and Finegan 2010). This reference tool can also be used for general public information (Canet-Desanti 2007).

## Local and Regional Management Strategies

The planning process traces a path toward a desired conservation state. It prioritizes, proposes objectives, and designs strategies. Planning has three stages: 1) describe the current state, 2) define the desired state, and 3) create strategies. We recommend using the Open Standards for the Conservation of Biodiversity (CMP 2013) for this action planning. Some components are common to all strategic planning and thus can be applied to biological corridors (Herrera *et al.* 2013).

Using Open Standards as a reference as well as Herrera's proposal (2012), modified by Canet and Herrera (n.d.), the following stages should be completed when planning for conservation connectivity and locally sustainable development.

### I. Planning Process Organization

**Definition of the planning team.** The team should be multidisciplinary, multi-sectorial, and represent the entire geography of the corridor. Members should also have general understanding of biological corridors, a strong commitment to the plan development process, and the biological corridor in general.

**Values and philosophy.** The planning process should also address and identify core values and the operative organizational philosophy, in order to allow for the harmonization of actions aimed at reaching conservation goals. Values to be considered include

personal values of team members, values of the organization as a whole, organizational culture, groups of interests and stakeholders within and outside the organization (Chassot 2005, Chassot *et al.* 2013).

**Definition of boundaries.** Every biological corridor has geographic boundaries. During planning these should be defined, at least, preliminarily, if the design has not yet been completed. It should identify the planning horizon of the plan with a maximum of five years.

### II. Evaluation of the Current State of Biodiversity and the Socioeconomic Context

**Preliminary evaluation of the biological corridor context.** This step consists in evaluating the natural, social, cultural, and institutional aspects of the biological corridor, paying special attention to conservation targets and their strategies. By analyzing the site as a system and how resources are distributed, the evaluation should measure the impacts and results with respect to community wellbeing and ecosystem sustainability (Emery and Flora 2006, Bautista-Solis and Gutiérrez-Montes 2012).

**Priority of conservation targets.** Conservation targets are a reduced group of biodiversity elements whose conservation covers a wide range of associations, communities, and species in the biological corridor. Given that a corridor harbors a diversity of biotic and abiotic elements, planners must identify which of those contribute to the fulfillment of objectives to maintain landscape-scale connectivity and ecosystem viability as well as provision of ecosystem services.

**Evaluation of the state of conservation and conservation targets.** This phase compares the state of the conservation targets with desired states, in terms of both ecological integrity (in the case of ecological communities and systems) or viability (in the case of species [Granizo *et al.* 2006]). Herrera and Corrales (2004) present an evaluation methodology for protected area ecological integrity, which can also be used for biological corridors.

**Anthropogenic Threat Analysis.** This step identifies land and natural resource uses that degrade conservation targets. It is essential to prioritize all

threats and pressures that affect target ecological attributes as well as the anthropogenic sources of those pressures.

**Situation analysis.** Previous results (conservation targets and threats) are integrated into concept models along with analysis of key stakeholders in order to relate those threats with their associated actors. It further identifies opportunities to reverse the threats by working with the corresponding actors.

### III. Conservation Strategies that Promote Connectivity and Sustainable Human Wellbeing

**Vision.** A key early planning step is to define the vision for the corridor. The vision unites committee members by providing a management direction as well as a sense of pride. The visioning process should be collective involving as many stakeholders as possible. The goal is to construct a common but higher ground that integrates their different and individual perspectives in order that each can participate in achieving the objectives of connectivity and sustainable development of the biological corridor.

**Goals.** Goals aim to reduce the impact of threats on conservation targets and improve conditions to implement actions necessary to achieve them (i.e., capacity building, long-term financing). In general, factors such as the degree of corridor vegetative coverage and the maintenance of connectivity, a biological corridor should conserve or restore biodiversity and contribute to human wellbeing.

After defining goals, then a strategic plan requires actions that will achieve them. Being “strategic” means prioritizing actions using the most efficient and equitable means possible.

As well goals can be grouped into strategies that orient actions into thematic areas such as environmental education, biodiversity protection, restoration of connectivity, to name just a few.

