Begins 1 July 2019

Deadline 30 September 2019

GLOBAL ONLINE CONSULTATION

(Draft) ***Guidance for safeguarding ecological corridors in the context of ecological networks for conservation***

Review of this Consultation Draft

Who:
On behalf of the IUCN World Commission on Protected Areas (WCPA), the Connectivity Conservation Specialist Group (CCSG) is fielding input from *individuals and institutions* to improve the (Draft) ***Guidance for Safeguarding ecological corridors in the context of ecological networks for conservation***.

What and why:
There is now a large and growing body of scientific literature on biological, ecological, and applied research related to connectivity conservation and how it functions for biodiversity and ecosystem maintenance. IUCN has been working for over two decades to incorporate these scientific underpinnings into more coherent large-scale conservation measures that conserve, restore, and complement protected and conserved areas (aka OECMs). The 2016 IUCN World Conservation Congress, by adopting Resolution 2016-087, invited IUCN Members and governments to focus attention on an advanced draft of existing guidelines for connectivity conservation, and to work toward further development, designation, planning, and management of connectivity areas and expanded networks.

Efforts to establish these consistent global approaches for connectivity conservation has progressed well since 2016. Based on the advanced draft, a series of consultations was held around the world in 2017 under the auspices of the CCSG. Based on feedback from the consultations, collaboration among a core group of lead authors and experts throughout 2018 and early 2019 resulted in this revised draft that seeks to clarify and standardize approaches for protecting the physical spaces that connect protected and conserved areas, enhance comprehensive management through overarching ecological networks, and thus improve large-scale conservation outcomes.

How:
This draft is being disseminated across IUCN, WCPA, CCSG, and wider networks to gather specific input to inform revision and eventual publication in the IUCN WCPA Best Practice Protected Area Guidelines Series in 2020. Here's how to contribute:

- A survey form will be available online here https://forms.gle/6RvPCSbijWEbWEx6A for providing comments between the dates of 1 July - 30 September, 2019. Please note that only comments using this form can be considered when making future revisions. All respondents are also made aware that the survey software does not support saving the form and returning to it later until it is actually submitted. Therefore, we have formatted the survey to provide a unique link to each respondent that will allow access and editing after clicking "Submit Form". You must however save the "Edit this form" link (e.g. bookmark and/or send via E-mail) to have the opportunity to return to your individualized survey, advance to the sections where you left off, and continue input.
- Comments are sought primarily regarding additions and clarifications on substantive issues.
- In anticipation of future stages of work, additional suggestions for case studies are greatly appreciated with focus on highlighting best-practices in connectivity conservation management.
- Editorial comments are not necessary, because the document will be thoroughly edited and proofread before publication.
- This consultation is being distributed to approximately 1,000 recipients around the world. The comment form has been designed to help focus and manage responses. If necessary, please include links to more information

When:

- The survey will be activated on 1 July 2019 and all comments received by 30 September 2019 will be reviewed and considered by the core group of lead authors. However, it is not anticipated to reply to all comments unless further clarification is required. All those contributing will be acknowledged in the final document.
- Final publication (following peer review, formal IUCN approval, and layout) is foreseen by May 2020 for wide dissemination and official launch at the 2020 IUCN World Conservation Congress (Marseille, France 11-19 June).

About IUCN WCPA's Best Practice Protected Area Guidelines Series

This is the world's authoritative source for protected areas policy and management. Through collaboration and contributions from dedicated experts, the publications support institutional and individual capacity to manage protected area systems effectively and equitably, and to support better approaches in the field. Additionally, they support national governments, protected areas agencies, non-governmental organizations, communities, and private sector partners to meet their commitments and goals, especially in regard to the Convention on Biological Diversity's Programme of Work on Protected Areas.

(DRAFT) GUIDANCE

Safeguarding ecological corridors in the context of ecological networks for conservation

Contents

IUCN

Founded in 1948, the International Union for Conservation of Nature (IUCN) is an international membership organisation uniquely composed of both government and civil society organisations. It has evolved into the world's largest and most diverse environmental network. IUCN harnesses the experience, resources, and reach of its 1,300 Member organisations spread across 179 countries and the input of some 10,000 experts. Uniquely, it brings together States, government agencies, and a diverse range of non-government organisations in a world partnership.

As a Union, IUCN provides public, private, and non-governmental organisations with the knowledge and tools that enable human progress, economic development, and nature conservation to take place together. It seeks to influence, encourage, and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable. IUCN builds on the strengths of its members, networks, and partners to enhance their capacity and to support global alliances to safeguard natural resources at local, regional, and global levels.

IUCN is the global authority on the status of the natural world and the measures needed to safeguard it. Its experts are organised into six commissions: species survival, environmental law, protected areas, social and economic policy, ecosystem management, and education and communication.

The ability to convene diverse stakeholders and provide the latest science, objective recommendations, and on-the-ground expertise drives IUCN's mission of informing and empowering conservation efforts worldwide. It also provides a neutral forum for working together globally and locally to forge and implement solutions to environmental challenges.

The World Commission on Protected Areas (WCPA)

IUCN's World Commission on Protected Areas (WCPA) is the world's premier network of protected area expertise. Working collaboratively with IUCN's Global Protected Areas Programme (GPAP), the Commission has more than 2,500 members, spanning 140 countries. WCPA is one of six voluntary Commissions of IUCN and is administered by the GPAP at IUCN's headquarters in Gland, Switzerland. WCPA's mission is to promote the establishment and effective management of a worldwide representative network of terrestrial and marine protected areas, as an integral contribution to the IUCN mission. WCPA works by helping governments and others plan protected areas and integrate them into all sectors, providing strategic advice to policy makers and practitioners to help strengthen capacity and investment in protected areas, and convening the diverse constituency of protected area stakeholders to address challenging issues. For more than 50 years, IUCN and WCPA have been at the forefront of global action on protected areas.

NOTE: The views expressed in this publication do not necessarily reflect those of IUCN or other participating organisations.

ADVANCED DRAFT STATUS: This document is (*Draft) Guidance on safeguarding ecological corridors in the context of ecological networks for conservation*. As part of its drafting, this guidance was based on inputs and comments generated in two previous iterations led by Graeme Worboys as a *Preliminary Draft* (December 2015) and as a *Consultation Draft* (January to May 2016).

From additional inputs and comments received between June 2016 – April 2019, including in-person consultations held with members and interested stakeholders in Australia, Canada, India, Kenya, Romania, and Tanzania, it has been edited by a small editorial group comprising Jodi Hilty (Canada), Graeme Worboys (Australia), Annika Keeley (Germany/US), Stephen Woodley (Canada), Barbara Lausche (US), Harvey Locke (Canada), Mark Carr (US), Ian Pulsford (Australia), James Pittock (Australia), Will White (US), Dave Theobald (US), Jessica Levine (Canada), Melly Reuling (US), Rob Ament (US), and Gary Tabor (US/Australia).

CITATION: When referenced this document should be referred to as:

Hilty, J., Worboys, G., Keeley, A., Woodley, S., Lausche, B., Locke, H., Carr, M., Pulsford I., Pittock, J., White, W., Theobald, D., Levine, J., Reuling, M., Ament, R., and Tabor, G. (May 2019). (*Draft) Guidance on safeguarding ecological corridors in the context of ecological networks for conservation*. Gland, Switzerland: IUCN.

Foreword

[By CBD Executive Secretary and IUCN Director General]

Acknowledgements

This guidance is a principal output of the IUCN World Commission on Protected Areas Connectivity Conservation Specialist Group (CCSG), established in 2016, and contributes toward fulfilment of IUCN Resolution WCC-2016-Res-087 “Awareness of connectivity conservation definition and guidelines”. A considerable number of individuals and organisations have supported this collective effort. We are grateful to the staff at the Center for Large Landscape Conservation for their leadership in supporting the development of these standards and organising the global consultation process.

During the development process, CCSG members and other experts provided much valuable feedback, information, and case studies. Appreciation is expressed for contributions and assistance made so far directly and indirectly to the development of this manuscript by (case study contributors are marked with an asterisk): Sirili Akko (Tanzania), James Allan (Australia), Irene Amoke (Kenya), Gillian Anderson (Australia) Henry Bailey (UK), Mark Baker (UK), Damien Bell (Tanzania), David Beroff (US), Nina Bhola (UK), Sophie Bickford (Australia), Julian Blanc (UK), Mary Bonet (Australia), Keith Bradby (Australia), Peadar Brehony (UK), Sue Brieschke (Australia), Lorraine Briggs (Australia), Silvia Ceppi (Italy), Jumapili Magotto Chenga (Tanzania), Sarah Chiles (US), Peter Cochrane (Australia), Isabelle Connolly (Australia), Rose Crane (Australia), Tyler Creech (US), Laury Cullen* (Brazil), Tim Davenport (UK), Jon Day (Australia), Bob Debus (Australia), Teresa di Micco De Santo (Kenya), Steve Dovers (Australia), Liz Drury (Australia), Todd Dudley* (Australia), Susie Duncan (Australia), Nathan Eamon (New Zealand), April Eassom (UK), Ancuta Fedorca* (Romania), Sue Feary (Australia), Simon Ferrier (Australia), Penelope Figgis (Australia), Kathleen Fitzgerald* (US), James Fitzsimons (Australia), Erica Fleishman (US), Charles Foley (UK), Adam Ford (Canada), Mridula George (Australia), Liz Gould (Australia), Larry Hamilton (US), Ruth Hardy (Australia), David Harmon (US), Ian Harrison (UK), Peter Hetz (US), Marc Hockings (Australia), Gary Howling (Australia), Tim Hughes (Australia), Brooke Hynes (Australia), Peter Jacobs (Australia), Moses Jaokoo (Kenya), Bruce Jeffries (Australia), Menna Jones (Australia), Rob H.G. Jongman* (The Netherlands), Aditya Joshi* (India), Angella Kangethe (Kenya), David Kilonzi (Kenya), Chris Klemann* (The Netherlands), Naomi Kingston (Ireland), Margaret Kinnaird (US), Bill Laurance (US), Sadiki Lotha Laiswer (Tanzania), Annette Lees (New Zealand), Laly Lichtenfeld (US), Marcelo Lima (Brazil), Belinda Low Mackey (UK), Arianne Lowe (Australia), Brendan Mackey (Australia), Ireene-Rose Madinou (Kenya), Alphonce Mallya (Tanzania), Ally-Said Matano (Kenya), Meredith McClure (US), Mel McRoberts (Australia), Dismas Meitaya (Tanzania), Nick Mitchell (UK), Heather Moorcroft (Australia), Magnus Mosha (Tanzania), Philip Muruthi (Kenya), Sheetal Navigire* (India), Kimani Ndung’U (Kenya), Genevieve Northey (New Zealand), Silvanus Okudo (Tanzania), Robert Olivier (UK), Leslie Olonyi (Kenya), Ezra Onyango (Kenya), Milind Pariwakam* (India), Belinda Parkes (Australia), Lesley Peden (Australia), Exper Pius (Tanzania), Johannes Refisch (Germany), David Rush (Australia), Meinrad Rweyemamu (Tanzania), Chira Schouten (Tanzania), Samwel Shaba

(Tanzania), Rachael Scrimgeour (UK), Kanyinke Sena (Kenya), Craig Shafer (US), Neovitus Sianga (Tanzania), Makko Sinandei (Tanzania), Cate Tauss (Australia), Kim Taylor Thompson* (Canada), Michele Thieme (US), James Tresize (Australia), Peter Tyrrell (Kenya), Srinivas Vaidyanathan* (India), Jacqueline Williams (UK), Lucy Waruingi (Kenya), Hui Wan* (China), Dave Watson (Australia), Jacky Williams (Australia), Mike Williams (Australia), Hannah Wood (UK), Jeff Worden (Kenya), Carina Wyborn (Australia), Virginia Young (Australia), Edoardo Zandri (Italy), Dorothy Zbicz (US), and Kathy Zischka (Australia). [...]

Acronyms

CBD	Convention on Biological Diversity
CCSG	Connectivity Conservation Specialist Group of WCPA
CMS	Convention on Migratory Species of Wild Animals
COP	Conference of the Parties
EU	European Union
GPAP	IUCN Global Protected Areas Programme
IUCN	International Union for Conservation of Nature
OECM	Other Effective Area-based Conservation Measure or Conserved Area
SSC	IUCN Species Survival Commission
UN	United Nations
UNEP	United Nations Environment Programme
WCPA	IUCN World Commission on Protected Areas

Glossary of terms

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

Conserved Area: (See 'OECM' below)

Ecological connectivity (sometimes referred to in shorthand as connectivity): The movement of populations, individuals, genes, gametes (mature male or female haploid germ cell that can unite with another of the opposite sex), and propagules (pollen, plant parts, and seeds) between populations, communities, and ecosystems as well as non-living material from one location to another.

Ecological corridor: A clearly defined geographical space, not recognised as a 'protected area' or an 'other effective area-based conservation measure (OECM or conserved area)', that is governed and managed over the long-term to conserve or restore effective ecological connectivity, with associated ecosystem services and cultural and spiritual values (*See* below section on the definition of ecological corridors for further details).

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

Ecological network for conservation: A system of protected areas, conserved areas, and ecological corridors, which is established to conserve biological diversity (*See* Ecological Networks for Conservation section later in this paper for further detail).

Ecosystem: A dynamic complex of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit (CBD Article 2, 1992).

Ecosystem functioning: The collective life activities of plants, animals, and microbes and the effects these activities - feeding, growing, moving, excreting waste, etc. - have on the physical and chemical conditions of the environment (Naeem et al., 1999).

Ecosystem services: The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth (Millennium Ecosystem Assessment, 2005).

Ecosystem structure: The biophysical architecture of an ecosystem; the composition and arrangement of all the living and non-living physical matter at a location (Russi et al., 2013).

Flyway: The entire range of a migratory bird species (or groups of related species or distinct populations of a single species) through which it moves on an annual basis from the breeding grounds to non-breeding areas including intermediate resting and feeding places as well as the areas within which the birds migrate (Boere & Stroud, 2006).

Governance authority: The institution, individual, Indigenous Peoples or communal group, or other body acknowledged as having authority and responsibility for decision-making over an area, and that may include management of an area (IUCN WCPA, 2019; Borrini-Feyerabend, et al., 2013).

Governed: Implies that the area is under the authority of a specified entity or entities. Ecological corridors can be governed under the same range of governance types as protected areas (*See* section below "Governance of the Ecological Corridor" for more detail).

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

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

Landscape: A heterogeneous space comprising a cluster of interacting ecosystems, including terrestrial and freshwater components, geology, and ecological processes, and often including human influences (Forman & Godron, 1986; Wu, 2008). Landscapes are generally large, but can be defined at a range of spatial scales.

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

Managed: Assumes some active steps to conserve or restore the natural (and possibly other) values for which the ecological corridor was established; note that "managed" can include a decision to not actively manage the area (*See* also below section on management required to achieve objectives).

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

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

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

OECM (Other Effective Area-Based Conservation Measure or 'Conserved Area'): A geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity with associated ecosystem functions and services and where applicable, cultural, spiritual, socio–economic, and other locally relevant values (IUCN WCPA, 2019).

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

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

Resilient: In the context of ecological networks for conservation, the term refers to the capacity of a part or the whole of an ecological network to respond to a perturbation or disturbance by resisting damage or recovering.

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

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

Seascape: A spatially heterogeneous marine region that can be delineated at a range of scales and includes oceanographic, geologic, and chemical properties. It can be a combination of adjacent coastline and sea such as mangroves, coral reefs, seagrass beds, tidal marshes, and deep seas. It includes the features of the geology and morphology of the sea floor as well as the living communities of the benthos, water column, and surface, and it often includes the influence of humans (Figure 1; Pittman, 2017; Fuller, 2013). Seascapes are generally large, but can be defined at a range of spatial scales.

Structural connectivity: A measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances, and other land- or seascape elements presumed to be important for organisms to move through their environment (Hilty et al., 2019).

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

System of protected, conserved areas, and ecological corridors: The total of protected areas, other effective area-based conservation measures (OECMs, aka conserved areas), and ecological corridors in a region of conservation focus.

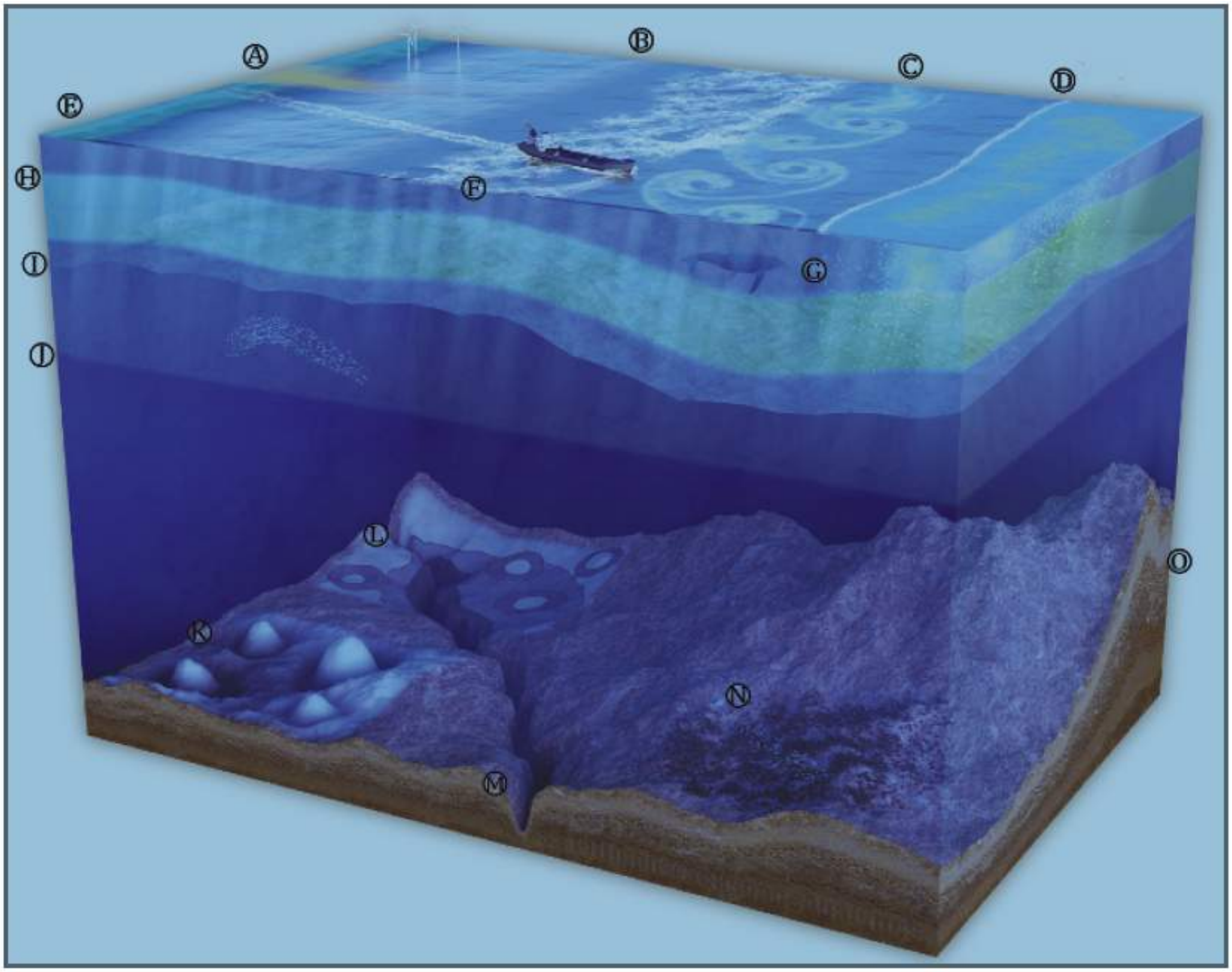

Figure 1. Seascape showing spatial structure in the sea: A. Runoff plume; B. Temperature front; C. Eddies with entrained phytoplankton; D. Thermal front; E. Salinity gradients; F. Surface roughness; G. Plankton patches; H. Thin horizontal layer of plankton; I. Internal wave; J. Thermocline; K. Seafloor terrain morphology from bathymetry (three dimensional); L. Benthic habitat map representing patch-mosaic patterns (two dimensional); M. Geological features (canyons and seamounts); N. Within-patch structure (biological assemblages); O. Surficial sediment and geological strata. (From Pittman, 2017 with permission from authors and John Wiley and Sons).

1. Introduction

The following guidelines have been drafted to help guide the global shift in conservation practice from that of individual protected area conservation to that of large landscape and seascape conservation. Around the world, we are seeing conservation planning and implementation occurring at larger spatial extents, aiming to accomplish conservation across many different jurisdictions. In the IUCN literature we have seen the emergence of terms like ecological networks, corridors, and connectivity. We aim to clarify and standardize this shift in conservation and these concepts, discuss how they interrelate with other long-standing tools such as protected areas, and new tools such as other effective area-based conservation measures (OECMs, hereafter also referred to as conserved areas). Finally, to address the need for a common guidelines regarding connected protected areas, we formalise a new tool that protects areas needed to conserve connectivity between protected and conserved areas. While many conservation efforts seek to address the need for large landscape and seascape conservation both within and across countries, IUCN has not yet defined all elements of ecological networks for conservation, a concept long-discussed by IUCN (Bennett, 2003). This document seeks to provide clarity about the purpose of ecological networks for conservation and defines the physical spaces that function to connect protected and conserved areas, as well as other areas deemed important for conservation. A common understanding of the conservation tools that promote conservation at the large scale at which many ecological processes and many species function, is essential for guiding planning, decision-making, management, and policy.

Do areas that conserve connectivity need a new and separate standard?

A fundamental question relating to connectivity areas is whether IUCN needs to establish a new conservation designation that would recognize conservation status to connectivity areas. Part of the confusion is that both protected and conserved areas may provide for connectivity within their boundaries. However, neither of these tools allows for the creation of bounded areas strictly to conserve connectivity, while allowing other compatible human activities (Table 1). There is an outstanding need to identify and conserve areas of importance for connectivity that are neither protected nor conserved areas (Tabor et al., 2019). Given this outstanding need, it is of critical importance to recognize a new conservation designation to ensure that protected areas and landscapes across multiple tenures are effective in conserving species and maintaining ecosystem functions. This is because it is widely recognised that the survival of many species and ecosystems relies on the ability of plants and animals to move and adapt as conditions change and meet their seasonal requirements, and these requirements often extend beyond the boundaries of protected areas (UNEP-WCMC, IUCN & NGS, 2018).