One approach to formulating objectives is the use of results chains (CMP 2013). These chains

found in a conceptual model transform threats into factors in order to formulate goals. This technique makes explicit the causes behind the biodiversity threats which assists in the design of goals, objectives, and actions.

**Monitoring.** Monitoring refers to the collection, analysis, and distribution of information in order to continually improve biological corridor management. It measures follow up and evaluation of how plan implementation is proceeding as well as the impact on biodiversity. Ideally monitoring supports a learning process that then promotes strategic adaptation. Monitoring should also focus on management capacity as part of the overall corridor monitoring strategy.

It should be mentioned that the local committee should monitor impacts of climate change on biodiversity and ecosystems services within the corridor. Consequently, the corridor would also have climate change adaptation and mitigation strategies. Section 3.6 presents guidelines to this end.

## Biological Corridor Management

Effective management rests on continual planning and learning, based in public participation. This participation contributes to building and maintaining a shared, multi-sectorial vision that later leads to biodiversity conservation and ecosystem service objectives (Canet-Desanti *et al.* 2008, Herrera-F 2010).

As mentioned previously, management works to maintain ecological integrity and population viability by means of reducing sources of pressure without forgetting the wellbeing of resident communities. Since change is continuous in nature (Walker y Salt 2006, Walker y Salt 2012), we need to define guidelines for conservation and sustainability that are both dynamic and adaptive (Canet-Desanti *et al.* 2008).



## Box 5. Creation of a Local Biological Corridor Management and Strategic Planning in San Juan-La Selva

The Local Committee of the San Juan-La Selva Biological Corridor was officially formed in March, 2001 as a result of an alliance between the Tropical Science Center, the Wildlife Conservation Society, the Organization for Tropical Studies, the Mesoamerican Biological Corridor-Costa Rica, and the Great Green Macaw Research and Conservation Project. Likewise, in 2002, the Local Office of the San Juan-La Selva Biological Corridor was created in Puerto Viejo. The Committee has its headquarters at the Tropical Science Center in San José and assumes responsibility for coordinating and promoting the corridor. Currently, the Local Committee includes 24 organizations from government and civil society. It has been named by CATIE as the most advanced connectivity initiative within the Mesoamerican Biological Corridor. Each organization has clearly defined responsibilities within the Local Committee of the corridor.

### Planning

The Local Committee bases its fundraising on the its strategic plan. Given the diversity of donors and the relatively small amounts that they give, cash flow often fluctuates significantly. Another challenge is the voluntary participation of coordinators which has complicated project implementation. One alternative was to request that each member organization make a financial contribution. This would have helped to cover the salary of a project coordinator.

Furthermore, the composition of working teams varies constantly and depends on the focus of each project. Similarly, the membership of the executive committee varies over time, with some organizations participating much more than others. Currently the Tropical Science Center contributes in good measure to the salaries, office supplies (paper goods, computer, telephone, internet access, courier service, publicity, and office space), per diem, and transportation. In short, it supports a somewhat centralized structure for the management of the biological corridor. Nevertheless, given the size and complexity of the area, it is the only way to work given that no local organizations have the institutional capacity, interest, or geographic reach to assume the management of an area so large. The TSC, neither too big nor too small, enjoys certain prestige and can assume this central role (Villate *et al.* 2010).

During a corridor's early years, managers must focus on consolidation. Some principal functions include forging of strategic alliances, promoting the corridor's existence, defining work plans, carrying out environmental education, and offering trainings for corridor users. Financial sustainability is fundamental for achieving corridor objectives as well as ensuring following over time (Canet-Desanti 2007, Canet-Desanti *et al.* 2012).

Activities that strengthen human capital and focus on the inhabitants of the corridor are also fundamental management tasks. Among these activities are environmental education, trainings especially in schools, directed at local production groups and small business-people. Interchanges are a valuable technique. The local committee also must focus on implementing projects not just within the committee, but also along with users of

the corridor. These efforts concentrate on strengthening natural capital with forestation, restoration of degraded habitat, wildlife management, biological monitoring without forgetting training and environmental education (Canet-Desanti 2007).

## Conservation and Management Monitoring

Monitoring is a pillar of conservation and development. It measures biodiversity impacts caused both by planned actions and other human activity (Canet-Desanti *et al.* 2012). Monitoring can verify management efficiency and effectivity as well as achievements and weaknesses and, as necessary, implement corrective

## Box 6. Biological Corridor Management

The executive committee supervises two natural resource specialists from the Tropical Science Center. It also uses consensus to approve projects when it meets ten times a year (generally not in January and some other month that also has significant other activities going on). The meetings occur between San Carlos y Sarapiquí, depending on the location of the host organization. Sometimes it even meets in San José. Participation is voluntary, but the committee requests justification for not participating. The degree of attendance depends greatly on the location of the meeting. It generally enjoys the participation of 10–12 organizations, which is generally higher than it was in 2007. This indicates a growing interest by local organizations in the alliance.

The Local Committee has involved communities in these meetings to contribute to important decisions. This promotes local ownership. Other positive aspects of this management network include the involvement of many stakeholders, especially small and local organizations, close to the problems. This has led to greater resource acquisition as well as diversity of opinions; Because NGOs and government agencies work together, there has not been much need for bureaucratic structures. Finally, this is about a horizontal alliance in which participants retain their autonomy and participate in projects. As such greater commitment and responsibility toward management results (Villate *et al.* 2010).

actions to adjust strategies (Finegan *et al.* 2007, Finegan *et al.* 2008, PNUD 2009).

Canet-Desanti *et al.* (2008) developed a methodology to evaluate management effectiveness in biological corridors, using a tridimensional standard: ecological, socioeconomic, and management-related. A complete version of this approach can be found in Canet-Desanti (2011). The reader should consider that this methodology, although it generates important results, must be linked to the biological corridor strategic planning process to be most effective.

The ecological dimension seeks to understand the population viability of natural communities as well as the continuity of ecological landscape processes (Canet-Desanti *et al.* 2008). It also evaluates whether implemented actions have contributed to the reduction of fragmentation, conservation of biodiversity, improvement of connectivity, viability of wildlife populations and communities, reduction in human impacts, and the degree to which environmental services have been provided (Canet-Desanti *et al.* 2008).

The management dimension identifies the degree to which the biological corridor has increased consolidation through a diverse and multi-sectoral public participation (Canet-Desanti *et al.* 2008). This is measured by the participation of different actors, institutional development of the corridor, as well as implemented conservation strategies (Canet-Desanti *et al.* 2012).

The socioeconomic dimension identifies if the quality of life of those who live in the corridor improves by way of conservation, sustainable use, and environmentally friendly practices (Canet-Desanti *et al.* 2008). It measures the degree to which actors in the corridor contribute to conservation, if the biological corridor concept helps people in this pursuit, if they implement actions that reverse anthropogenic impacts that threaten biodiversity, if communities sustainably manage their own resources, and if natural resource conservation contributes to elevate quality of life of corridor inhabitants (Canet-Desanti *et al.* 2012).

Ecological monitoring, moreover, is that “process which determines the state and trends of biodiversity within the management objectives of the area” (SINAC 2007).

In this way, it evaluates factors that affect communities, species, ecological and evolutionary processes that prove relevant for conservation.

It further foresees and prevents undesirable changes by adopting management mechanisms that slow those changes (Chediack 2009). Monitoring, then, is “a continuous process of collecting, analyzing, and disseminating appropriate information about a specific set of variables or indicators, to improve the management of a given system” (SINAC 2007).

The first step in developing an ecological monitoring program is to define the objectives and variables (program indicators). These can be species, habitat, and community characteristics. Then, managers define monitoring methods. The program further needs to establish a baseline for the current state of the biological corridor. Also important is the identification of pressures and threats to selected objectives (SINAC 2007).