Table 1. Similarities and differences between protected and conserved areas, and ecological corridors. Ecological corridors only need to achieve their defined connectivity objectives. Protected and conserved areas *may* provide connectivity but *must* provide in-situ conservation.

	Protected Area	Conserved Area (OECM)	Ecological Corridor
Must conserve in-situ biodiversity	X	X	
Can conserve connectivity	X	X	X

Must conserve connectivity			X

The call for connectivity as a separate and distinct conservation element can be found in the Aichi Biodiversity Targets, the Convention for Biological Diversity Guidance Documents, the World Business Council for Sustainable Development Call to Action for Landscape Connectivity 2017, and in the Guidelines for Applying Protected Area Management Categories (Dudley, 2008). In 2010, the parties to the United Nations Convention on Biological Diversity (CBD) adopted a Strategic Plan for Biodiversity for the 2011–2020 period which included the twenty Aichi Biodiversity Targets (CBD, 2011). Aichi Target 11 states that by 2020 the terrestrial area under protection will be increased to at least 17% in ‘effectively and equitably managed, ecologically representative and well-connected systems of protected areas’ (CBD, 2011). Currently, all protected areas combined add up to approximately 15% of the terrestrial area (Saura et al., 2018), thus approaching the CBD’s 2020 target of 17%. However, recent studies measuring the degree of connectedness of protected areas determined that only about half of the protected area can be considered connected (Saura et al., 2017, 2018). Most countries lag significantly behind the Aichi Target 11 connectivity element.

With increasing human alteration of the earth, coupled with rapid climate change, we must think and act at the larger spatial scales at which many species and processes actually operate; this is the scale of land- and seascapes. Moving from individual protected and conserved area conservation to land- and seascape conservation requires the inclusion of the areas that connect protected and conserved areas, and other areas important for biodiversity. Therefore, areas that only conserve connectivity need to be a new and separate conservation entity, with their own guideline. Providing a clear definition of ecological networks for conservation and guidelines on how to establish, measure, and report ecological corridors will aid countries in reaching the connectivity element such as spelled out in Aichi Target 11. Considering the importance of ecological networks to preserve the ecological values of protected and conserved areas, it is important for all parties to recognize ecological corridors in order to be successful in nature conservation.

2. Background

Habitat loss and fragmentation are causing the loss of biodiversity worldwide, and climate change is exacerbating this problem. Today we face what many scientists are referring to as the 6th mass extinction. We are seeing species loss, decreasing population sizes, and significant range contractions caused by human development and activities that will have negative impacts on ecosystem functions and services. These changes are happening on a more rapid time scale than previous extinctions (Ceballos et al., 2017). Protected areas, such as national parks, have long been the primary focus of conservation. Starting in the 1960s, the area of land and sea included in protected areas has increased exponentially (Figure 2). Nevertheless, biodiversity loss has continued to accelerate. One reason for this continued loss is that most protected areas are not large enough to maintain species or ecological processes within their boundaries (Newmark, 1987). As adjacent areas experience increasing human impacts, the habitat outside of protected areas is lost, and the protected areas themselves become more isolated. Species that used to move into and out of protected areas during their daily movements, during migration, or to find new home ranges will not be able to do so anymore. If the climate becomes unsuitable in an isolated protected area species will not be able to move to find newly suitable habitat. Thus, isolation negatively impacts populations and the communities and ecosystems comprised of those populations, and may ultimately lead to species extinctions.

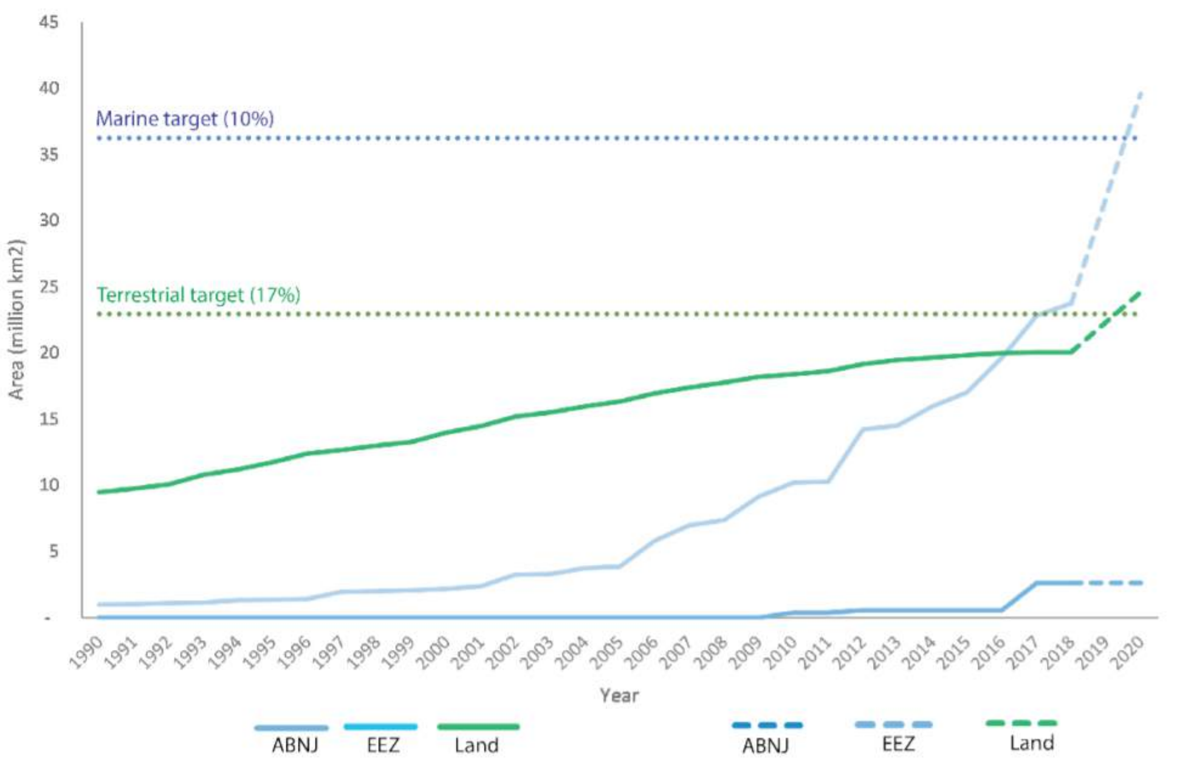

Figure 2. Growth in protected area coverage on land and in the ocean (EEZ and ABNJ) between 1990 and 2018 and projected growth to 2020 according to commitments from countries and territories. ABNJ: Areas Beyond National Jurisdiction (>200 nautical miles from the coast); EEZ: Exclusive Economic Zones - marine areas under national jurisdiction (0-200 nautical miles from the coast). Conserved areas are new and therefore not incorporated into the figure. (From UNEP-WCMC, IUCN, and NGS, 2018)

Protected and conserved areas themselves can provide connectivity such as among different habitat patches or resources that fall within their boundaries. However, connecting protected and conserved areas, and other areas important for biodiversity can increase their effective size and thereby reduce extinction risk (Newmark et al., 2017). Therefore, improving or sustaining connectivity among protected and conserved areas is key for the effective conservation and management of biodiversity. In the face of climate change, connectivity becomes even more important, because many species can respond to climate change by moving to climatically suitable areas. As the climate changes in a protected area, resident species may need to move to find newly suitable habitat, ultimately resulting in species' range shifts. Similarly, other species may need to be able to reach protected areas because they will offer newly suitable habitat.

Conservation practitioners and scientists have demonstrated that conservation of species, ecosystems, and habitats can only be achieved if protected areas are functionally connected (Trombulak & Baldwin, 2010). Although connecting protected and conserved areas has not been proven to strengthen conservation in every situation and other factors may at times limit their effectiveness, connectivity has been demonstrated as an important, if not essential, component. Conservation strategies that maintain biodiversity in human-modified landscapes/seascapes beyond protected area borders are essential (Hilty et al., 2019).

Ensuring that reserves are functionally connected is important in and among terrestrial, freshwater, marine, and aerial environments (Hilty et al., 2019; Marine Protected Areas Federal Advisory Committee Products, 2017). Examples of organisms and processes that move between these realms are anadromous fish that move from the sea up rivers to spawn, amphibians that inhabit multiple ecosystems during different life stages, and butterflies (e.g., monarch butterflies, *Danaus plexippus*) that use numerous ecosystem types in their continental scale, trans-generational migration. Processes that occur across realm boundaries include nutrient cycles, and natural disturbances such as flooding.

Ecological connectivity may have temporal aspects, for example where migratory species are involved on a seasonal, annual, or multi-year cycle. Usually, movement occurs in all directions, but there are instances of unidirectional movement, such as during long-term climate change when species shift their ranges pole ward or upslope. Connectivity can be protected at a variety of spatial scales, from small scales (e.g., streams, coral reefs, and sea grass beds) to regional and even continental scales (e.g., chains of islands, mountains, major river systems, and deep-sea hydrothermal vent ecosystems). Thus, connectivity conservation can occur at both local and regional levels. Many large-scale conservation visions seek to connect protected areas on land, in freshwater, and in the ocean (Figure 3). Approaches for implementing these visions are already well established. Notable examples include Baja to Bering, Great Eastern Ranges Initiative in Australia, Europe’s Natura 2000 Protected Area Network, Amazon Freshwater Connectivity, Yellowstone to Yukon Conservation Initiative, and Vatu-i-Ra Seascape in Fiji. (For more information and examples, see the Appendix and Hilty et al., 2012.) The connectivity guidelines described in this document builds on those efforts.

3. Ecological networks for conservation

a. Definition of ecological networks for conservation

(also referred to by other terms; *See* Table 2)

An Ecological Network for Conservation is a system of protected areas, conserved areas, and ecological corridors, which is established to conserve biological diversity. Ecological Networks for Conservation are more effective (i.e., in achieving biodiversity conservation objectives) than a collection of individual protected and conserved areas because they connect populations, maintain ecosystem functioning, and are more resilient to climate change. Connect (in the context of ecological connectivity) refers to the enabling of movement by individuals, genes, gametes, and/or propagules (*See* glossary of terms for definitions of other key terms used within this definition).

Table 2. Other terms that have been used to describe what this guidance document calls "ecological networks for conservation" (sorted alphabetically).

Term	Example
Area of connectivity conservation (ACC)	The Great Eastern Ranges Initiative is an effort to establish a conservation corridor that may encompass a range of land uses –such as agriculture, industry and human settlements –in addition to protected and conserved areas.
Biological corridor	Mesoamerican Biological Corridor: initiated in the 1990s to maintain biological diversity, reduce fragmentation and improve the connectivity of the landscape and ecosystems in Central America and southern Mexico[1].
Conservation lands network	In the San Francisco Bay Area of California, USA: a regional prioritization of connected lands that are important for the protection of biodiversity[2].
Conservation management network	Land-based networks for conservation of threatened ecological communities and remnant vegetation. They are supported through a network of landowners/land managers and the community[3]. The term is commonly used in Australia.
Ecological network	Dutch National Ecological Network: a network designed to link nature areas more effectively with each other, and with surrounding farmland[4]. The term is commonly used in Europe.
Territorial system of ecological stability	In the Czech Republic, an interconnected complex of both natural and near-natural ecosystems that maintain natural balance[5].
Marine protected areas network (MPAs)	Connected MPA networks can be found in, for example Australia and off the coast of California (California Marine Protected Areas Network)[6, 7].

[1] Ankersen, 1994; Ramírez, 2003.
[2] Bay Area Open Space Council, 2011.
[3] Context Pty Ltd., 2008.
[4] Jongman & Bogers, 2008.
[5] Jongepierová et al., 2012.
[6] Carr et al., 2017.
[7] Alameny et al., 2009.

Transboundary conservation areas (TBCAs)	These are defined as ecologically connected areas that cross international boundaries and contain protected areas. Research on TBCAs has been ongoing for more than 25 years, and the concept has been recognized by both IUCN and the Convention on Biodiversity.

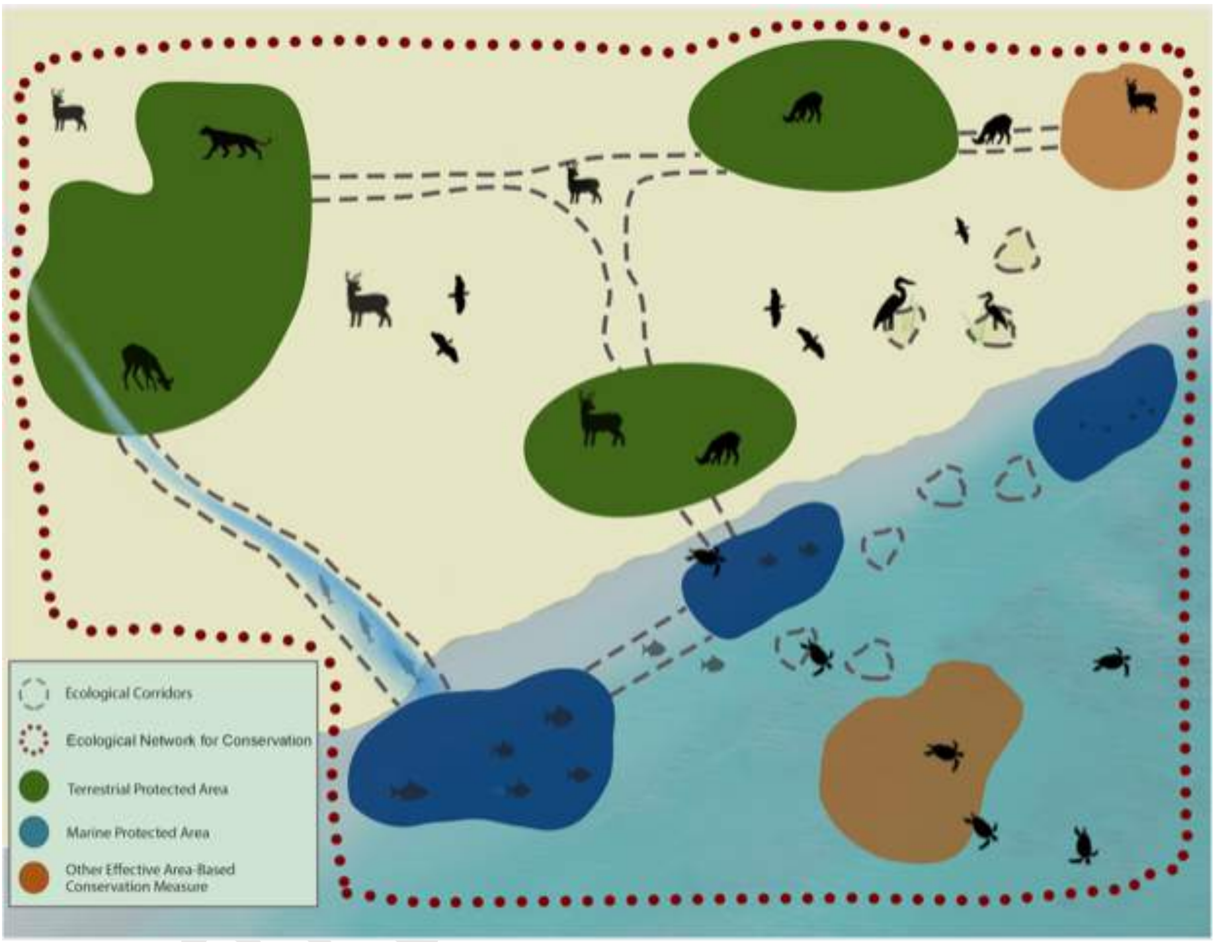

Figure 3. A conceptual representation of an ecological network for conservation. Terrestrial protected areas are in dark green. Marine protected areas are in dark blue. Conserved areas are represented in tan. Ecological corridors, both continuous and stepping stones, are outlined with dashed lines. The ecological network for conservation is represented by the dotted red line.

b. Characteristics of effective ecological networks for conservation

Protected areas cannot maintain all species in the long term when they are isolated (Noss & Harris, 1986). Individual protected areas are rarely big enough to maintain minimum viable populations of large, wide-ranging species; small protected areas will not even support populations of small animals over extended periods (e.g., Henderson et al., 1985). Protected areas also do not adequately cover the range of ecosystems necessary to protect biodiversity in different regions. Globally, terrestrial protected areas are disproportionately located at high elevation; highly productive areas are generally not well protected (Pimm et al., 2018). Marine protected areas are disproportionately located in coastal or near-shore waters, with a few large deep-water marine protected areas being created in recent years in waters within national jurisdiction (UNEP-WCMC & IUCN, 2019). In addition, existing terrestrial protected areas are increasingly isolated from other such areas (Wittemyer et al., 2008) and that isolation increases the risk of species extinctions within the protected areas (Newmark, 1995, 2008; Brashares et al., 2001; Parks & Harcourt, 2002; Prugh et al., 2008). The relationship between isolation and extinction is founded in the theory of island biogeography and metapopulation theory (MacArthur & Wilson, 1967; McCullough, 1996; Hanski, 1999); many subsequent studies support these theories. The theory of island biogeography states that on an island the rate of new species arrival and the rate of species extinctions depend on the size and shape of the island and its distance from the mainland. This concept has been transferred from islands to mainland ecosystems where isolated protected areas and conserved areas are like islands in the ocean, separated by an uninhabitable matrix. In reality the matrix is more of a filter whereby some species can use or pass through the matrix and others cannot. Metapopulation theory explains that spatially separated subpopulations are connected internally, as well as with other subpopulations by individuals moving among the subpopulations leading to genetic exchange and the possibility of re-establishing a subpopulation that was extirpated. Together these theories support the conclusion that bigger and more well-connected areas are more likely to maintain higher biodiversity over time, supporting the need for ecological networks in large landscape and seascape conservation.

Ecological networks for conservation consist of two main elements, 1) protected and conserved areas and 2) ecological corridors. Ideally, when designing ecological networks, systematic conservation planning is employed to identify the minimum set of sites needed to protect the most biological diversity in a given region (Margules et al., 1988). Targets for conservation, which may include focal species, Key Biodiversity Areas, population sizes, or habitat areas, are set and the ecological network for conservation is optimized to contain these targets, while also considering their spatial configuration. Appropriate protected and other conserved area sizes depend on ecological and landscape/seascape factors and today are often constrained by existing ownership or resource use rights and human activities across the landscape or seascape. To ensure that individuals can move between individual protected and conserved areas in an ecological network, distances between them ideally should be minimized and the area between should be managed so as to maintain ecological connectivity. The latter is important in order to allow individuals to move among patchy resources and among populations/subpopulations and to facilitate seasonal migrations. Ecological corridors are also important to facilitate dispersal movements which ensure genetic diversity and permit recolonization after populations have gone extinct in a protected or conserved area. Finally, ecological corridors help maintain ecological processes such as pollination and seed dispersal between otherwise isolated protected and conserved areas.

Ecological networks for conservation have been recognized as a means to help species respond to climate change. When well designed, ecological networks can enable species to shift their ranges to newly suitable habitats and climatic conditions. Conservation strategies that make ecological networks more effective to facilitate adaptation to climate change include increasing the number and size of protected and conserved areas, managing habitats to increase their resilience, establishing or widening connectivity areas, locating reserves in areas of high heterogeneity, and spanning elevational gradients (Heller & Zavaleta, 2009; Elsen et al., 2018). Of the different climate adaptation strategies, increasing the amount of conserved habitat is one of the most effective ones (Synes et al., 2015, Table 3). However, habitat should be conserved throughout the landscape or seascape, instead of increasing the size of a few, isolated protected and conserved areas (Hodgson et al., 2012). Connectivity areas between protected and conserved areas can also effectively facilitate range expansion, especially when they are wide and contribute to connecting protected and conserved areas that together contain temperature gradients. These might be connecting lower to higher elevation sites, inland to coastal areas, sites at different latitudes, different ocean depths, or even salinity gradients (*See* section 4e). The Appalachian Mountains in the eastern United States are an example of a mountain range critical for facilitating pole-ward movements (Lawler et al., 2013). An example from the Albertine Rift region of Africa shows how elevational and latitudinal connectivity is being conserved (Ayebare et al., 2013; Plumptre et al. 2016). In summary, ecological networks for conservation can help protect genetic diversity to enhance the capacity of species to survive, respond, and adapt to environmental change.

Table 3. Advantages and disadvantages of strategies to facilitate range shifts with ecological networks for conservation (adapted from Keeley et al. 2018).

Strategy	Advantages	Disadvantages
Increasing the amount of suitable habitat throughout the land- &seascape	Increases speed of range shifts in fragmented land- &seascapes; benefits most species	
Concentrating suitable habitat in few, large areas	Increases species persistence for some species	Slows speed of range shifts
Adding connectivity areas between natural or protected areas	Increases speed of range shifts in fragmented land- & seascapes; benefits most species	Potential investment trade-off between protecting a connectivity area and increasing a protected area; Most effective for species with medium dispersal capabilities in moderately fragmented land- & seascapes with lower climate velocity
Creating small stepping stones embedded in the matrix	Increases speed of range shifts in fragmented land- & seascapes	Benefits select species capable of using stepping stones.
Increasing the size of existing protected areas	Increases size of existing protected areas; increases species persistence; improves temporal connectivity for some species	May not facilitate connectivity to other resources wildlife needs; may not provide adequate space for species to move with climate change.

4. Ecological corridors

The concept of ecological corridors (i.e. for wildlife) or enhancing connectivity between protected and conserved areas has been around for many decades. Unlike protected areas, connectivity, and how to achieve it, has not yet become a clear and globally accepted standard. Because ecological corridors are a key component of ecological networks for conservation, the following seeks to define both terms and tools for connectivity.

First, we offer a summary of how ecological corridors are different than other components of ecological networks for conservation and are **not a substitute or a replacement for protected or conserved areas**. Rather, ecological corridors provide specific complementary connectivity value to protected areas and conserved areas (Table 4). The prime purpose of an ecological corridor is to facilitate a defined type of ecological connectivity between and among protected and conserved areas. **Ecological corridors may support a variety of human activities that practice sustainable use including farming, forestry, grazing, hunting, fishing, and other resource extraction, as long as they are also managed for, and effectively achieve, the identified ecological connectivity objectives.**

Protected areas remain the indispensable cornerstone of biodiversity conservation. Complemented by conserved areas, protected areas can provide core habitats for species to breed, rear young, interact within community dynamics, and find secure habitat to adapt to climate change. In most instances, ecological corridors will connect protected core habitats. However, in some regions, an ecological corridor designation may be needed to funnel the migration of species, such as sea turtles and pelagic fish, through bottleneck zones that do not necessarily connect to protected areas or conserved areas.