## Climate Change Planning

Biological corridors are a conservation strategy deployed across a landscape offering a range of opportunities for biodiversity and human mitigation and adaptation in the face of climate change (Groves *et al.* 2012). Protected areas and other forest ecosystems mitigate climate change by storing carbon. From the point of view of adaptation, they also serve to prevent natural disasters, protect biodiversity, provide potable water, store genetic diversity and sources of food as well as provide ecosystem services to rural communities (MacKinnon *et al.* 2011).

Given that biological corridors promote ecological connectivity, some regard them as a principal strategy for facilitating climate change adaptation, given that corridors allow for species dispersal between different habitats as environmental conditions change (Heller and Zavaleta 2009). They also promote biodiversity

### Box 7. Biological Corridor Management Evaluation and Monitoring

Consistent with results from the biological corridor management evaluation tool (see Canet *et al.* 2008 for the methodological details) in Costa Rica’s San Juan La Selva Biological Corridor, “the different social sectors that make up the biological corridor contribute to natural resource conservation; thanks to the attitude that people have about natural resource conservation, it is possible to conserve; local groups implement actions to reverse anthropogenic threats to biodiversity; communities sustainably manage their natural resources; conservation contributes to increasing the quality of life for those who live within the biological corridor.” The current legal and political framework supports the consolidation of the biological corridor in the long term; the support and participation of diverse actors contribute to reaching a sustainable management process.

Since natural systems are complex and knowledge about them limited, the corridor initiative includes species and biological process monitoring, based on scientific methods. Basic information is imperative in order to better assess the current biological status of the area now and in the future.

The Great Green Macaw has been the flagship species and primary indicator species of the corridor. Its population has been monitored within the biological corridor since 1994. Its change in breeding population is a principal indicator of corridor success, given the corridor’s dependence on this species. One monitoring strategy involves marking adults and juveniles with microchips during the breeding season in order to identify breeding individuals in succeeding years.



governance, natural resources management, forest cover increases, forest landscape fragmentation reduction, and improved agricultural practice, all of which constitute climate change mitigation strategies (Heller and Zabaleta 2009).

Planning covered in the previous section can include climate change among its strategies for adaptation and mitigation. Piedrahita (2013) in fact proposes a methodology for this which we detail below.

## **Climate Change Adaptation: Evaluation and Strategies**

According to the IPCC in its fourth report (2007),  $Vulnerability = Potential Impact - Adaptive Capacity$ . Understanding these terms is key to evaluating the nature and magnitude of climate change as a threat, detecting principal sources of climate vulnerability, and identifying actions to reduce or stop threats. Based on the results of this vulnerability, adaptation strategies can be designed.

By analyzing the exposure and sensitivity of biodiversity to changes in the climate, understanding of potential impacts ensues. This step requires that investigators evaluate vulnerability and identify what kind of data they have (studies, evaluations, climatological databases, models). Potential impacts are not the same for all regions and can target different aspects of the system. Besides, the potential impact of climate change will affect biodiversity at different scales from genes all the way to biomes (Bellard *et al.* 2012).

To analyze a biological corridor's sensitivity across different climate change scenarios must depend on historic climate data. Analysts must research changes in different components of biodiversity. In the case of biological corridors, any change to ecological processes associated with connectivity will be, by definition, priority.

Different models exist to evaluate possible future conditions. The outputs of these models, nevertheless, are not exact, but do guide researchers in their understanding how future states might look (Glick *et al.* 2011).

Adaptive capacity or autonomous biodiversity adaptation includes evolutionary changes and ecological responses to those changes. In order to estimate this kind of capacity, the following variables should be considered: genetic diversity, evolutionary rates, dispersal and colonization ability (Glick *et al.* 2011). Given the estimate's complexity and difficulty, adaptive capacity can also be interpreted as the human capacity to manage, adapt, and reduce impacts on biodiversity (Williams *et al.* 2008).

Piedrahita (2013) suggests the use of both management and socioeconomic indicators to evaluate adaptive capacity. These indicators indirectly measure the degree to which society facilitates biodiversity adaptation to climate change. For example, for the Bellbird Biological Corridor, Piedrahita selected indicators related to representativeness of different participant sectors, degree of leadership in decision-making, financial support of corridor management, quantity and quality of biodiversity conservation activities, collaboration of biological corridor tasks with those of protected areas, representation of organizations whose principal objective is to strengthen natural capital, awareness and environmental education focused on natural resource conservation and climate change, and, finally, if local residents assist animal migration through their terrains.

### **Design of Adaptation Strategies**

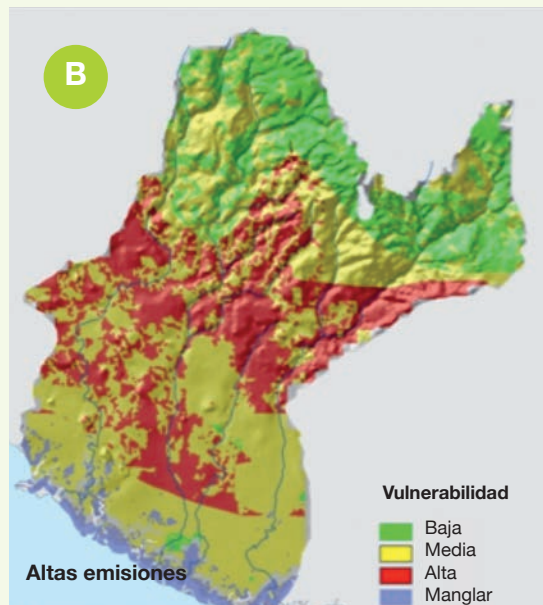
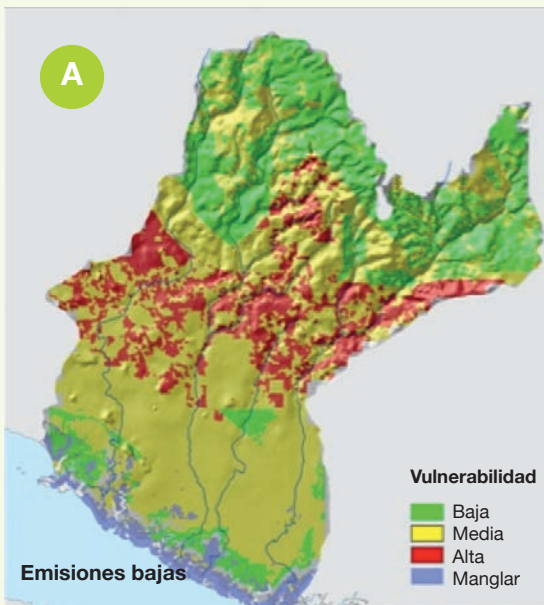
Adaptation strategies reduce vulnerabilities within the biological corridor in the face of climate change (Piedrahita 2013). They include a wide range of strategies, summarized by Heller y Zavaleta (2008). Some of the most recommended in the literature include restoration of connectivity, habitat conservation, increased habitat size, species translocations, as well as those that improve human capacity and attitudes toward climate change.

### Box 8. Climate Change Vulnerability Analysis of the Bellbird Biological Corridor, Costa Rica (adapted from Piedrahita 2013)

The Bellbird Biological Corridor is located on the Pacific slope of Costa Rica with an altitudinal range from sea level to 2,500 m. In order to design adaptation strategies, potential climate change impacts were estimated. Researchers used four indicators to measure these impacts. At the ecosystem scale, they used an index for leaf cover as well as indices for fragmentation such as core area, patch size, distance of closest patch, number of patches, and patch density. At the species level, they measured the potential distribution of several species chosen for their threat level, endemism, and national importance. They considered climate scenarios B1 and A2 (IPCC 2007) and evaluated the adaptive capacity indirectly with indicators associated with human-facilitated biodiversity adaptation.

For both scenarios, the most vulnerable sector within the B1 emissions scenario is found in the middle altitudes of the corridor, while the low zone shows generally medium vulnerability values with some sectors showing low values.

At the highest elevations, the lowest values dominate, although some zones show medium values principally due to a high adaptive capacity. It is anticipated that the impacts in these high zones will be elevated.