It should be noted that connectivity may already be effectively conserved *within* protected and conserved areas through specific management objectives. In these cases, the connectivity function is considered part of the protected or conserved areas and does not need an ecological corridor designation. However, in many cases it may not be feasible for areas important for connectivity to be designated as protected or conserved areas because the area does not meet protected or conserved area standards, or because such formal designation is not a priority of a government or desired by the landowner(s) or rightsholder(s).

Humanity will not meet the global objective of conserving biodiversity without ecological connectivity. The guidelines provided in this document normalize and define ecological corridors. Ecological corridors along with protected and conserved areas will help ensure that all life on earth flourishes in the face of the major global and environmental transformations underway.

Table 4. Similarities and differences between ecological corridors, conserved areas, and protected areas (PAs).

	Ecological Corridors	Conserved Areas (OECMs)	Protected Areas
Key Differences	Sites dedicated to a defined objective of ecological connectivity that may be managed for a variety of other outcomes that do not impair the connectivity objectives. Sites are neither protected nor conserved areas. It is recognised that both, protected and conserved areas, can and do provide ecological connectivity. Ecological corridors are sites that provide only connectivity for defined elements and are institutionally less complex.	Sites that result in the effective conservation of nature regardless of their management objectives. Sites are not protected areas but provide ecological outcomes equivalent to protected areas.	Sites dedicated to the conservation of nature, where the protection of nature is always the overriding objective of management.
Defining Elements			
a. Geographically defined space	An ecological corridor should be clearly delineated as a geographically defined space, with clearly demarcated boundaries by the entity(ies) governing the ecological. These boundaries may sometimes be defined by physical features that move over time, such as river banks or sea ice. The mechanism for an ecological corridor to move in time and space may be articulated in the management approach. Although the size of ecological corridors will vary, an ecological corridor should be large enough to	Geographically defined space implies a spatially defined area with agreed and demarcated borders, and includes land, inland waters, marine and coastal areas or a combination of two or more of these. These borders can sometimes be defined by physical features that move over time, such as a river banks or sea ice. While the size of conserved areas can vary, they should be large enough to achieve the *"in-situ* conservation of biodiversity", as defined by the CBD.	Geographically defined space implies a spatially defined area with agreed and demarcated borders, and includes land, inland water, marine and coastal areas or a combination of two or more of these. These borders can sometimes be defined by physical features that move over time (e.g., river banks) or by management measures such as zoning. While the size of protected areas varies, they should be large enough to achieve their conservation objectives.

	achieve its specific ecological connectivity objectives over the long term. An ecological corridor may be discontinuous (stepping stone corridors) provided that the objectives, governance, and management are the same across the segments.		
b. Not recognised and reported as a protected area or an OECM	Ecological corridors are separate conservation entities from either an OECM or a PA and should not be part of either. Ecological corridors are meant to provide a defined type of ecological connectivity between PAs and/or OECMs.	Areas that are already designated as protected areas or lie within protected areas should not also be recognised or reported as OECMs. While protected areas and OECMs are mutually exclusive at any point in time, both protected areas and OECMs have value for biodiversity conservation and some OECMs may be recognised as protected areas instead of OECMs over time.	The IUCN definition of a protected area is: A clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values. The CBD definition of a protected area is: a geographically defined area which is designated or regulated and managed to achieve specific conservation objectives.
c. Governed	As with protected areas and OECMs, governance of ecological corridors can be by any of the four IUCN governance types. Governance arrangements need to be clearly articulated in the ecological corridor documentation. As with PAs and OECMs, governance should strive to be ‘equitable’ and accord with human rights norms recognised in international and regional human rights instruments and in national legislation. Any recognition of ecological corridors should require the free, prior and	Governed implies that the area is under the authority of a specified entity. OECMs can be governed under the same range of governance types as protected areas, namely: governance by governments (at various levels); shared governance (i.e. governance by various rights holders and stakeholders together); governance by private individuals, organisations or companies; and governance by indigenous peoples and/or local communities. As with protected areas, the governance of OECMs should strive to be ‘equitable’ and accord with	IUCN envisages four distinct types of governance: governance by governments (at various levels); shared governance (i.e. governance by various rights holders and stakeholders together); governance by private individuals and organisations; and governance by indigenous peoples and/or local communities.

	informed consent of the relevant governing bodies. Ecological corridors will often be in private governance types with arrangements based on, for example, land owner agreements, conservation easements, and part of lease agreements.	human rights norms recognised in international and regional human rights instruments and in national legislation. Any recognition of OECMs should require the free, prior and informed consent of the relevant governing bodies.	
d. Managed	Management within an ecological corridor is required to retain, restore, or enhance ecological connectivity of the ecological corridor. There could be many more allowable human activities within an ecological corridor than in a PA or OECM, as long as those activities do not impact the defined connectivity value of the ecological corridor. Management will be context specific depending on the defined connectivity objective. For example, a multipurpose ecological corridor which is designed to facilitate the movement of all species due to climate change would need many more prohibited uses than an ecological corridor which is focused on facilitating the movement of a single species at a specific time of year.	'Managed' specifies that the area is being managed in a way that leads to positive biodiversity conservation outcomes. This means that an area where there is no management regime is not an OECM. Therefore, areas of open ocean without management or control and areas currently in a natural or near-natural state should not be considered as OECMs. 'Managed' can include a decision to leave the area untouched. The management of OECMs should include 'effective means' of control of activities that could impact biodiversity, whether through legal measures or other means (such as customary laws and sanctions).	Assumes some active steps to conserve the natural (and possibly other) values for which the protected area was established; 'managed' can include a decision to leave the area untouched if this is the best conservation strategy. Protected areas must have a 'legal or effective means' of control. This means that protected areas must either be gazetted (that is, recognised under statutory civil law), recognised through an international convention or agreement, or else managed through other effective but non-gazetted means, such as through recognised traditional rules under which community conserved areas operate or the policies of established non-governmental organisations.
e. Long-term	Ecological corridors are expected to persist in the long term. This can be demonstrated in the expected longevity of the governance arrangements. Some governance mechanisms may be time-limited and subject to	OECMs are expected to be governed and managed over the long term (i.e., in perpetuity) in ways that deliver the *in-situ* conservation of biodiversity. OECMs do not result from short-term or temporary management strategies. For	Protected areas should be managed in perpetuity and not as a short-term or temporary management strategy. Temporary measures, such as short-term grant-funded agricultural set-asides, rotations in commercial forest management or temporary

	formal periodic renewal. Such cases can demonstrate longevity by specifying that renewal is highly likely, including that it has happened before.	example, a fishing closure which stays in place only until an overfished area recovers, is not a long-term measure. Seasonal arrangements (e.g., sites for migratory bird species) may qualify as OECMs if they are managed long-term and contribute to year-round *in-situ* conservation of biodiversity.	fishing protection zones are not protected areas as recognised by IUCN.
f. Effective	Monitoring and evaluation should be implemented to ensure the ecological corridor is meeting the defined connectivity objectives. Monitoring and evaluation should support an adaptive approach to ecological corridor management, inform changing climate impacts, aid in effective resource allocation, promote accountability, and increase public awareness of and support for the ecological corridor	OECMs should demonstrate ***effective*** sustained *in-situ* conservation of biodiversity. This may include strict protection or certain forms of sustainable management consistent with the CBD definitions of "*in-situ* conservation" and "biodiversity". Practical steps must be in place for reporting on, monitoring and evaluating OECMs.	Implies some level of conservation effectiveness. Although the PA category will still be determined by the objective, management effectiveness will be recorded on the World Database on Protected Areas and over time will become an important contributory criterion in identification and recognition of protected areas.
g. In-situ conservation	Ecological corridors do not require a focus on in-situ conservation, or conserving nature as a whole. The focus of an ecological corridor is to allow a defined type of connectivity and this can range from simple to complex ecological conditions. For ecological corridors aiming at multi-generation connectivity, they may specify that it be done through approaches of in-situ conservation. These types of ecological corridors may be more similar to OECMs or even	OECMs are expected to conserve species within broader ecosystems and habitats as opposed to focusing on a single species or groups of species, without also protecting the wider environment.	The CBD defines '*in-situ* conservation' as: "the conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties". IUCN guidance on 'conservation' in the context of protected areas is: the *in-situ* maintenance of ecosystems and natural and semi-natural habitats and of viable populations of species in their natural surroundings and, in

	PAs but without the formal legal requirements.		the case of domesticated or cultivated species in the surroundings where they have developed their distinctive properties.
h. Biodiversity	In the context of ecological corridors, biodiversity refers to those elements for which corridors are designed and managed. Depending on the ecological corridor, this will range from single species to entire ecosystems. The structural needs of the species or ecosystems will also be a function of the connectivity objectives.	Given the explicit link in Target 11 between OECMs and biodiversity conservation outcomes, it is implicit that OECMs must achieve the effective *in-situ* conservation of biodiversity. The conservation values of OECMs should be described and tracked over time.	'Biodiversity' is defined by the CBD as: 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 part: this includes diversity within species, between species and of ecosystems. The CBD further defines 'ecosystem' as: "a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit". IUCN guidance on protected areas references 'nature'. Nature *always* refers to biodiversity, at genetic, species and ecosystem level, and often *also* refers to geodiversity, landform and broader natural values.
i. Ecosystem services	As with protected areas and OECMs, ecological corridors may consider associated ecosystems in their management. While corridors may enhance ecosystem services, they may or may not be designed with that goal in mind.	Ecosystem services include provisioning services to humans such as food and water; regulating services such as regulation of floods, drought, land degradation and disease; and supporting services such as soil formation and nutrient recycling. Management for these ecosystem services will be a frequent driver in the recognition of OECMs. Such management - for example for one particular ecosystem service - should not impact negatively the site's biodiversity conservation values.	Ecosystem services include provisioning services to humans 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. The IUCN definition of a protected area includes associated ecosystem services as well as biodiversity values.

j. Cultural and spiritual values	As with protected areas and OECMs, ecological corridors may wish to consider associated cultural and spiritual values in their management. These include recreational, spiritual, religious, aesthetic, and other non-material benefits, with a particular focus on those that contribute to ecological connectivity conservation outcomes.	OECMs include areas where the protection of key species and habitats and management of biodiversity may be achieved as part of long-standing and traditional cultural and spiritual practices. In such cases, it will be essential to assure the recognition and protection of the associated cultural and spiritual values and practices that lead to positive biodiversity outcomes. Conversely, management for cultural and spiritual practices within an OECM should not impact negatively on biodiversity conservation values in the long-term.	Includes those cultural and spiritual values that do not interfere with the conservation outcome (*all* cultural values in a protected area should meet this criterion), including in particular: a) those that contribute to conservation outcomes (e.g., traditional management practices on which key species have become reliant); and b) cultural practices that may themselves be under threat.

a. Definition of ecological corridors

This section defines ecological corridors and key terms used in its definition. It is important to refer to these terms of the definition when interpreting the criteria for corridor designation and implementation.

An **Ecological Corridor** is a clearly defined geographical space, not recognised as a protected area or other effective area-based conservation measure (OECM), that is governed and managed over the long-term to conserve or restore effective ecological connectivity, with associated ecosystem services and cultural and spiritual values.

b. Discussion

It is worthwhile to elaborate here some key phrases and concepts used in this definition to be clear about their intended scope and application in the context of these particular guidelines:

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

Associated ecosystem service values refer to ecosystem services that are related to but do not interfere with the aim of ecological connectivity conservation (*See* Glossary of Terms for definition of ecosystem services).

Associated cultural and spiritual values include cultural values such as recreational, spiritual, religious, aesthetic, and other non-material benefits, with a particular focus on those that contribute to ecological connectivity conservation outcomes. These values may be provided by traditional management practices that are themselves under threat on which key species have become reliant.

c. Guidelines for an ecological corridor

This section defines the guidelines IUCN recommends for ecological corridors. Guidelines include the ecological objectives for the ecological corridor, how it is governed, how the boundaries are delineated, management required to reach objectives, and a monitoring plan.

Ecological corridors should be documented and may be voluntarily tracked globally through the UN Environment World Conservation Monitoring Centre (UNEP-WCMC) (*See* section below). In addition, ecological corridors should be monitored for their effectiveness. This helps in establishing and tracking global commitments as well as monitoring effectiveness and evaluating against goals.

i. Basic information

Documentation of ecological corridors should include:

- Name of the site;
- Geographic description of the ecological corridor representing the spatial location using a polygon shapefile;
- Year of establishment;
- Contact information of reporting organisation.

ii. Objectives

The documentation should clearly state the following: ecological connectivity objectives, any associated ecosystem services the ecological corridor provides and associated cultural or spiritual values the ecological corridor holds, if relevant.

Ecological connectivity objectives: The most critical step in documenting an ecological corridor is to define its objectives for ecological connectivity. Connectivity can be established or maintained for any one or a combination of the following purposes: (1) movements of individuals between habitat patches, 2) genetic exchange, (3) movement of individuals to meet life cycle needs including migration, (4) provision of habitat for multi-generational movement, (5) maintenance of ecological processes, or (6) movement and adaptation responses to global change including climate change. An ecological corridor should have clear and measurable ecological objectives meeting at least one of the above purposes. Examples of these different ecological connectivity objectives are provided in Box 1.

Box 1.
Ecological corridor objectives: some examples

1. **Movement of individuals:** To allow for the movement of dispersing tigers (*Panthera tigris*) between India's Dudhwa and Jim Corbett National Parks; to allow wildebeest (*Connochaetes taurinus)* to move from the Serengeti Plains in Tanzania and the Masai Mara Reserve in Kenya in a clockwise motion; or, to aid in recovery of the biota after habitat destruction, e.g., due to mining at deep sea hydrothermal vent ecosystems (Van Dover 2014).
2. **Genetic exchange:** To allow for the movement of giant pandas (*Ailuropoda melanoleuca*) between population segments that have been separated by a highway and associated development.
3. **Movements individuals/migration:** to facilitate the annual June passage of Wood turtles (*Glyptemys insculpta*) from habitat in Canada's La Maurice National Park to breeding beaches outside of the park; *or* To conserve the movement pathway of fish to breeding site such as the Dorado catfish (*Brachyplatystoma rousseauxii)* in the Amazon or green sturgeon (*Acipenser medirostris*) in the Pacific northwest of the United States; or to conserve one or more of the stop-over sites that maintain the migration of spoon-billed sandpipers (*Calidris pygmaea*) and/or other migratory sandpipers that breed in Russia's Siberia and Kamchatka and migrate along the Pacific coast of Asia, wintering from eastern India to southern China.
4. **Multi-generational movement:** To provide habitat for monarch butterflies (*Danaus plexippus*) migrating over several generations along a central flyway in the states of Minnesota, Iowa, Missouri, Kansas, Oklahoma, and Texas, USA ("Monarch Highway")
5. **Maintenance/restoration processes:** To restore hydrologic function by removing dams from small streams in Wisconsin, USA.
6. **Climate Change Adaptation:** To facilitate range shifts to adjacent mountain ranges through restoring riparian corridors in agricultural landscapes in California, USA.

Associated ecosystem service values (if applicable): Ecosystem service objectives, which often can be achieved along with connectivity conservation, should also be documented. These can include maintaining or enhancing provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; and supporting services such as soil formation and nutrient cycling. While management for specific ecosystem services may be an important objective, this management should not undermine the ecological corridor's ecological connectivity objectives. Detailed guidance for documenting ecosystem services can be found in the IUCN publication "Tools for measuring, modelling, and valuing ecosystem services" (Neugarten et al., 2018).

Associated cultural and spiritual objectives (if applicable): Conservation of important long-standing traditional cultural and spiritual values may be associated with the ecological corridor. These values should be documented and should not interfere with ecological connectivity objectives. It is important to document the cultural values that contribute to connectivity conservation outcomes (e.g., traditional management practices on which key species have become reliant) and those that are themselves under threat.

iii. Contribution of ecological corridors to an ecological network for conservation

The contribution of the ecological corridor to an ecological network for conservation should be documented. For further reference, Beger et al., 2010 provide detailed guidance on how to incorporate many of the considerations of ecological networks.

iv. Conservation of ecological corridors as a geographically defined space by legal or other effective means

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

Geographical space may have three dimensions generally encompassing some equivalent of width, length, and height. The governance or management regime may need to account for the third (vertical) dimension if biodiversity is to be effectively conserved. Designations of ecological corridors, conserved areas, or protected areas will often have limits in the third dimension (e.g., only apply to a certain depth underground or below the water surface). This has become particularly controversial in marine protected areas, where vertical zoning for commercial purposes may undermine conservation objectives, e.g., by disrupting ecological connectivity, as it is extremely challenging to monitor or enforce. The key point is that height and depth dimensions need to be consistent with effective management of an ecological corridor to achieve its connectivity objectives. Another aspect of this concerns subsurface rights because accessing underground resources can undermine conservation values.

An ecological corridor may be discontinuous (stepping stone corridors) provided that the objectives, governance, and management are the same across the segments. In cases where there is more than one governance or management entity, actions should be demonstrated to be harmonized and coordinated.

Delineation should be based on ecological needs for connectivity, rather than on land and sea ownership (cadastral) boundaries. However, where cadastral boundaries approximate the ecological needs, it may be useful to use such boundaries for management and governance efficiency. For sites crossing political or jurisdictional boundaries, where it is not feasible to have a common governance mechanism, separate ecological corridors may be needed or the governance mechanism for a cross-boundary ecological corridor may be comprised of more than one entity with an umbrella coordination mechanism such as a formal committee or decision-making process.

v. Governance of the ecological corridor

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

The element of ‘how’ concerns ensuring transparency, participation, and justice in decision-making processes. Governance of the ecological corridor should strive to be equitable and reflect human rights norms recognised in international and regional human rights instruments and in national legislation. Any recognition of the ecological corridor requires the free, prior and informed consent of the relevant governance authority(ies). These principles are fully applicable to any decision-making on design, establishment, management, redesign, monitoring, or evaluation of ecological corridors.

The element of ‘who’ relates to the entity or an agreed-upon combination of entities with authority over the ecological corridor. Ecological corridors with complex tenure situations (‘tenure’ being who owns or controls the land or resource use rights), may require a diversity of governance authorities along with an agreed-upon mechanism for coordination and oversight. However, ecological corridors may be governed by the same range of governance types as protected and conserved areas (Dudley, 2008; Stolton et al., 2013; Borrini-Feyerabend et al., 2013):

a) Governance by government (at various levels);
b) Shared governance (sometimes called co-management):
   - Transboundary governance (formal arrangements between one or more sovereign States or Territories)
   - Collaborative governance (through various ways in which diverse actors and institutions work together)
   - Joint governance (pluralist board or other multiparty governing body)
c) Governance by private individuals, organisations or companies; and
d) Governance by indigenous peoples and/or local communities.

The governance authority may be the same as the landowner or rightsholder of a given ecological corridor. A conservation NGO or a conservation conservancy might hold a conservation easement or develop a written voluntary landowner agreement on a privately owned parcel of land which allows them to manage the area for specific connectivity values. Likewise, a group of entities might enter a cooperative agreement or a local indigenous or traditional community may hold legal rights (either by statute or customary law) to certain lands or ocean space, such as for sustainable use of a fishery.

Effective ecological corridor governance necessitates involving the full diversity of interests, building trust, working towards shared values and goals, and developing collaboration across the interests of an ecological corridor (Pulsford et al., 2015).

vi. Tenure (lease or freehold or community or other)

For a given ecological corridor, the tenure(s) of the area should be clear and articulated. Tenure(s) involves the conditions and rights under which land, sea, freshwater, or airspace, or their associated natural resources are held, occupied, or used.

vii. Legal or other effective mechanisms for the ecological corridor

Documentation of the legal or other effective mechanism should describe the governing authority and the legal or customary mechanisms that established the area's tenure(s). Given the various contexts for the application of ecological corridors around the globe, there will be a diverse and flexible array of mechanisms for implementation ranging from formal legal agreements/covenants to regulatory natural resource use zoning approaches on land and sea, to written voluntary landowner/rightsholder agreements.

viii. Longevity of the ecological corridor

Ecological corridors are expected to endure over time. Their documentation needs to demonstrate the longevity and succession of the governance arrangements. In the case of written voluntary agreements, a process or mechanism to transfer implementation activities to subsequent owners should be obligatory. However, some governance mechanisms (e.g., hunting, grazing, soil conservation, fishing regulations, or seasonal use) may be time-limited and subject to formal periodic review and renewal. Such cases can demonstrate longevity by specifying that renewal is highly likely, including that it has happened before.

ix. Management required to achieve objectives

This section of documentation should describe management actions required to retain, restore, or enhance ecological connectivity of the ecological corridor. The allowable activities within a corridor should relate directly to its purpose and therefore will be context specific. A multipurpose ecological corridor which is designed to facilitate the movement of all species due to climate change likely would need many more prohibited uses than an ecological corridor which is focused on facilitating the movement of a single species at a specific time of year, since it would need to take the requirements of only one species into account. It should articulate management in terms of:

Structural needs: Are there structural ecological elements that are important to retain or enhance the ecological corridor to ensure the site meets its objectives? Examples might include maintenance of a percentage of tree cover, restoration of a coral reef, implementation of riparian setbacks, or maintenance of in-stream habitat components, such as shaded areas (*See* below section Modelling and Prioritising Ecological Corridors for a related discussion on structural and functional connectivity).

Human activity management: What human activities in the ecological corridor need to be maintained or conversely controlled or prohibited, permanently or at different times, to ensure that the site meets its connectivity conservation objectives? These might include human activities, such as hunting, fishing, boat passage, research, livestock grazing, or recreation, or the building of human structures such as road infrastructure, ports, or marinas. If the site includes use by livestock, are there considerations of stocking intensity or fencing? If the site allows logging or other resource extraction, what management is needed to meet connectivity objectives? Are any human activities, such as transportation infrastructure construction or industrial development incompatible with the objectives? Can designs incorporate wildlife connectivity needs such as created of wildlife overpasses or tunnels where transportation or other infrastructure may otherwise impede wildlife connectivity? The ecological corridor management documentation should list specific prohibited or permissible activities or articulate restoration needed to achieve connectivity. For some activities, it may be necessary to specify and generally define the acceptable level (high, medium, or low) that is compatible with the connectivity objectives of the site. One approach may be to create a decision framework for allowable activities (Saarman et al., 2013).

x. Monitoring, evaluation and reporting requirements

Ecological corridor documentation should include a monitoring and evaluation plan, along with a strategy for securing resources to effectively implement monitoring and evaluation. Authorities responsible for the ecological corridor should plan and implement monitoring to track progress, evaluate effectiveness toward achieving stated objectives, and adapt management strategies based on results. Monitoring and evaluation should support an adaptive approach to ecological corridor management, inform on changing climate impacts, aid in effective resource allocation, promote accountability, and increase public awareness of and support for the ecological corridor (Hockings et al., 2006). Recognising that monitoring resources are variable across the world, the plan should recognise aspirational and immediately feasible components.

Monitoring is the collection of information on specific indicators repeatedly over time to discover trends in the status of the ecological corridor and the activities and processes of management. To evaluate an ecological corridor's effectiveness, monitoring provides data needed to assess the extent to which an ecological corridor is achieving connectivity objectives. In doing so, monitoring helps assess the adequacy of management systems and processes to promote the long-term persistence of connectivity values and identify necessary management adjustments (Hockings et al., 2006). Monitoring and evaluation should be a long-term commitment of the ecological corridor governing authority(ies) and should be integrated into its management with appropriate resource allocations.

Monitoring the effectiveness of the ecological corridor for specific connectivity objectives can take various forms, including monitoring of habitat measures, threats, occurrence of individuals within the ecological corridor, actual movements of individuals through the ecological corridor and within an ecological network for conservation, population genetics, specific climate change impacts, and status of populations and natural communities connected by ecological corridors (Bennett, 2003). In some cases, geospatial data technologies such as remote sensing, aerial photograph, and satellite imagery may be other data sources to assist with monitoring over time. Monitoring approaches may involve time-series collection of information or use of control/comparison groups. The monitoring plan should identify specific achievable, relevant, time-bound, and measurable indicators. Monitoring methods may be qualitative, quantitative, or both. Selected methods need to be reliable, cost-effective, feasible, and appropriate. The type of monitoring undertaken will depend upon, and should respond to, the specific connectivity objectives of the ecological corridor. Monitoring data need to be analysed at an appropriate level to meet the information needs. Data analysis should be done regularly, so that needed adjustments to management strategies can be identified and made as part of the ongoing process of adaptive management (Conservation Measures Partnership, 2013).

The monitoring plan needs to identify the audience(s) (e.g., communities, donors, project partners, management authorities, and certifying authorities) and their specific information needs. Collaboration with partners early and throughout the implementation and monitoring process can be important (Citanovic & Hobday, 2018). It is essential to identify when, by whom, and where data collection and data analysis will happen and to ensure the necessary resource allocations.

Because transparency and accountability are essential components of ecological corridor governance, monitoring results and lessons need to be documented and shared with the public. Ecological corridor documentation should include a communication plan indicating how, with whom, and when these results will be communicated to key external audiences. These audiences may include affected landowners and rights holders, and a range of stakeholders, such as local communities, project partners, agency staff, policy makers, and donors.

d. Applications and benefits of ecological corridors

Connectivity is relevant across a range of environments from terrestrial and marine to freshwater and air spaces. The discussion below elaborates on ecological corridor applications and benefits in different environments.

In the ***terrestrial environment***, ecological corridors may facilitate daily movements, migratory movements, or dispersal movements. The latter ensure gene flow between populations such as by young animals looking for a new home range, or propagules such as wind-dispersed seeds. Ecological corridors can also serve multi-generational dispersers such as dispersal-limited plants and animals that require genetic connectivity or climate related shifts through time and space. Ecological corridors may vary greatly in size to facilitate long- or short-distance migrations, such as caribou (*Rangifer tarandus*) migration over hundreds or thousands of kilometres or Jefferson salamanders (*Ambystoma jeffersonianum*) in Burlington, Ontario from upland forests to temporary ponds where they lay their eggs. An ecological corridor may be a continuous space, such as for connecting lions (*Panthera leo)* in the Kavango-Zambezi Transfrontier Conservation Area across communal pastoral lands, reinforcing traditional compatible coexistence practises. Alternatively, ecological corridors may be a set of discontinuous terrestrial spaces such as stopover sites for migratory animals like monarch butterflies (*Danaus plexippus*) or red knots (*Calidris canutus*), the latter of which migrates between the northern and southern hemispheres.

Ecological corridors in ***freshwater systems*** should conserve the flows of water, sediment, and natural material and promote the movement of native animals and plants dependent on these systems. Freshwater ecological corridors may enable movement between freshwater lakes, rivers, and streams to conserve species requiring access to multiple freshwater environments during different phases of their life cycles. Freshwater ecological corridors may conserve lateral connectivity between the river channel and the adjacent floodplain to help maintain the exchange of matter and energy and to sustain viable populations of species dependent upon that exchange, as demonstrated in gravel-bed ecosystems (Hauer et al., 2016). They may also help conserve aquifers over large areas and protect groundwater-dependent ecosystems such as springs, karst wetlands, and some floodplains (Tomlinson & Boulton, 2010). Freshwater ecological corridors often include riparian vegetation that may provide habitat and travel corridors for some terrestrial species, and act as filter for surface flow run-off. Freshwater ecological corridors may be established for constantly flowing water bodies or intermittently flowing creeks and rivers. Finally, wetlands and other freshwater areas may be part of a discontinuous ecological corridor such as when supporting habitat for migratory waterfowl along international flyways, for example, the East Asian-Australasian flyway.

Marine environment ecological corridors may connect marine protected areas (MPAs) or other key marine or coastal habitat areas (Day et al., 2012). MPAs are unlikely to encompass full movements of highly mobile marine mammals, fishes, or reptiles, or accommodate the full larval stages of sessile fishes, invertebrates, plants, and algae. Ecological corridors can effectively conserve known marine migration routes and bottleneck zones that are vulnerable to human activities that may impair long-established migratory routes. Conservation of marine connectivity is also relevant for juvenile fishes and larvae of invertebrates that disperse via ocean currents for days to months before settling on reefs or other substrates (Gillanders et al., 2003; Cowen & Sponaugle, 2009), as well as for larger animals such as whales and turtles that migrate across one or more oceans. Marine ecological corridors may be especially important for species that use different environments at different stages of their life cycles. For example, marine turtles nest on beaches and may use coastal waters before moving into the high seas. These ecological corridors also facilitate continued service of MPAs as sources of immigrants to populations outside MPAs. Marine ecological corridors may need to be quite large given the extent to which marine processes and the recruitment of marine organisms is affected by oceanic currents, eddies, and tides. Alternatively, they may be relatively small, protecting migrations of a few kilometres for invertebrates such as red crabs (*Gecardoidea natalis*) on Australia's Christmas Island. Siting of three-dimensional marine ecological corridors may be affected by water depth, geological features such as deep-sea vents, stratification of the water column, or seasonal currents or wind flows (Cowen et al., 2007).

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

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

Likewise, mixed ecological corridors may link MPAs to estuaries to facilitate the movement of species necessary to sustain populations and evolutionary processes. These ecological corridors also may connect MPAs and terrestrial protected areas to sustain ecological processes such as migration.

Many birds, insects, and animals move through the air. The concept of an air-based or air column connectivity area is an emerging issue because of, for example, collisions of birds and bats with wind turbines, high-rise buildings, and other human structures (Rydell et al., 2010; Loss et al., 2013). In some cases, conservation of airspace may be necessary and feasible to protect some or all movements of a species. Airspace is not being addressed in this guideline as it was seen as insufficiently developed at the time of this writing. Further work needs to be done on this topic before being included in ecological corridor standards.

e. Ecological corridors for climate resilience and adaptation

During this time of rapid climate change, biodiversity conservation needs to increase ecosystem resilience and provide opportunities for species to adapt to the changing conditions. Ecological corridors, as a component can contribute to both climate resilience and adaptation. Large, connected terrestrial and aquatic ecosystems are more resilient to climate change because ecological processes important for ecosystem stability are functioning (Walker & Salt, 2006). Connected protected and conserved areas allow for adaptation by enabling species to respond to climate change by shifting their ranges to new, suitable habitats and climates. In contrast, habitat loss and fragmentation prohibit these range shifts in many landscapes and seascapes. Therefore, protecting and establishing ecological corridors can be an effective strategy to facilitate species persistence and range shifts (reviewed in Keeley et al., 2018). Ecological corridors can be designed and managed taking climate considerations into account. Approaches include:

- ensuring that ecological corridors contain diverse topography that provides different microclimates for species persistence,
- establishing ecological corridors to connect protected areas and conserved areas that can serve as climate refugia,
- prioritising ecological corridors that contribute to connecting protected areas and conserved areas that together contain temperature gradients,
- considering the velocity of climate change in an area,
- considering animal and plant population dynamics at the leading and trailing edges of ranges,
- designing for multiple species redistributions to maintain critical species interactions (e.g., mutualists),
- designing to representatively facilitate redistribution of genetic diversity,
- designing corridors that can change spatially with climate change (e.g., changing winds, ocean currents, riparian zones),
- ensuring that ecological corridors are sufficiently wide to provide live-in habitat for slow-moving species,
- using best available science to identify large portions of the water column as an ecological corridor, especially in the deep sea, to allow species and processes to move and adapt to chemical and temperature changes as the result of climate change, and
- if appropriate, restoring or enhancing the vegetation in ecological corridors with species that are drought resistant and will provide resources for wildlife throughout the year.

f. Modelling and prioritising ecological corridors

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

There are a number of ways to categorise connectivity. At the highest level, a key distinction relevant to ecological corridors is that connectivity has both *structural* and *functional* components, which are described further below. Although not addressed in depth in this document, it is worth noting that scientists and practitioners characterise connectivity based on the type of habitat (e.g., marine, freshwater, and terrestrial, as described above in "Applications and Benefits of Ecological Corridors"); the degree of human disturbance (e.g., hedgerows to remnant forest corridors; Theobald, 2013); the scale (local, regional, cross-oceanic, continental); or objectives (daily or seasonal movement, dispersal or habitat, long-term persistence, adaptation to climate change; Crooks & Sanjayan, 2006; Rudnick et al., 2012; Olds et al., 2016; Hilty et al., 2019).

Functional connectivity describes how well genes, gametes, propagules, or individuals move through land- and seascapes (Rudnick et al., 2012; Weeks, 2017). Identifying areas that provide functional connectivity now and in the future based on the known movements of individuals is a practical way to delineate movement corridors (e.g., Sawyer et al. 2009; Seidler et al.; 2015; Hilty et al. 2019). Because it can be difficult to track a sufficient number of individuals over time at the needed scale, a suite of other approaches to define connectivity has been developed (Rudnick et al., 2012). In some cases, indicator or umbrella species are used to identify connectivity areas for a suite of species (e.g., Weeks, 2017). For long-lived species that are difficult to monitor, indirect approaches that can account for changes over time such as in genetic make-up can be effective (Proctor et al., 2015). However, such genetic approaches are generally a first step to identifying where once continuous populations are fragmenting so that the next step of delineating potentially important connectivity areas can be taken. Such genetic tools can also potentially validate functionality and be a monitoring tool for ecological corridors over time.

Structural connectivity is a measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances, and other land- or seascape elements presumed to be important for organisms to move through their environment (Hilty et al., 2019). Structural connectivity modelling aims to identify areas through which a diversity of species may be able to move, often prioritising ecological corridors characterised by a low degree of human modification. Especially species that are sensitive to human disturbance are assumed to be able to move through these areas (Dickson et al., 2017). In addition, linear areas that provide connectivity, such as river corridors, ocean currents, or linear forest fragments can be identified and prioritised for conservation (e.g. Rouget et al., 2006). Systematic conservation planning is increasingly incorporating connectivity as a component of planning (e.g., Hodgson et al., 2016; Rayfield et al., 2016; Albert et al., 2017). With a growing number of quantitative approaches, numerous tools are available to map and model connectivity (Table 5). Increasingly, efforts to model connectivity are recognising the dynamics of the ecological systems, including seasonal or annual dynamics and long-term climate-induced changes (Rouget et al., 2006; McGuire et al., 2016; Simpkins & Perry, 2017).

Table 5. Common approaches to connectivity modelling (Urban & Keitt, 2001; McRae, 2006; Theobald, 2006; Rudnick et al., 2012; http://conservationcorridor.org/corridor-toolbox/).

Model Type	**Brief explanation**
Least Cost	Estimates the least-cost movement path from one location (source patch) to another location (destination patch) that an individual or process would likely take, assuming knowledge of the destination location, moving across a surface represented by “costs” (corridordesign.org; McRae, et al., 2014). Either the single shortest path from one location to another or the full surface of least-cost distances can be used. Cost-distance surfaces can be combined that were created from single, pairwise, factorial, or randomly placed locations.
Circuit Theory	Adapted from electrical circuits, circuit theory identifies connectivity by modelling random walkers to move from sources across a surface of resistances to destinations (grounds), allowing multiple pathway options (McRae, 2006; circuitscape.org; Carrol et al. 2012).
Graph Theory	Graph theory is the study of graphs which formally represent a network of interconnected objects. Graph theory provides the basis for nearly all connectivity methods, including least-cost and circuit theory. In addition, to prioritise ecological corridors graph-theoretic metrics can be applied across a “land- or seascape graph” where patches are nodes and areas of connectivity are edges (Urban and Keitt, 2001; Theobald, 2006; University of Lleida, 2007).

Resistant Kernel	Based on least-cost movement from all locations across a land or seascape, implemented using a kernel (moving window) approach (Compton et al., 2007). This approach calculates a relative density of dispersing individuals around source locations.
Reserve Design	An approach to guide systematic multi-objective planning to support spatial decision-making about the design of terrestrial, marine, and/or aquatic reserves and management areas (e.g., Moilanen et al., 2008; White et al., 2013).
Individual-based Modelling	Simulates movement paths of individuals by following movement rules. The estimated relative frequency of use is mapped (Horne et al., 2007; Ament et al., 2014; Allen et al., 2016).

g. Law and policy instruments

At the international level, there is growing recognition in law and policy of ecological connectivity. Most global and regional legal instruments dealing with terrestrial, aquatic, and marine biodiversity conservation, climate change, and environmental sustainability have objectives that will not be met without addressing connectivity conservation effectively and over the long-term. Ecological corridors provide an important mechanism for countries to advance legal obligations and policy commitments, which notably include the Convention on Biological Diversity (CBD), Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention), Convention on the Conservation of Migratory Species of Wild Animals (CMS or Bonn Convention) and its ancillary instruments, World Heritage Convention, UN Convention on the Law of the Sea (UNCLOS), UN Framework Convention on Climate Change (UNFCCC), and UN Educational, Scientific and Cultural Organization’s (UNESCO) Man and the Biosphere Programme (MAB). There are also numerous regional conventions, including the Revised African Convention on the Conservation of Nature and Natural Resources (Maputo Convention) and the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention; promoting the European ‘Emerald’ Network). At the supranational law level, the European Union’s (EU) ecological network, Natura 2000, covers terrestrial and marine environments and applies to all EU Member States, along with other directives such as the Water, Marine Strategy, and Maritime Spatial Planning Frameworks (Lausche et al., 2013; European Parliament & Council, 2014).

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

While connectivity objectives are increasingly prevalent in national and subnational planning and policy initiatives, examples of country efforts to enact stand-alone generic connectivity legislation are rare (Lausche et al., 2013, p. 84). At the same time, site-specific legislation has been enacted in some countries. For example, the South Korea Act on the Protection of the Baekdu Daegan Mountain System, 2003 (Act no. 7038), which came into effect in 2005, designates an area of 263,427 hectares, of which 86% is made up of 183 existing protected areas and 14% consists of new buffer and core areas creating a biodiversity corridor along the main mountain range of the Korean Peninsula (Miller & Hyun, 2011; *See* also Farrier et al., 2013, for other case studies of legal actions to protect specific connectivity areas; KLRI, 2014).

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

Economic instruments are another suite of available tools that may reinforce direct regulation or serve as an alternative approach to support connectivity conservation. These instruments may encourage certain behaviour which could include actions of landowners and rights holders to support specific ecological corridor objectives. Such instruments include positive incentives (e.g., technical assistance, subsidies, tax credits, reduced tax liability), negative incentives (e.g., tax increases, withholding of technical assistance), compensation for conservation actions or loss of economic productivity, payments for environmental services or stewardship (e.g., maintenance of forest cover, restoration of riparian areas), and market-driven tools such as tradeable permits and conservation/bio-banking (*See* Lausche et al., 2013 for an extensive discussion of such tools for both terrestrial and marine environments).

The formal process of amending or enacting new legal instruments takes significant time and should not delay efforts to protect and secure ecological corridors. While legal approaches will vary, most countries' legal systems — national and subnational (provinces, states, etc.) — already have a number of tools in place to begin the essential process of recognising and protecting ecological corridors. Analyses should be undertaken to identify and utilise these tools as soon as possible for key connectivity sites before their conservation is no longer economically or politically feasible, even as the longer-term process of amending or enacting new connectivity-specific legislation is pursued.

h. Nomination of ecological corridors and conservation networks for conservation to the Protected Planet Database for formal recognition

Governance authorities may voluntarily report ecological corridors and ecological networks for conservation to the Protected Planet Database managed by the UN Environment World Conservation Monitoring Centre (UNEP-WCMC) and IUCN.

Generally, the country's focal point for the Protected Planet Database will report the ecological corridor or an ecological network for conservation for a given country, using the reporting portal. There is also an opportunity for individual governance authorities to report directly to the Protected Planet Database. The WCMC will provide a table of documentation requirements based on these guidelines. Landowners or rightsholders retain the right to object to the external nomination or recognition of their area as an ecological corridor in cases in which their free, prior, and informed consent has not been sought and subsequently provided. This applies to all four governance types, as set out above.

Recognising an area as an ecological corridor places a heightened responsibility on the governance authority to continue to govern and manage the area in ways that achieve the specific connectivity goals. While national circumstances differ, it is hoped that national or regional legislation will provide greater support and recognition to existing governance systems and not supplant or unnecessarily alter any local arrangements.

The ecological corridor governance authority is responsible for reporting any changes in ecological corridor boundaries, governance, or objectives.

5. Conclusion

Ecological corridors both on land and in the sea are a critical conservation tool to augment ecological networks for conservation and ensure that ecosystem functioning and ecological processes are maintained or restored. Ecological corridors are an essential component of ecological networks for conservation, but do not substitute or replace protected areas, or conserved areas. Rather, ecological corridors provide specific complementary value to protected areas and conserved areas by ensuring connectivity between and among them, which is critical to maintain the value of these protected and conserved areas and the ecological network as a whole. Together, protected areas, conserved areas, and ecological corridors are a suite of tools to create effective land, freshwater, and marine ecological networks to better conserve biodiversity today and in the long term, especially during this unprecedented anthropogenic driven mass extinction of species caused by enormous alteration of ecosystems, and climate change.

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Appendix: Examples of conservation corridors in ecological networks

The case studies were selected as representative examples of ecological networks for conservation in terrestrial, freshwater, and marine ecological realms. They illustrate a range of ecological networks for conservation, from continental or oceanic to urban, and demonstrate a variety of ecological corridors.

Terrestrial connectivity

Africa

Kilimanjaro landscape: ensuring the viability of wildlife populations

By Kathleen H. Fitzgerald, Vice President, African Wildlife Foundation

Context and challenge

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

The greatest threat in the landscape is habitat loss and fragmentation (Fig. 2). A majority of the group ranch land surrounding the park was subdivided into 2-acre, 10-acre and 60-acre lots allocated to individual Maasai landowners. The sub-division is primarily due to a breakdown in communal systems, failure of the group ranch system to deliver equitable benefits and improve community livelihoods, and a more sedentary way of life. Some Maasai landowners are selling their land for development and agriculture.

Approach

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

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

AWF worked with individual landowners to help them understand that collectively their land was more valuable than individually, which resulted in the landowners forming associations. This enabled them to make collective decisions while retaining and benefitting from their individual land ownership. These landowner associations range in size from 50 to 90 landowners. Through these associations, AWF engaged the landowners in a discussion about conservation leases and Payment for Ecosystem Services (PES), where AWF proposed to lease land from the Maasai via a PES arrangement and pay them to keep their land open for wildlife. Different organizations now manage and pay for the leases in the Amboseli ecological corridors, including AWF, Tawi Lodge (www.tawilodge.com), the Big Life Foundation (www.biglife.org), and IFAW (www.ifaw.org).

Example of an ecological corridor

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

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

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

Results

Currently there are five community conservancies with more than 350 individual landowners that protect approximately 20,000 acres of ecological corridors. With an average household of seven, the lease program is directly benefitting over 2,450 individuals, and this does not include employment beneficiaries, such as scouts.

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

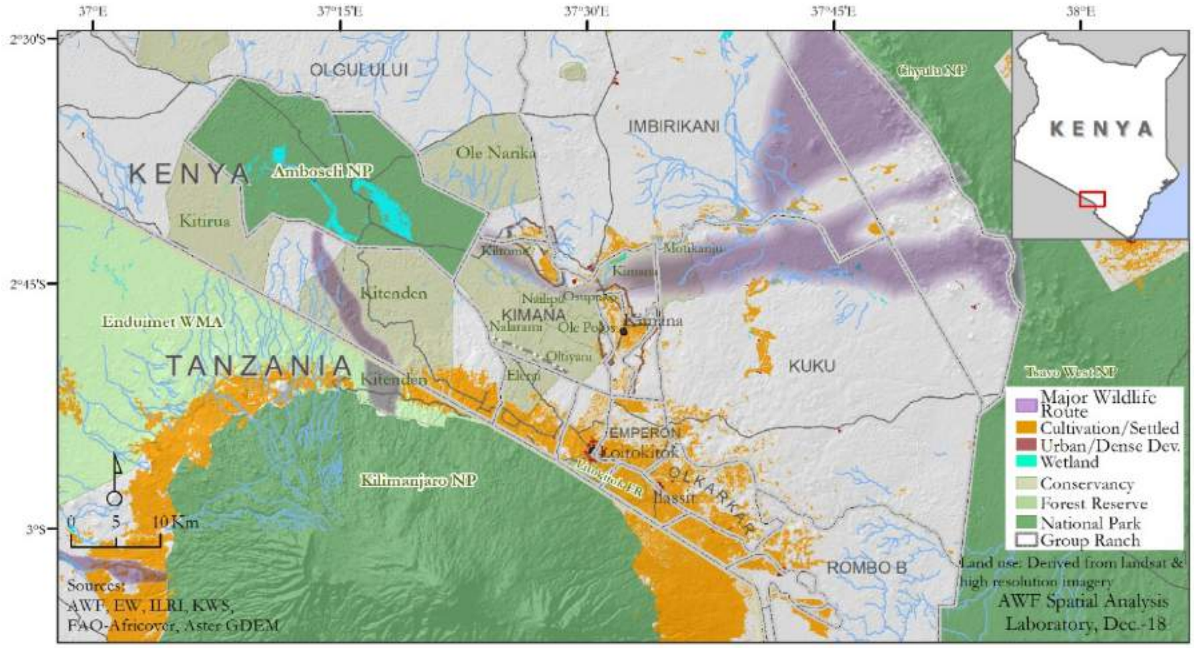


Figure 1. The Kilimanjaro landscapes showing community owned wildlife conservancies established by the African Wildlife Foundation to protect key wildlife corridors.