## Climate Change Mitigation: Strategies and Opportunities

Climate change mitigation seeks to reduce greenhouse gases by protecting and promoting carbon sinks through soil and habitat management (IPCC 2007). Both ecosystem conservation and restoration reduce unsequestered carbon in the atmosphere. It is estimated that around 428 Gt of carbon are stored in forests and soils (Secretariat of the Convention on Biological Diversity 2009).

Biodiversity supports processes that sequester carbon in natural systems. Poorter *et al.* (2015) report that tropical forests, that cover 7–10% of the planet's surface and house more than 95% of the world's tree species, store 25% of the terrestrial carbon in biomass.

Biological corridors, as Herrera notes (2016), are opportunities to establish mitigation projects, such as REDD+.

These participatory projects not only imply greater impact, but also can integrate into other conservation and sustainable development strategies (Herrera 2016). This author also points out that biological corridors can also achieve political goals. For example, since 2010, the Government of Costa Rica has directed most of its forest-conservation environmental service payments to biological corridors.

## Synergies between Adaptation and Mitigation

Herrera (2016) presents a methodological guide that integrates the design of biological corridors with potential synergies between biodiversity and carbon capture at the landscape scale. This proposal can be combined with the methodology proposed in section 3.1 in order to achieve synergy between adaptation and mitigation.



Photo: Bernal Herrera-F





Photo: Olivier Chassot

## Final thoughts: The Way Forward

The detailed guidelines in this document have emerged over a decade through basic and applied research. This has been a participatory process involving local actors in Costa Rica who have participated in managing connectivity. Thus, the institutionalization of these programs at the regional and national levels (e.g. SINAC 2008 y ICF 2013) has been key to the development of land use management. This does not require only scientific information, but also national and international cooperation to ensure that connectivity conservation becomes institutionalized. This implies at the same time that there must be technical assistance at the local and national levels for public participation to occur and achieve its objectives (Perrens 2013). Costa Rica's experience has showed the need for organizations to take the lead of biological corridor management which may be more important than institutional participation (Canet 2007).



Biological corridors can integrate land use and biodiversity conservation. They can integrate different social sectors involved in land use planning (for example, municipalities) as well as national and local organizations interested in conservation and sustainable development. Corridors are inherently designed to integrate different aspects of land use, such as protected areas and productive uses. Corridor development, then, should value contributions of the productive sector to biodiversity conservation. Also these public participation forums can serve as negotiation space between organized groups in order to increase awareness and appreciation for biodiversity.

Despite important efforts, there are still significant holes in understanding. The work of Perrens (2013) is a first attempt to understand the benefits and financial mechanisms in biological corridors. Nevertheless, more investigation and investment are needed for this kind of strategy to work. Greater capacities along these lines

are also needed as well as the integration of actors and innovative mechanisms.

Although there exists sufficient evidence that demonstrates the importance of biological corridors, it is still necessary to generate even more about functional connectivity and how this can be integrated into management. From the conservation biology point of view, actions that maintain and conserve ecological connectivity should continue as an evidence-based adaptive process.

One theme that requires additional research and study is the governance of these platforms for social interaction to manage biological corridors. This theme underlies all conservation strategies. It is not sufficient to just have financial, technical, and administrative skills, if governance has not been properly explored. This is an area, therefore, that should be studied in the near future when designing biological corridors.







Photo: Olivier Chassot

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Photo: Bernal Herrera-F.

## Glossary



**Autonomous adaptation:** “Adaptation that does not constitute a conscious response to climatic stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation”. (IPCC 2007).

**Biodiversity:** ‘Biological diversity’ means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystems. (CBD 1992).

**Biological corridor:** A geographic region composed of core and interconnecting areas that, within different spatial configurations, maximizes and ensures connectivity of this region. It also constitutes a space for public participation to define objectives for the rational use of biodiversity that maintain the ecological processes that sustain biodiversity, related ecosystem services, and the benefits that these generate for local communities and society in general (Herrera-F 2010).

**Biological monitoring:** Method that describes changes in species and ecosystems over time as well as the consequences they suffer due to human influence. With this information, one can predict and prevent undesirable changes and adopt management strategies to mitigate those changes.