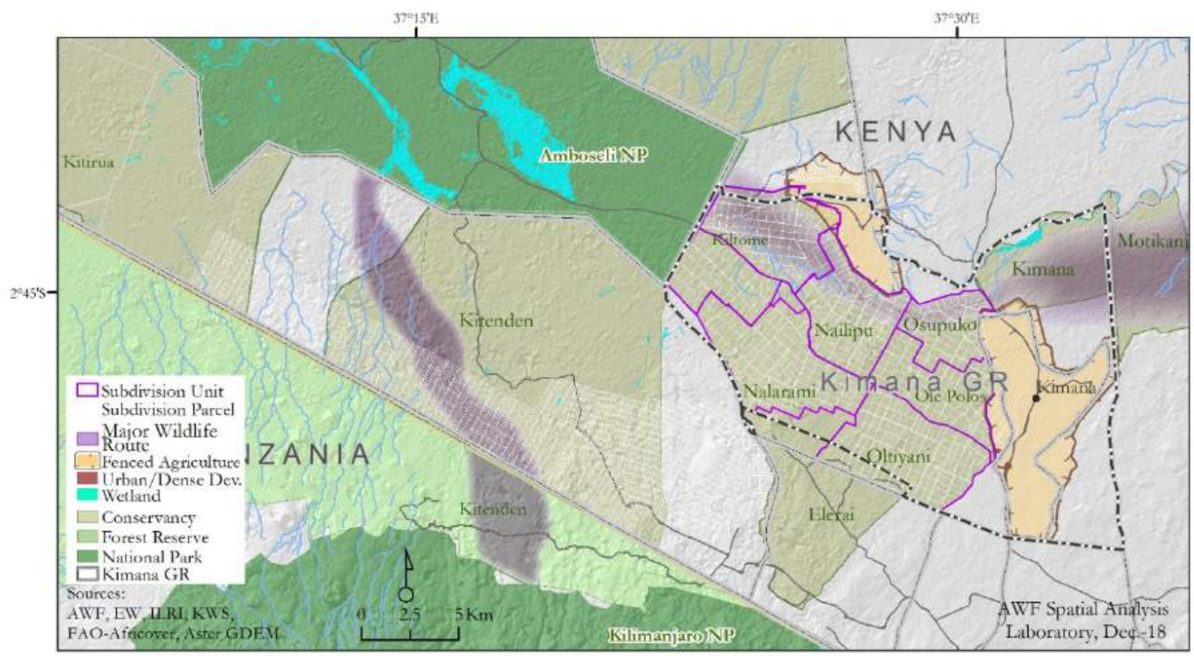


Figure 2. Land subdivision in the Kilimanjaro landscape. The Kimana Group Ranch is located east of Amboseli National Park.

Asia

Ecological corridor for the reunion of Giant pandas in the Qinling landscape

By Hui Wan, WWF

Context and challenge

National road 108 was built in the 1970s and over time brought heavy traffic (Fig. 1). The road cut the forest and together with the traffic caused the fragmentation of previously connected panda habitat. It also gave the local human population access to the forest. Consequent collection of wild resources further degraded the habitat. The resident panda population was gradually split into two separate groups: the Xinglongling subgroup to the west and the Tianhuashan subgroup to the east.

Approach

In 2000, a tunnel was built by the government to accommodate a new road. This provided the opportunity to reconnect the separated panda groups. In 2003, Shaanxi Guanyinshan Nature Reserve was legally established, and in 2005 the World Wildlife Fund (WWF) together with the Reserve launched the G108 Qinling vehicle tunnel corridor restoration project (Fig. 2).

The main strategic activities in the ecological corridor include:

- Baseline survey and mapping to understand the subgroup status, the physical distance between the subgroups, the socio-economic condition of local communities, the management capacity of the reserve, and the forest tenure distribution in the area.
- Habitat restoration in the ecological corridor in form of bamboo plantings in gap plots to improve habitat quality, provide connected habitat and thereby a path for panda movement.
- Local community engagement, including provision of sustainable livelihood support to local households, demonstration of sustainable forest management, and education programs about the significance of habitat conservation.
- Traffic management to enforce the ban of humans and vehicles using the abandoned road.
- Capacity enhancement to improve the management effectiveness of Guanyinshan Nature Reserve.
- Wildlife monitoring in the ecological corridor.

Results

Giant pandas have been documented in the ecological corridor, which includes the tunnel and surrounding lands connecting the core areas. The ecological distance between the subgroups has been decreased and is now shorter than the daily activity range of a panda. The number of mammal and pheasant species found in the corridor area has increased from 0 to 15.

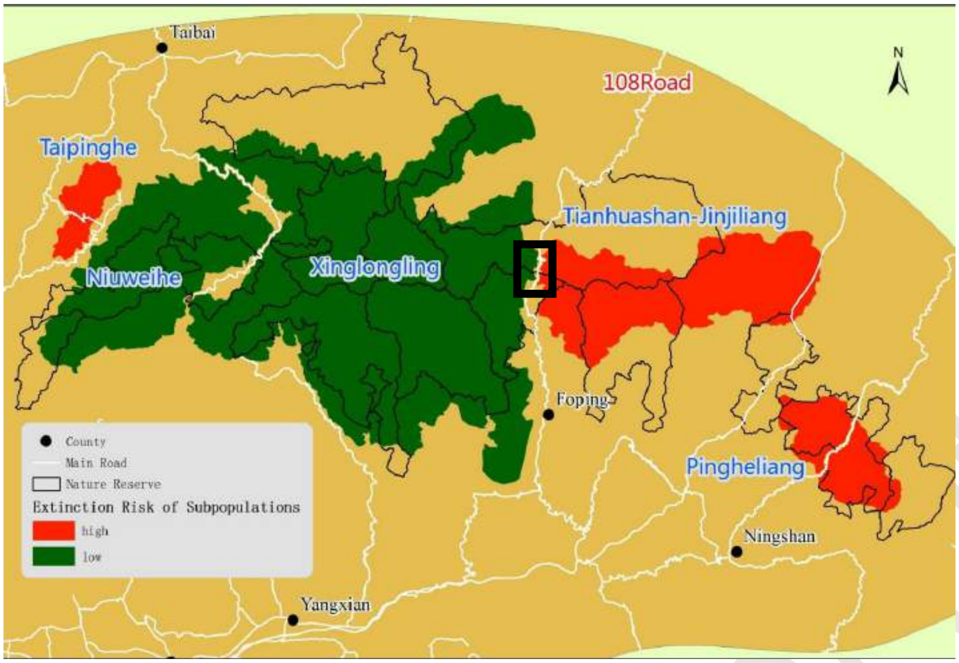


Fig. 1. Panda subpopulations in the Quinlin landscape. National Road 108 is running from north to south. The black square indicates the location of the ecological corridor.

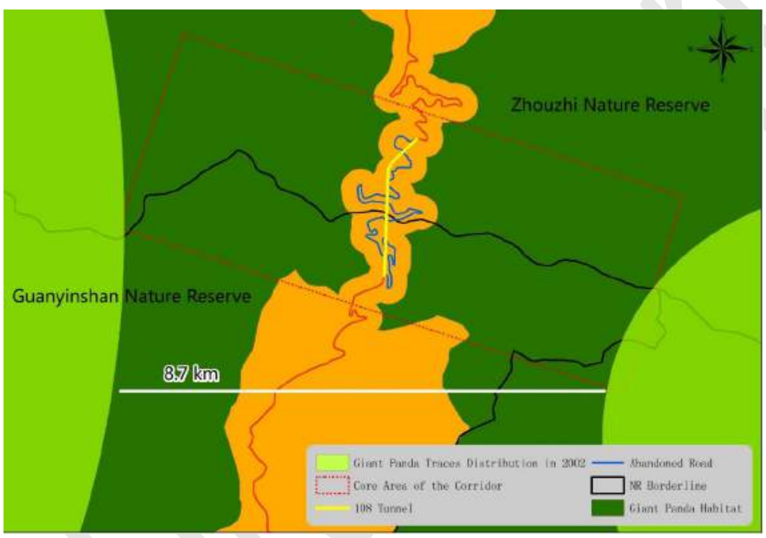


Fig. 2. The ecological corridor includes the non-protected area on both sides of the road (orange). It is now connecting the habitat of two panda subgroups.

Australia

East Coast Conservation Corridor in Tasmania

By Todd Dudley, North East Bioregional Network

Context and challenge

The East Coast Conservation Corridor (ECCC) is a landscape-scale ecological network for conservation extending 280 km north-south from Cape Portland to Cape Pillar, covering 2 ½ degrees of latitude on the East Coast and hinterland of Tasmania. The existing protected area system and ongoing conservation projects provide a solid foundation for realizing the vision of a protected connected landscape. In 2012, noted natural heritage expert Peter Hitchcock stated that "...the East Coast connectivity corridors have been assessed collectively to have National Heritage significance—one of the more important latitudinally connected tracts of native habitat in Australia."

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

Approach

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

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

Example of an ecological corridor in the network

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

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

- 30 permanent conservation covenants and 60 registrations under Land-for-Wildlife program on private land.
- Through ecological restoration projects the North East Bioregional Network has facilitated the employment and training of over 80 people over the last 5 years which has had significant ecological, social and economic benefits and helped consolidate conservation as a highly beneficial activity in remote rural communities.
- Prohibition of new subdivisions within 1 km of the coast in the Break O Day municipality, thus maintaining an ecological corridor between the coast and hinterland.
- Establishment of a North East Tasmania Land Trust as a tax-deductible organisation to purchase and receive donations of private land for nature conservation.
- Transfer of management of over 100,000 ha of public native forest from Forestry to National Parks and Wildlife in North East Tasmania (Fig. 1).
- Release of a conservation action plan for the Break O Day municipality
- Consideration of connectivity conservation plans in municipal land planning.
- Connectivity conservation plans produced which explicitly seek to protect wildlife corridors and landscape linkages from inappropriate development and are legally binding in municipal planning schemes.

Learn more: www.northeastbioregionalnetwork.org.au

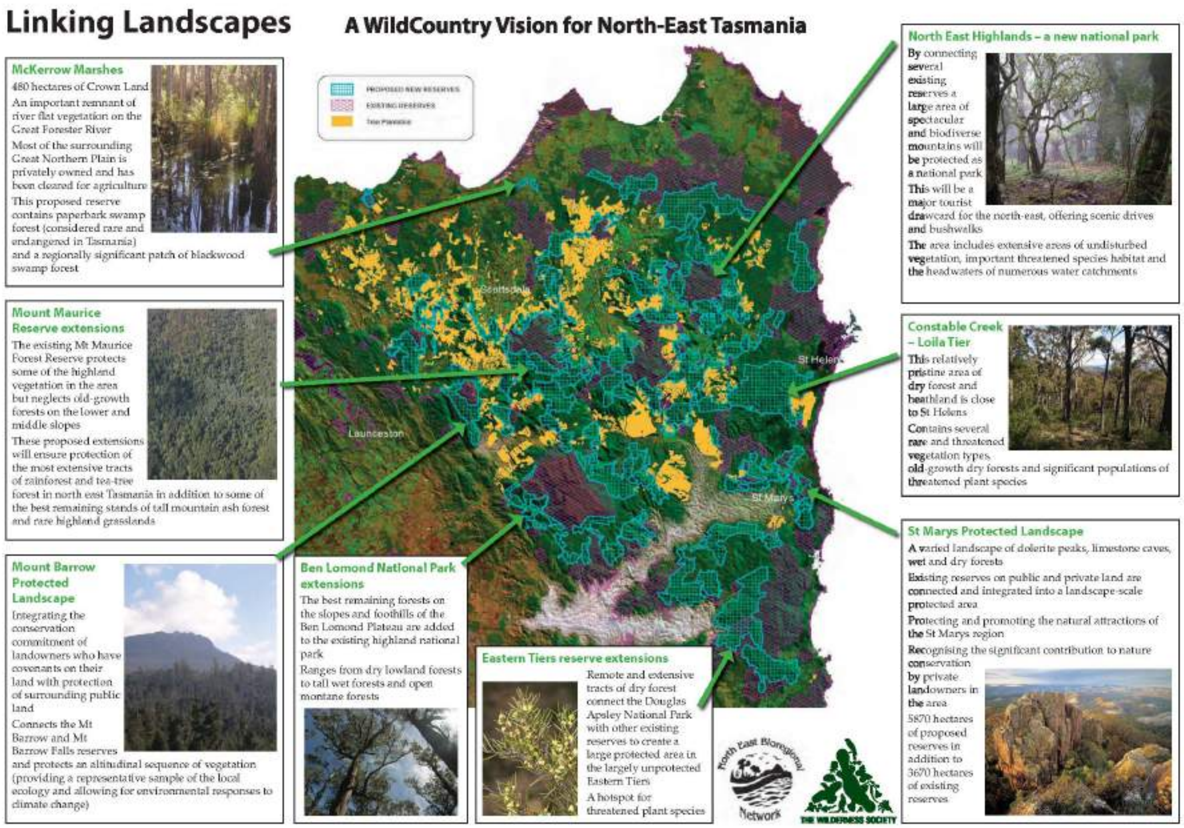


Fig. 1. Examples of concrete steps to make the WildCountry vision for North-East Tasmania a reality.

Fig. 2. Skyline Tier Ecological Restoration Project. A. Post harvesting of mature Radiata Pine plantation followed by hot ecological burn. B. 6 years later, intensive restoration work helped the regeneration of native forest.

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

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

Challenge

Australia is one of Earth's seventeen mega diverse nations and its 22,000 flora and 6,794 vertebrate fauna species include 1,350 endemic terrestrial vertebrates, the highest number for any nation. The greatest concentration of this outstanding biodiversity is found along the rugged eastern mountains and coast. This area comprises a substantial part of Conservation International's 35th Global High Biodiversity "Forests of East Australia" Hotspot. Substantial sections are conserved in an archipelago of embedded protected areas including three World Heritage Areas, as well as lands used for agriculture, mining, urban development, infrastructure and forestry. Clearing and fragmentation of habitat, land degradation, introduced exotic species of plants, animals, pathogens and climate change are major threats that degrade and sever this ecological network for conservation.

Approach

The Great Eastern Ranges Initiative (GER) was established in 2007 with a bold mission to protect, restore and relink habitat to allow nature and people to continue to thrive. Comprising mostly of essentially natural lands that extend along the mountainous ranges on the eastern seaboard of Australia for more than 3,600 km (2,600 miles) from the Grampian Mountains in Victoria, through eastern New South Wales (NSW) and the Australian Capital Territory (ACT), to Cape York in far North Queensland. Countless species rely on the Great Eastern Ranges to move and adapt to a climate of extremes. The GER Initiative is an ecological network for conservation that helps people to work together to restore and reconnect nature in areas of high biological importance such as gaps and areas that are fragmented. This work is guided by a vision for the ecosystems of Australia's Great Eastern Ranges to be healthy and connected which will contribute to long-term economic, social, cultural and spiritual wellbeing of the community, and of native plants and animals.

The GER Initiative is one of very few connectivity conservation initiatives worldwide that have been initiated by Government. It began in 2007 with funding from the state of NSW enabling its Department of Environment Climate Change and Water to demonstrate a new approach to conservation based on collaborative partnerships. Five 'regional partnerships' were established in five priority connectivity areas. Partners included non-government conservation organisations, land care groups, local government, Aboriginal groups, academic institutions, local government and government agencies. In 2010, governance devolved to a public-private partnership group of five non-government lead partners. Regional groups expanded to 10 regional groups by 2016. In 2017, governance was transferred to the Great Eastern Ranges Ltd. with a board of eight independent directors. The GER Ltd. is now a not-for-profit entity that operates as an equal partner in a national network of regional partners in 10 partnership areas in NSW, the ACT, Queensland and Victoria.

Examples of ecological corridors in the network

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

Results

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

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

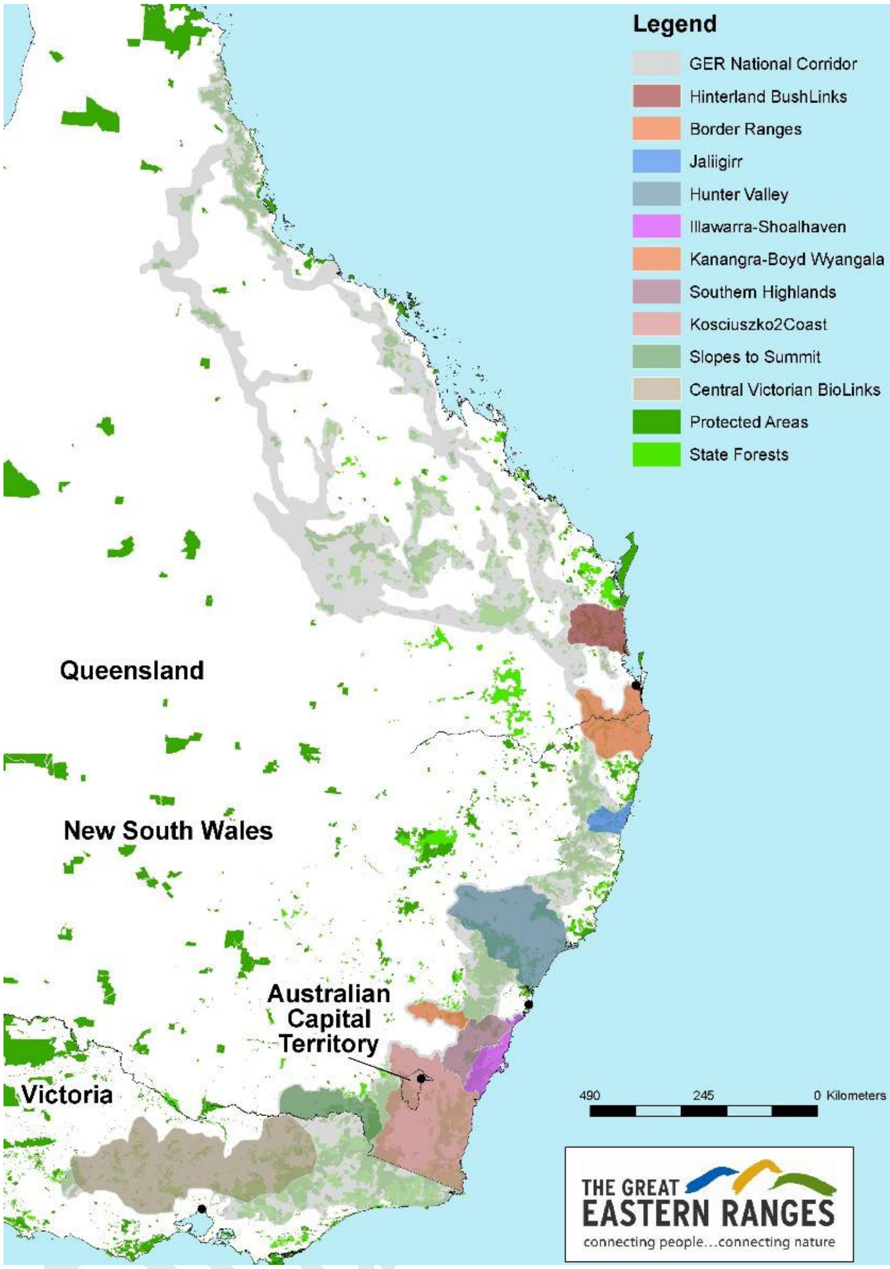


Fig. 2. Great Eastern Ranges network of regional partnership areas of connectivity conservation.

Europe

COREHABS to BearConnect: securing ROAMing in the wilderness corner of Europe

By Ancuta Fedorca, Transilvania University

Background and challenge

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

Approach

In 2015, an initiative called COREHABS (Ecological corridors for habitats and species in Romania) brought together six entities (two public universities, one national research institute and three NGOs) to design a national ecological network for ensuring habitat connectivity in tandem with sustainable development. COREHABS is providing corridor modelling outputs as a decision support tool for stakeholders, giving them the opportunity to develop infrastructure while considering the ecological measures necessary to ensure the long-term viability of species and habitats. In 2017, COREHABS combined forces with BEARCONNECT (Functional connectivity and ecological sustainability of European ecological networks – a case study with the brown bear), an organization focusing on the brown bear (*Ursus arctos*). To achieve wildlife corridor conservation and facilitate specific ecosystem processes the organizations are investigating the degree to which existing ecological networks, which include national protected areas and the Natura 2000 network, ensure landscape functional connectivity and ecological sustainability at different scales, and provide practical recommendations for connectivity conservation.

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

Development, local and regional councils, private forest owners, and NGOs.

Examples of ecological corridors in the network

Legislation (GO 57/2007) mandates the protection of connectivity by designating spatially explicit wildlife corridors based on field-informed modelling and empirical validation. An area of about 10x10 km has been identified as important to connectivity for brown bears between the Bucegi protected areas in the south and the Piatra Mare and Postavaru Protected Areas in the north. The majority of the land is owned by the state, small areas are held the community and private owners.

Results

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

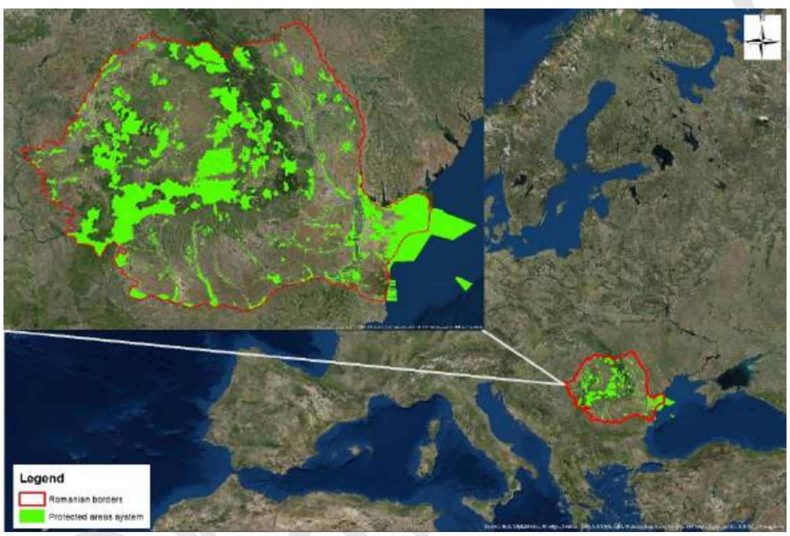


Fig. 1. Protected areas coverage at national level. The Carpathian mountain range runs in an arc through the center of Romania.

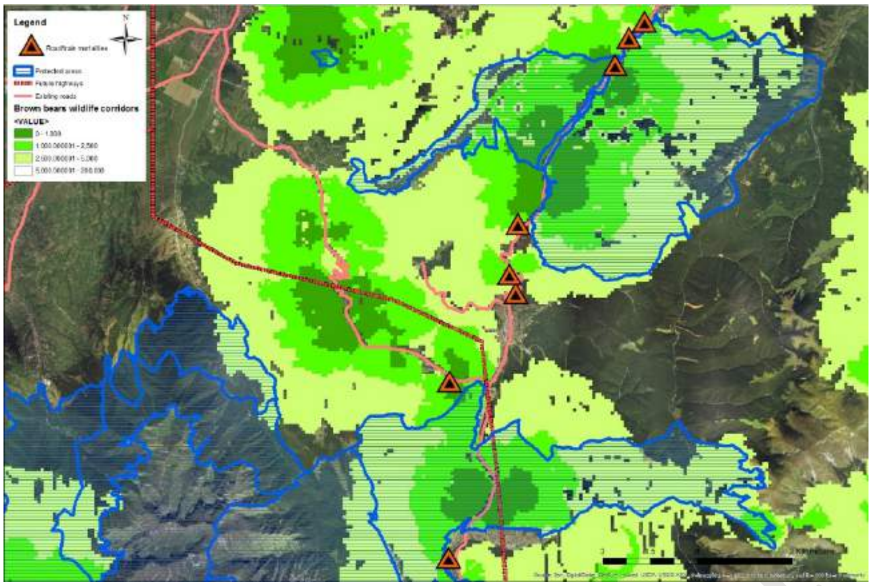


Fig. 2. The ecological corridor in the middle part of the map ensures connectivity between Bucegi Nature Reserve, Bucegi Natural Park, and Bucegi Protected Area in the north and Piatra Mare Protected Area and Postavaru Protected Area in the south.

Ecological connectivity in an urban context: Utrechtse Heuvelrug

By Rob H.G. Jongman, Independent scientist, and Chris Klemann, Province of Utrecht

Background and challenge

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

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

Approach

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

Examples of ecological corridors in the network

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

Accordingly, the province of Utrecht has elaborated plans and actions for the Utrecht Hills (http://www.hartvandeheuvelrug.nl/projecten/ecologische-verbindingen/). The project "Hart van de Heuvelrug" consists of two main ecological corridors that merge in the north (Figure 1). Whereas the western part is a forest corridor, the eastern ecological part is a heathland corridor. Both corridors contain many small tunnels to cross roads in the area (such as a tunnel in the south-east of the province under road N225 https://www.youtube.com/watch?v=hHAn-Clwy8Q&feature=youtu.be). To realize connectivity an additional five ecoducts have been built in these two conservation corridors, including the Ecoduct Op Hees (Figure 2), which was completed in 2013 and crosses a busy railroad line between the cities of Amersfoort and Utrecht. In addition to facilitating wildlife movements, it is also serves as a recreation corridor. For this purpose, the ecoduct has been made wider and cyclists and pedestrians have the possibility to cross the railway via the ecoduct.

Results

The two ecological corridors act as movement routes for mammals (such as roe deer, badger and tree marten) and as a temporary living and breeding area for smaller mammal species. Through these ecological corridors plants and animals can spread and move from the lake ‘Gooimeer’ in the north-west to the national park Veluwe in the south-east.

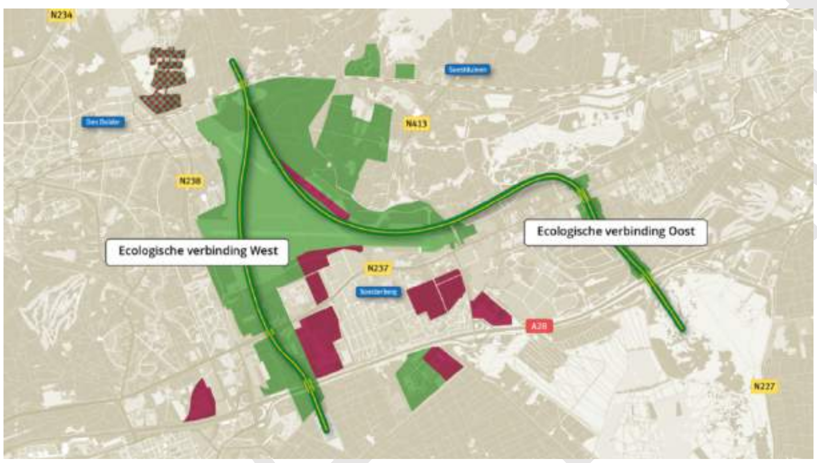


Fig. 1. Ecological corridors west and east in the Utrecht hills. The numbers indicate motorways (red) and link roads (yellow). The blue names indicate built-up areas, purple: heathland, green: forest

Fig. 2. Ecoduct Op de Hees, crossing the railroad Utrecht-Amersfoort. The recreation cycle path is situated at the left side of the bridge.

North America

Oak Ridges Moraine Natural Heritage System

By Kim Taylor Thompson, Ministry of Natural Resources and Forestry, Ontario, Canada

Challenge

The Oak Ridges Moraine (ORM) is a 160 km long upland area in Ontario, Canada. It is significant both hydrologically and ecologically, accounting for 20-60% of the base flow of streams and rivers in the area, creating an important cold-water fishery resource and providing a reliable drinking source of quality ground water. Within its boundaries, the ORM has many significant natural heritage features and areas, including areas of natural and scientific interest, a provincial park and numerous wetlands. There are also 11 endangered species, 10 threatened species, 6 special concern species and 24 tracked species with known habitat within the Oak Ridges Moraine boundary. This, combined with the significant ecosystems found within the moraine, shows the ORM to be making a significant contribution to the protection of in-situ biodiversity in southern Ontario. The moraine is 90% privately owned and 250,000 to 300,000 people live on the moraine. Also, a significant portion of the moraine is located immediately north of Toronto, Canada’s largest and most rapidly growing city, putting it under heavy development pressure. In recent years, roads, gravel pits, new subdivisions, and other human activities have threatened the moraine’s hydrological and ecological functions.

Approach

More than 30 years ago, the threats to the ORM from urban development resulted in land use conflict that went on for many years. Concern for the moraine’s environment led to the creation of STORM, the “Save the Oak Ridges Moraine” organization in 1991, which forced the government of Ontario to commission a number of studies to examine the significance of the ORM.

Since that time, political action resulted in several layers of legislation and policy protection:

1. The Provincial Policy Statement (PPS) provides provincial policy direction on land use planning in relation to natural heritage.
2. The Oak Ridges Moraine Conservation Act of 2001 requires that all decisions on planning applications shall conform with the Oak Ridges Moraine Conservation Plan. It directs municipalities to bring their official plans into conformity with the plan. The Act is in place as a statute for perpetuity.
3. The Oak Ridges Moraine Conservation Plan (ORMCP) provides land use and resource management direction. The municipalities must comply with the Oak Ridges Moraine Conservation Act and Plan. The actual management of properties is done by the land owners.
4. Municipal Official Plans guide both the short term and long-term development for a community or municipality.

Together, these laws and policies give legal protection to extensive core areas consisting of environmentally sensitive lands and long wide linkage areas that link the core areas, creating an ecological network for conservation (also called a natural heritage system in Ontario Provincial policy). These protections are primarily across private lands, many of which previously had been proposed for development, which are generally active agricultural lands outside of key natural heritage features and key hydrologic features. This ecological network for conservation ensures that the Oak Ridges Moraine area is maintained as a continuous natural landform and environment for the benefit of present and future generations while providing for land and resource uses and development that are compatible with biodiversity conservation objectives.

The ORM protects approximately 12 major Natural Core Areas connected by ecological corridors from intensive development. Most of the core areas are privately owned and are not classified under an IUCN protected area category or as conserved areas but protect biodiversity nevertheless. Urban development and industry are prohibited in both core and linkage areas with aggregate extraction and wayside pits being further prohibited in Natural Core Areas. Both core and linkage areas allow for activities such as forest management, agricultural uses, home businesses and home industries. The conservation objectives specifically of the linkage areas are to facilitate movement for all biodiversity, thereby allowing for species redistribution in response to climate change as well as preventing localized extinction and genetic isolation within the landscape.

Examples of ecological corridors in the network

The City of Vaughan is one of the municipalities within the Oak Ridges Moraine. Vaughan has one of the ORM's Natural Core designations running in a north-south direction with four linkage areas connecting to it. Ecological Corridor 1 is to the east of the Natural Core Area and is approximately 2.9 km long within the City of Vaughan and then extends to a length of approximately 8.3 km into King Township and is 2.8 km wide. Ecological Corridor 2 is west of the Natural Core Area and is approximately 2.6 km long and 1.5 km wide. Ecological Corridors 3 and 4 are south of the Natural Core Area and are much smaller. Ecological Corridor 3 is approximately 0.22 km wide and 1.7 km long while Ecological Corridor 4 is approximately 0.1 km wide and 1.4 km long. These lands are mostly under private ownership with a few small parcels owned by the "Corporation of the City of Vaughan". These lands are protected through both the Oak Ridges Moraine Conservation Plan and the City of Vaughan's Official Plan. The ecological corridors are under the "Natural Linkage Area Designation" in the Vaughan Official Plan and the allowable land uses within this zone are identical to those permitted within "Natural Linkage Areas" in the Oak Ridges Moraine Conservation Plan. In the By-Laws, the ecological corridors are either designated as "Open Space Environmental Protection Zone" or "Oak Ridges Moraine Zone" both of which have allowable land uses which are consistent with the spirit and intent of the both the Oak Ridges Moraine Plan and Act. In this way the direction to protect both the Natural Core Areas and Natural Linkage Areas (ecological corridors) is carried down through all levels of planning (provincial to municipal).

Results

The Oak Ridges Moraine land-use-planning process was precedent-setting in Canada, and possibly internationally. The Natural Core Area and Natural Linkage Area designations combine to protect an ecological network in perpetuity from urban development and aggregate extraction (the Core Areas) on lands which are mostly held in private ownership. Today, the Oak Ridges Moraine is a major ecological network for conservation, connecting to other ecological networks including the Niagara Escarpment Planning Area and the Lake Simcoe Planning Area. All municipalities within the Oak Ridges Moraine Conservation Plan area protect Natural Core and Natural Linkage Areas and have policies in their Official Plans and By- Laws in conformity with the ORMCP similar to the City of Vaughan. This is a requirement not only under the Oak Ridges Moraine Act, but under Section 3 (5) of Ontario's Planning Act.

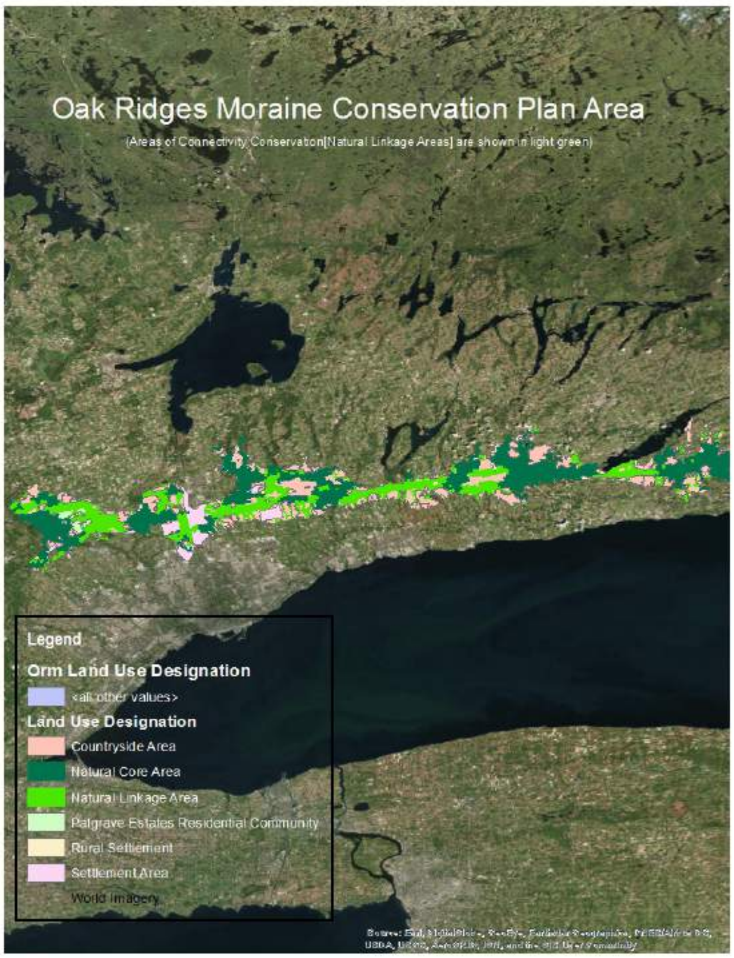
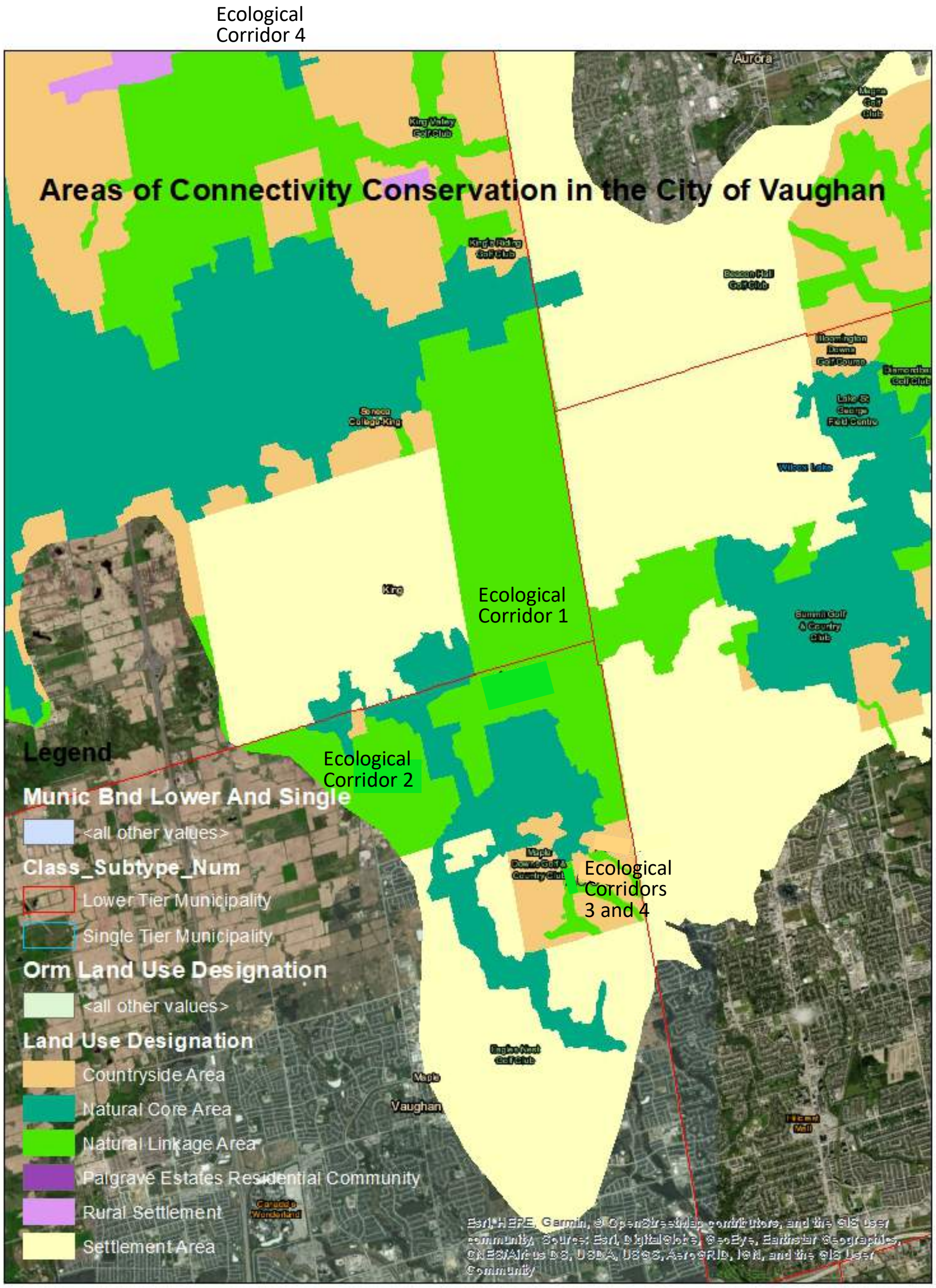


Fig. 1. Oak Ridges Moraine Conservation Plan Area. Ecological corridors are shown in light green while Natural Core Areas are shown in dark green. Together they create an ecological network for conservation.



Fig, 2. Ecological corridors in the City of Vaughan. The Natural Linkage Areas from the Oak Ridges Moraine Plan are considered ecological corridors.

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

By Jessica Levine, The Nature Conservancy

Challenge

The 80 million-acre (32 million-hectare) Northern Appalachian-Acadian ecoregion – which includes parts of five U.S. states and three Canadian provinces – contains the largest expanse of temperate broadleaf forest remaining in the world. Protected areas within the region have designations including national forest, state and provincial parks, national parks, and conservation easements. Yet these tracts are nested within a matrix of rural development and human uses. The region is only a half-day's drive from several major urban centers, including New York, Boston, and Montreal and is increasingly in danger of fragmentation from roads and human development. In 2009, public agencies and private organizations from across the bi-national region formed the Staying Connected Initiative (SCI) to address this challenge.

Approach

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

- Strategic land protection of priority parcels for connectivity such as forested pathways and riparian corridors
- Land use planning to steer development away from critical connectivity areas,
- Community outreach and engagement to build awareness and appreciation among private landowners and encourage private land management to maintain landscape permeability
- Habitat restoration in key locations, such as wetlands and roadside parcels
- Transportation mitigation to facilitate the movement of wildlife under roads, through improved bridges and culverts, signage, and fencing

At the regional scale, partners share best practices and lessons learned through a variety of communications outlets such as webinars, meetings, and written communications.

Example of an ecological corridor in the region: Jackson Valley in the northern Green Mountains

The Northern Green Mountain linkage area encompasses 722,183 acres (2,923 km2) and is centered on the spine of the Green Mountains. The linkage area stretches from Mt. Mansfield State Forest, which contains Vermont's highest peak, north to Mount Orford Provincial Park in

Quebec. Most of the area is forested, with agriculture and small towns and villages in the many valleys that bisect the mountain spine.

Within this linkage area, Jackson Valley is an important ecological corridor along the US-Canada border (Figure 2). A 2010 study of the 936-acre parcel found that it served as a key trans-border wildlife corridor for a range of animals. Jackson Valley links conserved Atlas Timberlands to the south, Jay State Forest to the east, and a 1,611 acre preserve in Quebec, protected by Nature Conservancy of Canada, to the north. In 2012, with funding from the U.S. Forest Legacy Program, The Trust for Public Land completed years of work to conserve Jackson Valley. The parcel is conserved as an ecological corridor with a conservation easement, held by the state of Vermont, that prevents development and subdivision and requires that its sustainable management for wildlife, timber, public recreation and soil conservation. It is open to hikers and skiers, and for other forms of non-motorized recreation.

Work to conserve this parcel as an ecological corridor is leveraged by the work of many SCI partners on both sides of the border. This work includes land protection in other parts of the linkage (over 30,000 acres to date), technical assistance to municipalities on land use planning to steer development away from critical connectivity areas, science along major roadways to identify potential sites for wildlife mitigation measures, and outreach to private landowners on sustainable forest management.