**Buffer Zone:** Usually surrounds or adjoins the core areas, and is used for cooperative activities compatible with sound ecological practices, including environmental education, recreation, ecotourism, and applied and basic research. In addition to the buffering function related to the core areas, buffer zones can have their own intrinsic, ‘stand-alone’ functions for maintaining anthropogenic, biological, and cultural diversity. They can also have an important connectivity function in a larger spatial context as they connect biodiversity components within core areas with those in transition areas (UNESCO 2014).

**Connectivity conservation:** Connectivity conservation management is a strategic approach that helps to link habitats across whole landscapes, which can enable species and their ecosystems to move or adapt as conditions change. Connectivity conservation is a way of maintaining connections for nature by involving people (Pulsford *et al.* 2015).

**Connectivity of ecological networks:** Connectivity between two or more core areas that emerge through different land uses and present only a minor barrier to species movement as well as the adaptive capacity to resist environmental and climatic changes and pressures (Céspedes *et al.* 2008).

**Conservation targets:** Biodiversity elements around which conservation strategies are planned. Targets can be species, ecosystems, or ecosystem services, among others. They represent the biodiversity of a biological corridor and therefore direct management action (Granizo *et al.* 2006).

**Core zone or area:** Securely protected sites for conserving biological diversity, monitoring minimally disturbed ecosystems, and undertaking non-destructive research and other low-impact uses (such as education). In addition to its conservation function, the core area contributes to a range of ecosystem services, which, in terms of the development functions, can be calculated in economic terms (for example, carbon sequestration, soil stabilization, supply of clean water and air, and so on). Employment opportunities can also complement conservation goals (for example, environmental education, research, environmental rehabilitation and conservation measures, recreation and ecotourism) (UNESCO 2014).

**Ecological monitoring:** An approach that determines the state and trends of some biodiversity component within the management framework of an area.

**Ecological or landscape connectivity:** Degree to which a landscape facilitates or impedes movement of organisms among resource patches (Taylor *et al.* 1993).

**Ecosystem services:** Benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other non-material benefits (Hassan *et al.* 2005).

**Ecosystem:** A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (CBD 1992).

**Fragmentation:** The division of continuous natural habitats into smaller fragments that remain separate from one another, principally due to changes in land use and conversion into agricultural and urban systems (Fahrig 2003). It is a dynamic process characterized by notable changes in habitat patterns within a given period of time (Bennett 2004). Important attributes of the fragments or patches include density, distance, size, form, aggregation (spatial distribution), and boundaries (Lord and Norton 1990).

**Functional connectivity:** Connection between habitat patches and their inhabitants by means of dispersal, allowing movement and dispersal of individuals among the patches (With *et al.* 1999).

**Functional landscape:** A landscape that conserves a great number of ecological systems, communities, and species within the natural range of variability

across all scales up to the regional (local, intermediate, and broad) (Lambeck y Hobbs 2002).

**Indicator:** A unit of information measured over time that documents changes in a specific condition. A given goal, objective, or additional information need can have multiple indicators. A good indicator meets the criteria of being measurable, precise, consistent, and sensitive.

**Landscape mosaic:** The portion of the landscape that is composed of the dominant type of land coverage.

**Landscape:** An area of land that contains a mosaic of ecosystems, including human-dominated ecosystems (Hassan *et al.* 2005).

**Patch viscosity:** The degree to which a landscape permits or impedes individuals from displacing across a landscape.

**Protected area:** A clearly defined geographical space, recognized, 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).

**Structural connectivity:** The spatial distribution of different types of habitat in a landscape, influenced by the appropriate continuation of habitat, distance between one habitat and another, and the existence of alternative routes, whether corridors or landscape matrix (Bennett 2004, Uezu *et al.* 2005).



The Tropical Agricultural Research and Higher Education Center (CATIE) is a regional center dedicated to research and graduate education in agriculture, and the management, conservation and sustainable use of natural resources. Its members include Belize, Bolivia, Colombia, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Venezuela, the Inter-American Institute for Cooperation on Agriculture (IICA) and the State of Acre in Brazil.



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