Results
Since 2009, SCI government and land trust partners have secured permanent protection of over 550,000 acres in the nine linkage areas. At least 30 land-use plans in the linkage areas, and all five State Wildlife Action Plans in the region explicitly incorporate wildlife connectivity. Partners from SCI helped to develop and advance the 2016 New England Governors and Eastern Canadian Premiers Resolution on Ecological Connectivity, and SCI government agency partners are leading its implementation. The resolution acknowledges the importance of ecological connectivity from a climate adaptation perspective and calls on relevant agencies within the eleven jurisdictions to work together for improved connectivity through transportation improvements, land protection, forest management, and other efforts.
Learn more: http://stayingconnectedinitiative.org/ and http://www.corridorappalachien.ca/en/

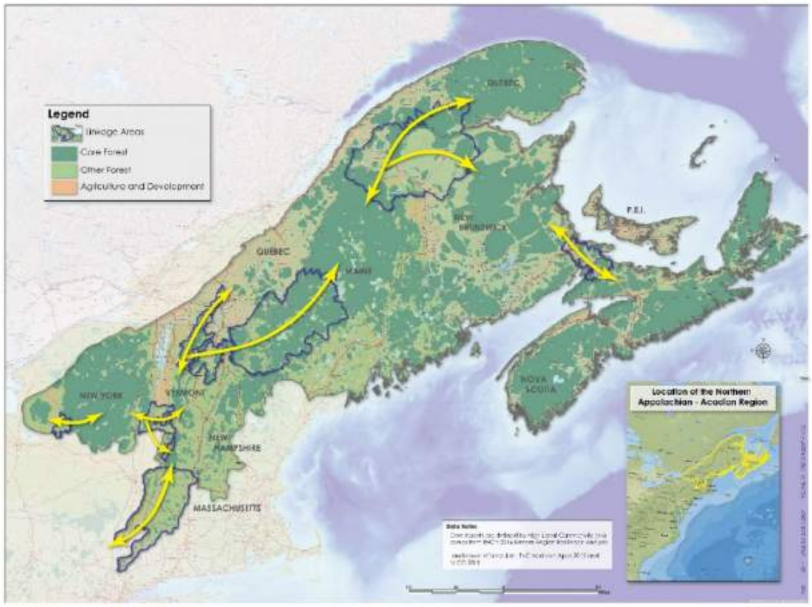


Fig. 1. Staying Connected Initiative region and linkage areas
Map credit: The Nature Conservancy

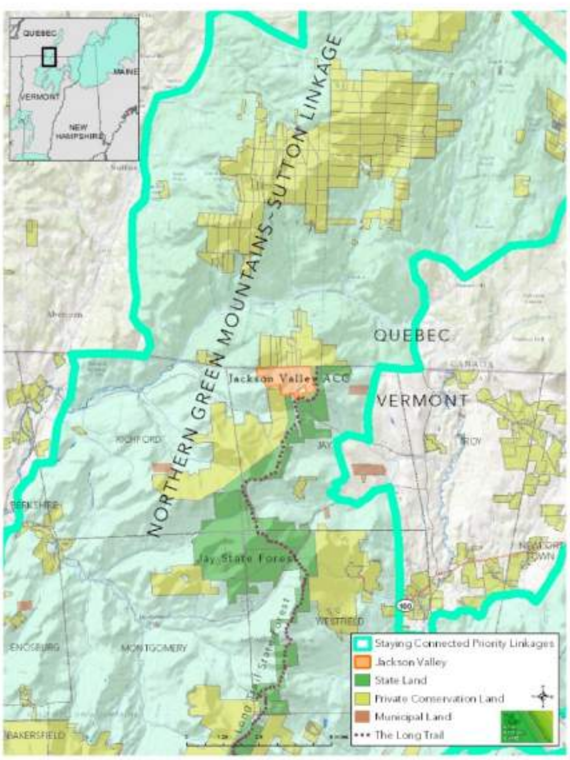


Fig. 2. Jackson Valley Ecological Corridor in the Northern Green Mountains linkage area
Map credit: The Trust for Public Land

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

By Jodi Hilty, Yellowstone to Yukon Conservation Initiative

Challenge

Increasing human activities threaten to sever this 3200 km long mountain region in western North America (Fig. 1) by impacting natural processes, wild areas, and wildlife ranging from grizzly bears and mountain caribou to jumping slugs and migratory birds. The region has a myriad of jurisdictions including many indigenous territories. The U.S. and Canadian governments have classified approximately 80% of the lands as public and 20% as private or tribal reservation lands.

Approach

Since 1993, more than 400 different entities have been or currently are engaged in conservation in the region. Conservation priorities range from protecting areas important for biodiversity and restoring and maintaining areas between protected and conserved areas for ecological connectivity, to directing development away from areas of biological importance and promoting people and wildlife to live in harmony across the region. Protected and restored areas include designations such as national, state and provincial parks, and wilderness areas. Areas important for connectivity may have a protected area designation, be private land conservation easements, or are under designated long-term management that allows for connectivity.

A joint Canada-U.S. not-for-profit organization, the Yellowstone to Yukon Conservation Initiative (Y2Y) brings partners together to achieve the vision of an ecological network for conservation. Since its inception the organization has worked with more than 300 partners. These include conservation groups, local landowners, indigenous entities, businesses, government agencies, funders and donors, and scientists. Y2Y has grown to currently 26 employees. A Board of Directors contributes to strategic planning and fiduciary oversight, and strategic advisors guide the organization's work.

Examples of ecological corridors in the network

Y2Y has worked to identify and protect key ecological corridors in the transboundary Cabinet Purcell Mountains where they have an ongoing partnership across a diversity of partners. They collaborated with land trusts to acquire key parcels in three primary pinch points identified by grizzly bear biologist Dr. Michael Proctor (Fig. 2). They have been and are restoring these properties to make them more secure for grizzly bears and other wildlife. Evidence suggests that grizzly bears are now using these ecological corridors.

Results

Tangible progress toward protecting an ecological network across the region can be seen across Y2Y. Protected areas increased from 11 to 21 percent across the region from 1993 to 2013, and many areas in between these protected areas now have increased conservation status to improve connectivity. Likewise, co-existence projects have multiplied across the region, some of which have significantly decreased human-wildlife conflicts. Some animals such as grizzly bears and wolves in the lower 48 states have increased in number and range, but significant conservation remains to be done as other animals such as mountain caribou have continued to decline in numbers across the region.

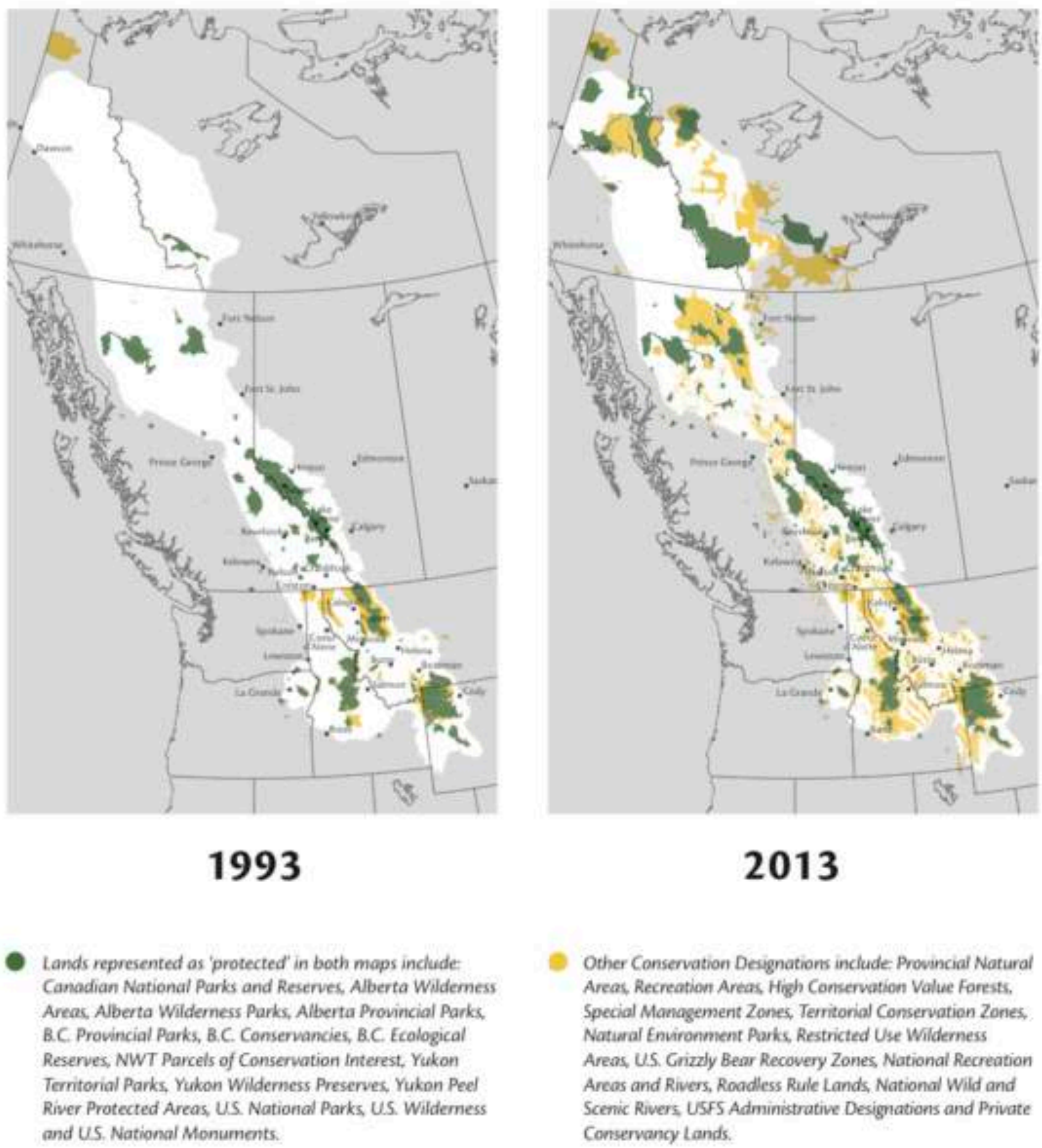


Fig. 1. Increase in protected areas over two decades in the Yellowstone-to-Yukon region of North America.

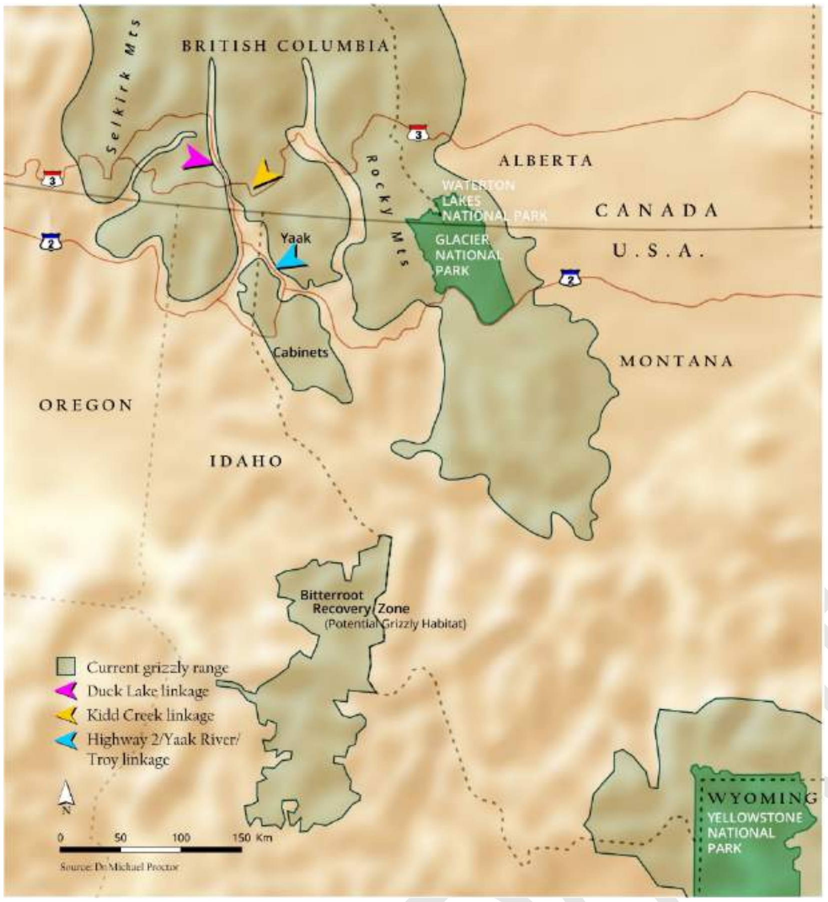


Fig. 2. The Y2Y transboundary region including key grizzly bear distribution and linkages. The three arrows point to three different linkages: The Duck Lake, Kidd Creek and Yaak River linkage where private land acquisitions have secured ecological corridors for grizzly bears (Map by Michael Proctor).

South America

Corridors for life: improving livelihoods and connecting forests in Brazil

By Laury Cullen, Instituto de Pesquisas Ecológicas, Brazil

Challenge

In Brazil, the largest forest remnants in the Atlantic Forest of the Interior lie in the Pontal do Paranapanema area in western São Paulo state. Originally a 124.000 ha public forest reserve was designated, but progressively encroached upon during 1960-1990 by large scale ranching and sugarcane establishments. In the mid-1990s, with pressure for land redistribution from the Landless Rural Workers' Movement (MST) and other groups, many such forests were first occupied by 6,000 families of MST affiliates and later expropriated for public land reform settlements, dramatically increasing the density of human occupation. After settlement of many landless households, the pace of land redistribution consequently slowed, and policies adopted at a national level now seek to consolidate existing settlements. There remains an urgent need to promote income generation for settlers. Also urgent is the protection of the remaining fragmented forests within this productive landscape before further pressures ensue. Although agrarian reform settlements and large land owners pose a series of barriers to biodiversity conservation, they also offer important and widely replicable opportunities for large scale landscape forest restoration.

Approach

The Corridors for Life project focuses on: 1) encouraging the adoption of "biodiversity friendly" land use options; 2) promoting the change in land use practices of small- and large-scale farmers in rural fragmented landscapes, and enhancing the adoption of sustainable agriculture and agroforestry in their lands; 3) improving the farmers' livelihoods and, 4) providing investors a return in the form of high-quality carbon offsets. Strategically selected areas for agroforestry and restoration will increase habitat viability by the formation of forest corridors to increase connectivity between "core" forest fragments ensuring genetic exchange. Where corridors are not feasible, this exchange will be achieved through developing stepping-stones. Agroforestry and restoration will also minimize degradation around biologically important landmarks, including the Morro do Diabo State Park, as the main reservoir of populations of key and endangered species. Enlarging and eventually connecting forest fragments are two main goals of reforestation projects. From an ecological perspective, this is essential to maintaining viable populations of flora and fauna and mitigating harmful edge effects, such as exposure to light and wind, diseases, and invasive species. The Instituto de Pesquisas Ecológicas (IPÊ) developed a "dream map" for Pontal de Paranapanema, the extreme western municipality of São Paulo where the NGO was founded. This plan for wide-scale reforestation of the Atlantic Forest takes into consideration information on local properties as well as proximity to public protected areas and existing forest fragments to calculate where reforestation efforts would be most efficient and effective (Fig. 1). Among the main project partners are state and federal rural extension agencies (ITESP and INCRA), private companies interested in the carbon neutralization market, companies that produce and commercialize ethanol and sugar, and other national and international electric power holding companies.

Example of an Ecological Corridors in the Network

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

Results

To date approximately 1800 ha of forest have been restored in Pontal do Paranapanema. This includes the 1.200 ha of the main ecological corridor, and another 600 ha in 5 smaller corridors and 90 agroforestry stepping stones on rural properties. This project consolidates strategies that represent sustainable livelihood alternatives for communities of the land reform movement in Brazil, leading to replication of good practices and policies in income generation and biodiversity conservation. At the policy level, IPÊ, together with other civil organizations in the region, are influencing policies that affect land use and conservation. Soon, the relevant laws on land use and settlement will be appropriate for supporting agroforestry and forest conservation. By using scientific evidence, cooperating with new settlers and large land owners, and collaborating with state and federal agencies, the program is implementing a land-use framework that promotes sustainable agriculture and biodiversity conservation over the long term.

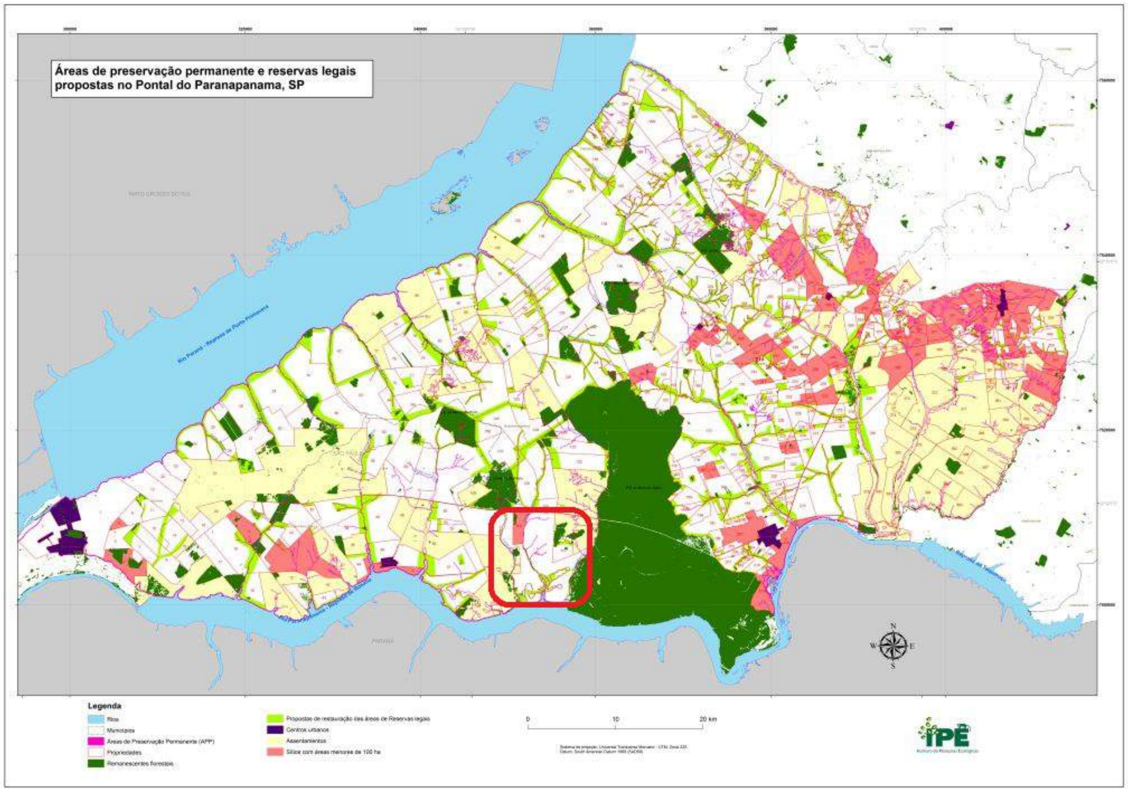


Fig. 1. IPÊ's Dream Map for Pontal de Paranapanema encompasses ecological and property data in order to estimate the best approach for reforestation efforts. The red polygon contains the largest ecological corridor (1.200 ha) restored in the Atlantic Forest linking the Morro do Diabo State Park and the Black Lion Tamarin Ecological Station.

Fig. 2. 2.4 million trees make up IPÊ's 1200-hectare ecological corridor connecting two main Atlantic Forest fragments, the largest in Brazil. (Image from IPÊ 2018).

Ecological corridors for Tigers in the central Indian and Eastern Ghats landscapes[…]

Mesoamerican Biological Corridor […]

Freshwater Connectivity

North America

Pacific Salmon Watersheds: Restoring Lost Connections

By Lauren Law and Jonathan Moore, Simon Fraser University

Background and Challenge

Coastal watersheds that drain into the North Pacific Ocean support populations of culturally- and economically-important migratory salmon. Pacific salmon are born and rear in freshwater environments and then migrate to the open ocean, where they forage and grow before returning to natal freshwaters to spawn. Across North American and Asian catchments that drain into the northern Pacific Ocean, 8% of high value catchments are at least partially protected, predominantly in areas that are higher in elevation and distant from the ocean (Pinsky et al. 2009). However, even if portions of catchments are protected, dams have disrupted the connectivity of many salmon systems. Dams, such as for hydroelectric production, may block or hinder salmon migration, alter hydrological regimes, and modify downstream river habitat. As a result of the imperiled or extirpated status of many salmon populations[1], there have been substantial investments in salmon conservation and recovery.

Approach

Over the last several decades, there has been increasing dam removal and mitigation to benefit salmon and other migratory fishes. Across the U.S., more than 1200 dams have been removed to until 2017[2]. Dam removal generally occurs through a decentralized decision-making process involving multiple stakeholder groups including federal agencies, state agencies, or private dam owners. Although some dam removals have been voluntary endeavours, many removal projects have been the result of legal proceedings that fall under the regulatory powers of the Federal Energy Regulatory Commission. Initial removal efforts were focused on older dam structures, which were too costly to maintain and no longer in compliance with modern safety standards. However, in recent years there has been a greater focus on dam removal for environmental

[1] Gustafson, R.G., R.S. Waples, J.M. Myers, L.A. Weitkamp, G.J. Bryant, O.W. Johnson, and J.J. Hard. 2007. Pacific Salmon Extinctions: Quantifying Lost and Remaining Diversity. Conservation Biology 21: 1009-1020.

[2] Bellmore, J.R., J.J. Duda, L.S. Craig, S.L. Greene, C.E. Torgersen, M.J. Collins, and K. Vittum. 2017. Status and trends of dam removal research in the United States. Wiley Interdisciplinary Reviews: Water 4: e1164.

protection and habitat restoration. In the U.S., the Wild and Scenic River Act (1968), is a legal mandate for the preservation of rivers in a free-flowing state that have exceptional natural, cultural, and recreational values.

Example of an Ecological Corridor in the Network

One of the largest dam removals that restored connectivity in a protected salmon watershed was on the Elwha River. The vast majority of the 72 km-long river resides within Olympic National Park, Washington, USA. Historically one of the most productive salmon rivers in the Pacific Northwest, in the early 1900s, two dams were constructed, disconnecting the protected upper portion of the watershed from the seascape that migratory salmon rely on. Migration of salmon was blocked, and the movement of sediment and woody debris was disrupted. The building of these large-scale dams led to a 90% reduction in fish populations, a loss of habitat connectivity, and decline in habitat complexity[3].

In 1992, the Elwha River Ecosystem and Fisheries Restoration Act authorized the removal of the dams to restore the river ecosystem. The National Park Service removed the dams using a phase-removal approach, starting with the removal of the smaller dam beginning in 2011 and eventually completing the removal of the larger dam in 2014.

Results

The removal of the Elwha River dams led to renewed riverine fluxes of sediments and large woody debris downstream that had been trapped in the dam reservoirs for nearly a century. Approximately 30 million tons of sediment were released, causing ~60 hectares of river delta growth[4]. The supply of sediment and large wood to the fluvial system restored channel morphology to its former complexity and resulted in increased river braiding, sediment-bar growth, and pool filling.

Renewed connectivity of upstream protected habitat with the seascape in the Elwha River watershed is fostering the return of Chinook, coho, chum, sockeye, and pink salmon as well as anadromous trout (e.g. steelhead and bull trout). Scientist have already observed record numbers of Chinook salmon returning to the Elwha with high returns anticipated to follow for other species. About 30,000 Chinook salmon and coho salmon and 270,000 for pink salmon are

[3] Pess, G.R., M.L. McHenry, T.J. Beechie, and J. Davies. 2008. Biological impacts of the Elwha River dams and potential salmonid responses to dam removal. Northwest Science 82: 72-91.

[4] Ritchie A.C., J.A. Warrick, A.E. East, C.S. Magirl, A.W. Stevens, J.A. Bountry, T.J. Randle, C.A. Curran, R.C. Hilldale, J.J. Duda, G.R. Gelfenbaum, I.M. Miller, G.R. Pess, M.M. Foley, R. McCoy and A.S. Ogston. 2018. Morphodynamic evolution following sediment release from the world's largest dam removal. *Nature Scientific Reports* 8: 13279

expected to return annually[3]. Salmon returns will also eventually sustain local and regional fisheries.

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

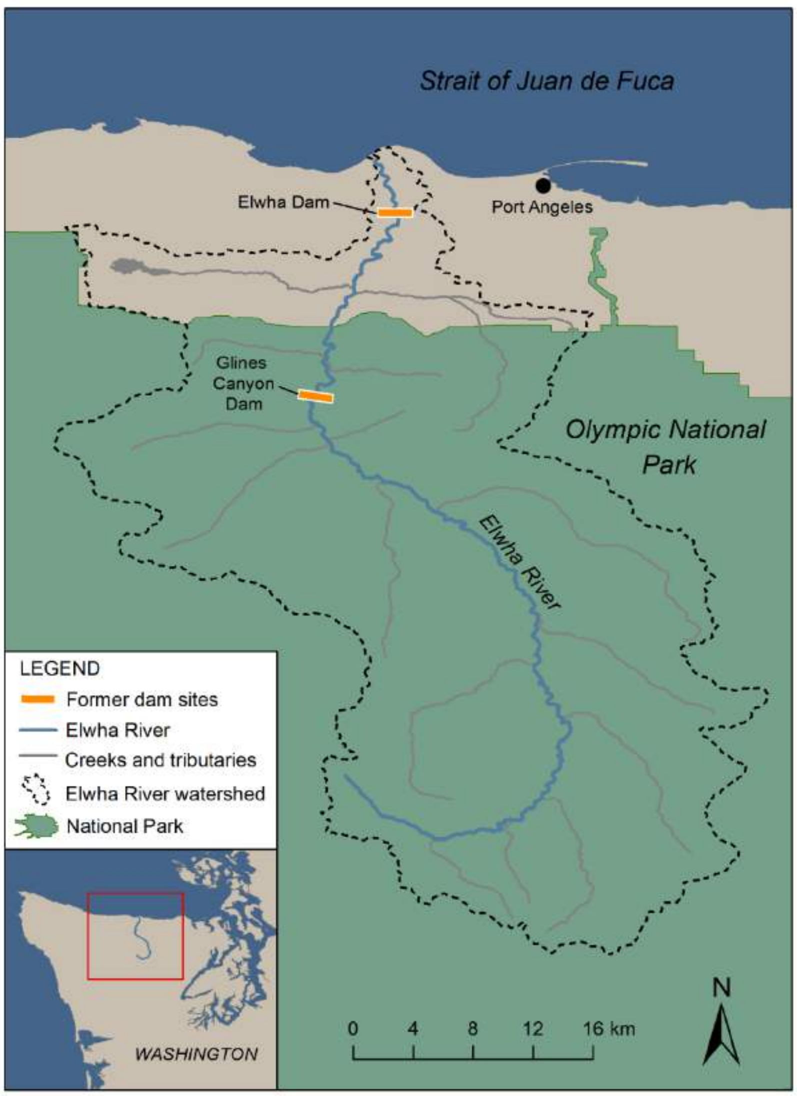


Fig. 1: Elwha River watershed within Olympic National Park, Washington, US. The removal of the Elwha Dam and Glines Canyon Dam restored connectivity between the upper and lower portions of the watershed.

Marine Connectivity

Australia

The Great Barrier Reef – Systematically protecting connectivity without connectivity data

By Michael Bode, School of Mathematical Sciences, Queensland University of Technology, Australia, and Jon C. Day, ARC Centre of Excellence for Coral Reef Studies, James Cook University, Australia.

Background and Challenge

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

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

Approach

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

The GBRMP was substantially rezoned and expanded in 2003, based on systematic planning principles. Eleven Biophysical Operating Principles (BOPs)[1] were devised to protect representative examples of each of the GBR's 70 bioregions (30 reef habitat; 40 non-reef).[2] The maintenance of connectivity was also an explicit goal of the marine park – both the total size of the no-take marine reserves, and their individual locations. As an overarching goal, BOP 9 recommended that no-take zones be chosen to maintain connectivity across the GBR. However, minimal data about connectivity was available at the time of the rezoning, and so several of the BOPs were designed to prioritise potential proxies for each form of connectivity. BOPs 1 and 2 aimed to protect larval connectivity, particularly self-recruitment. For example, BOP 2 recommended that no-take zones be as large as possible, motivated by models indicating self-recruitment increased with reserve dimensions. BOP 4 recommended that no-take zones include whole reefs where possible, to protect connectivity for foraging and migrating adults.

Results

Little information on connectivity was available for the 2003 rezoning, so proxies were used to design networks of no-take zones that would ensure the exchange of larvae between such areas, as well as the export of larvae to fished areas. Recent empirical studies and biophysical modelling demonstrate that this approach was successful to some extent, with larval dispersal connecting no-take zones at a range of scales, from local self-recruitment,[3] to consistent bi-directional exchanges over 250 km[4,5].

There are three possible reasons why a network of no-take zones that was not designed with explicit connectivity data was nevertheless able to achieve connectivity outcomes. First, the GBRMP contains a very large proportion of effective no-take zones (33% of the entire area). We would generally expect that higher levels of protection will achieve superior connectivity

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[1] *GBRMPA Technical Information Sheet* No. 6. http://www.gbrmpa.gov.au/__data/assets/pdf_file/0011/6212/tech_sheet_06.pdf.

[2] Fernandes, L., et al. (2005). 'Establishing representative no-take area in the Great Barrier Reef: large-scale implementation of theory on marine protected areas'. *Conservation Biology* 19:1733–1744.

[3] Harrison, H.B., Williamson, D.H., Evans, R.D., Almany, G.R., Thorrold, S.R. (2012). 'Larval export from marine reserves and the recruitment benefit for fish and fisheries'. *Current Biology* 22, 1023–1028.

[4] Williamson, D.H., Harrison, H.B., Almany, G.R., Berumen, M.L., Bode, M., Bonin, M.C, Choukroun, S., et al. (2016). 'Large-scale, multidirectional larval connectivity among coral reef fish populations in the Great Barrier Reef Marine Park. Molecular ecology'. 25(24): 6039-6054.

[5] Bode, et al. (In press). 'Successful validation of a larval dispersal model using genetic parentage data'. *PLOS Biology*.

outcomes. Second, explicit connectivity proxies form the basis of several BOPs, and these likely improved connectivity outcomes beyond the simple null expectation.

The final reason is less obvious. The GBRMP is a global exemplar of a systematically planned network. Several BOPs (specifically 5 & 7) aimed to create a "representative" network, with no-take zones distributed across bioregions, latitudes, and cross-shelf position. While these goals do not mention connectivity, evidence suggests that representation allows no-take networks to effectively protect previously unknown biodiversity features (e.g. mesophotic reefs[6]). It is entirely possible that representative principles are also responsible for the protection of connectivity in the GBR.

[6] Bridge, T.C.L, Grech, A.M., and Pressey, R.L. (2016). 'Factors influencing incidental representation of previously unknown conservation features in marine protected areas'. *Conservation Biology* 30.1: 154-165.

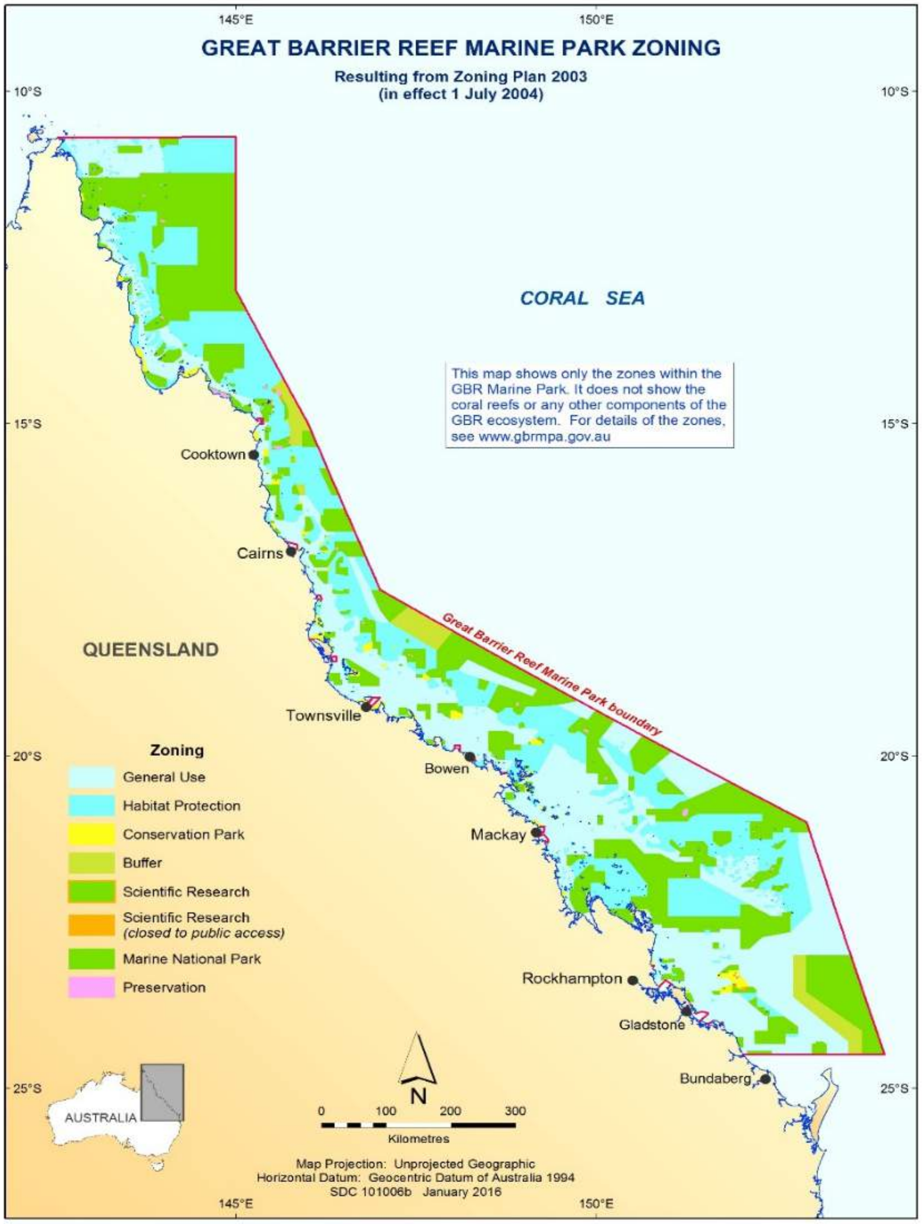


Fig. 1: Current zoning for the Great Barrier Reef Marine Park (resulting from the 2003 Zoning Plan - in effect 1 July 2004) © Commonwealth of Australia.

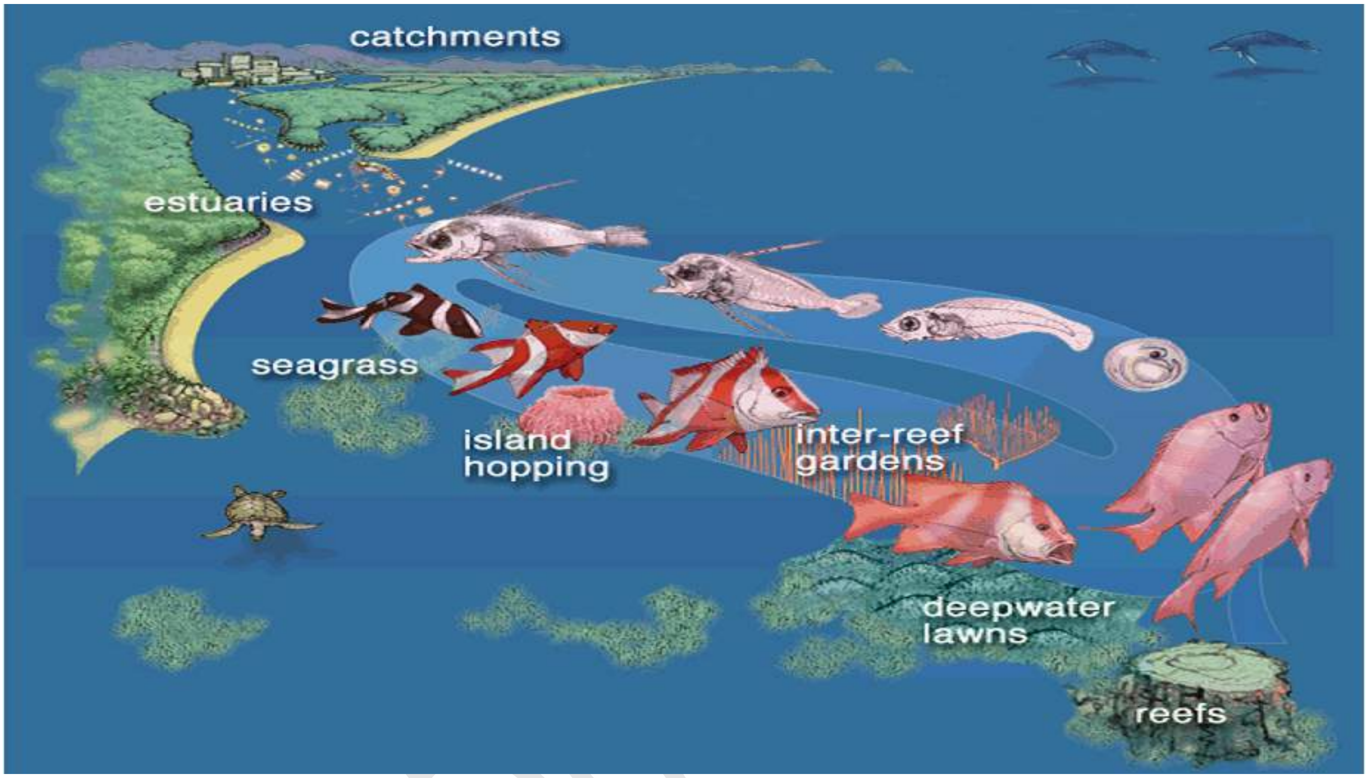


Fig. 2: '*Crossing the Blue Highway'*: The Red Emperor (*Lutjanus sebae*) spends different stages of its life cycle utilising different habitats across the GBR © *Russell Kelley/Australian Coral Reef Society,* http://www.russellkelley.info/print/the-blue-highway/.

North America

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

By Jennifer Caselle, Marine Science Institute, University of California Santa Barbara; Mark Carr, Department of Ecology and Evolutionary Biology, University of California Santa Cruz; and J. Wilson White, Coastal Oregon Marine Experiment Station, Oregon State University

Background and Challenge

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

In 1998, a group of fishermen, managers, and other citizens were concerned about declining fishery resources such as abalone, lobsters, and nearshore rockfishes in the near-shore ecosystems including kelp forests in southern California, USA.

Approach

This group approached the California Fish and Game Commission with a proposal to set aside areas for protection in the northern Channel Islands, a chain of 4 islands northwest of Los Angeles, and separated from the mainland by the Santa Barbara channel. In 2003, following a multi-year public process, the State of California, in collaboration with the Channel Islands National Park, created 13 marine protected areas (MPAs) within state and national park waters. In 2007, the National Oceanic and Atmospheric Administration extended eight of these areas into Channel Islands National Marine Sanctuary waters (Figure 1). Thus, the MPAs encompass both state and federally managed waters. The objectives of the MPAs were to help restore biodiversity, ecosystem health and fisheries species by protecting marine life and habitats. Extending from the intertidal zone to depths of 1400 meters, the MPAs encompass a diversity of ecosystems, distinguished by seafloor type (rock versus sand) and depth.

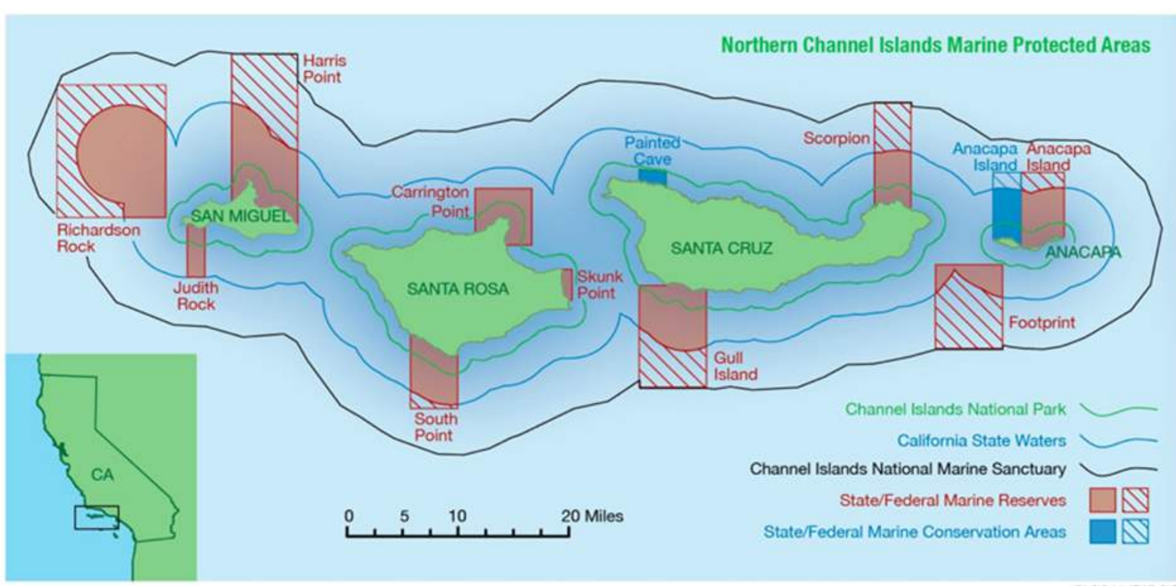
Today's Channel Islands MPA network has a large number of overlapping agency jurisdictions. Eleven federal, state, and local agencies have some jurisdiction in the planning region. While both the Channel Islands National Marine Sanctuary (CINMS) and the Channel Islands National Park (CINP) overlap around the northern Channel Islands, neither agency regulates commercial or recreational fishing. The California Department of Fish and Wildlife (CDFW) manages all fisheries in state waters (within 5.6 km of the shore), while the California Fish and Game Commission (an appointed body) has authority to set all state fishery regulations, including the creation of MPAs.

Examples of ecological corridors in the network

Though not originally designed as a network of MPAs connected to one another by the dispersal of young (i.e., fish and invertebrate larvae), subsequent analyses of oceanographic currents and larval dispersal patterns indicated that young generated in the MPAs very likely are transported to and contribute to the replenishment of populations and communities in other MPAs, thus forming an MPA network. The primary way corridors have been analysed is by simulating the movement of larvae using numerical ocean circulation models that describe currents in the region. For example, Watson et al. (2010[1]) simulated the movement of larvae of three important fishery species – kelp bass and kelp rockfish – to and from sites throughout southern California, including the Channel Islands MPAs. The simulations provide the probability of larvae traveling from one location to another; Watson et al. multiplied those probabilities by estimates of the spawning biomass at each location to predict how many larvae travelled along each potential connectivity corridor. The analysis showed that kelp bass larvae produced inside MPAs on Santa Cruz and Anacapa islands likely disperse to other MPAs in the network and to fished areas; the same was true of kelp rockfish larvae produced in MPAs on San Miguel Island (Fig. 2). Thus, the MPAs are linked by connectivity corridors, but different corridors are used by different species, depending on habitat. In this case, kelp bass prefer the warmer water of the eastern islands while kelp rockfish prefer the cooler western waters.

Results

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



[1] Watson, J.R., S. Mitarai, D.A. Siegel, J.E. Caselle, C. Dong, and J.C. McWilliams. (2010). 'Realized and potential larval connectivity in the Southern California Bight'. *Marine Ecology Progress Series* 401:31-48.

Fig. 1. Map of the distribution of marine protected areas across the Northern Channel Islands archipelago off the coast of southern California (see inset). Map indicates the jurisdictional ranges of state and federal institutions and the two types of protected areas (Marine Reserves and Marine Conservation Areas).

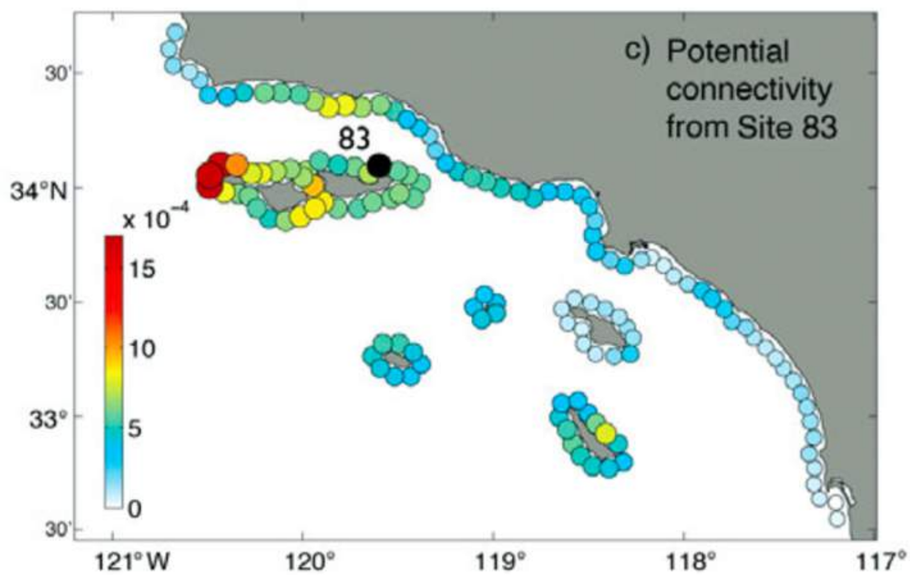


Fig. 2. Predicted dispersal of larval kelp bass using an ocean circulation model of the Southern California Bight (Watson et al., 2010). Each coloured circle corresponds to a spatial node in the model from which simulated larvae could be released and to which they can settle. In this example, the connectivity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