CMS

TECHNICAL GUIDANCE ON SYSTEMATIC CONSERVATION PLANNING WITH CONNECTIVITY

CENTER for LARGE LANDSCAPE CONSERVATION

Technical Guidance on Systematic Conservation Planning with Connectivity

Report prepared for the Secretariat of the Convention on Migratory Species (CMS) by the Center for Large Landscape Conservation, April 2024.

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ACKNOWLEDGEMENTS

Dagmar Zikova, CMS Scientific Adviser

Dunia Sforzin, AEWA and CMS Information Assistant, for the layout

SUGGESTED CITATION

Faselt, J, Keeley, A, Laur, A, and Oppler, G. 2024. Technical Guidance on Systematic Conservation Planning with Connectivity. Center for Large Landscape Conservation and Convention on the Conservation of Migratory Species of Wild Animals. Bozeman, USA and Bonn, Germany.

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1. Executive Summary

This Technical Guidance lays out a science-based approach to planning the expansion of ecological networks for conservation while increasing their ecological representativeness and connectivity. Both of these characteristics of ecological networks are key to the persistence of biodiversity through time.

With a primary goal of assisting Parties to the Convention on the Conservation of Migratory Species of Wild Animals (CMS), the guidance is relevant for governments, conservation organizations, land planners, and any entity aiming to strategically expand protected area networks in alignment with Target 3 of the Convention on Biological Diversity's (CBD) Kunming-Montreal Global Biodiversity Framework (KMGBF).

The approach laid out in the guidance combines Systematic Conservation Planning (SCP) and ecological connectivity modeling – hereafter referred to as "connectivity modeling"; both methods are generalizable and adaptable globally and can be applied to diverse landscapes (i.e., mountains, wetlands, deserts, forests).

In the past, connectivity considerations have not commonly included in protected area planning. However, in recent projects in Saudi Arabia and Jordan, the Center for Large Landscape Conservation combined the well-developed science-based approaches of SCP and connectivity modeling to provide decision support maps for expanding networks of protected and conserved areas. These projects incorporated modeled ecological corridors or areas important for connectivity as features in the SCP analysis, ensuring that the resulting conservation plan presents a connected, representative ecological network for conservation.

The comprehensive approach of SCP features stakeholder engagement and considers different values and costs, including economic, social, and environmental, helping to ensure a balanced conservation strategy. Connectivity modeling aids in identifying optimal movement paths and designing conservation corridors. The integration of SCP and connectivity modeling allows for decision support in expanding ecological networks to meet conservation goals effectively while minimizing costs and conflicts.

After presenting the series of steps to conduct SCP with connectivity, the guidance concludes with an example of where this could be applied in the transboundary Mountain Ecosystems of Koytendag (MEK) including parts of Turkmenistan and Uzbekistan. This region is well-suited for future application of the approach detailed here, as some preliminary work has been undertaken by CLLC and partners in a project supported by the Critical Ecosystems Partnership Fund (CEPF).

This guidance is intended to help strategically inform and direct development and implementation of projects that integrate creation or expansion of protected areas (PAs) and Other Effective area-based Conservation Measures (OECMs) with more wholistic design of ecological corridors, and thereby establishment of well-connected, representative ecological networks. It contributes to conservation planning activities across Central Asia and the world, including objectives to improve transboundary management for PAs, OECMs and migratory species to meet global conservation commitments, especially implementation of the CMS Samarkand Strategic Plan for Migratory Species 2024-2032 and the CBD KMGBF.

2. Introduction

The Convention on the Conservation of Migratory Species of Wild Animals (CMS), a legally binding treaty of the United Nations, provides the primary specialized intergovernmental framework for cooperation on ecological connectivity and migratory species. For over a decade, the Convention has been enhancing understanding and delivery of connectivity conservation approaches. This has included resolutions and decisions on meeting the needs of migratory species by advocating selection of areas for conservation across ranges, setting network-scale objectives, eliminating barriers to movement, reducing habitat disturbance and fragmentation, strengthening transboundary efforts, and implementing measures on the ground based on best-available information and guidance.[1]

Recently in February 2024, the 14th Conference of the Parties to CMS adopted Resolution 14.16 "Ecological Connectivity" which includes an update to the definition of ecological connectivity as the "unimpeded movement of species, connection of habitats without hindrance and the flow of natural processes that sustain life on Earth" (CMS, 2024a). Resolution 12.26 also recognizes "the important role played by existing ecological networks worldwide in the conservation of migratory species particularly through the role of these networks in supporting connectivity [...]."[2] Additionally, operative paragraph 1 of the Resolution "Urges Parties and invites others to give special attention to the issues highlighted in this Resolution […], including in particular when […] (ii) identifying, prioritizing, designating, restoring and managing protected areas and developing other effective area-based conservation measures, both within and beyond areas of national jurisdiction, taking account *inter alia* the best available science, **the need for connectivity to be a key factor in the definition of appropriate conservation management units**, including at the flyway, landscape or seascape scale, and the need for actions to be addressed to the connections between places as well as to the places themselves;"

By building a body of commitments, resources, and actions, CMS is now leading the integration of ecological connectivity as key to achieving the objectives of many Multilateral Environmental Agreements, including the Convention on Biological Diversity, Ramsar Convention on Wetlands, UN Convention to Combat Desertification, UN Framework Convention on Climate Change, and UNESCO World Heritage Convention. Focusing in on CBD, Goal A of the KMGBF calls for Parties to collectively maintain or enhance the integrity, connectivity, and resilience of ecosystems.[3] To reach this goal, Target 3 calls for countries to:

> *"Ensure and enable that* ***by 2030 at least 30 per cent of terrestrial, inland water, and of coastal and marine areas,*** *especially areas of particular importance for biodiversity and ecosystem functions and services, are* ***effectively conserved and managed through***

[1] CMS website, "Ecological Connectivity". https://www.cms.int/en/topics/ecological-connectivity.
[2] UNEP/CMS/Resolution 14.16 "Ecological Connectivity". https://www.cms.int/sites/default/files/document/cms_cop14_res.14.16_ecological-connectivity_e.pdf.
[3] CBD COP15 Decision 15/4: https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf.

ecologically representative, <u>well-connected</u> and equitably governed systems of protected areas and other effective area-based conservation measures, recognizing indigenous and traditional territories where applicable, and integrated into wider landscapes, seascapes and the ocean*, while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of indigenous peoples and local communities, including over their traditional territories.*"

Currently, just under 17% of terrestrial and inland water and 8% of marine areas are conserved as PAs and OECMs. Out of the total terrestrial surface, only 7.04% is both protected and connected, rising to 7.84% with OECMs (UNEP-WCMC & IUCN, 2024). With adoption of the KMGBF, countries around the world are tasked with increasing this coverage to at least 30% while ensuring that the resulting global ecological network for conservation is ecologically representative and well-connected. Bolstering commitments and plans to achieve the KMGBF, Resolution 14.3 "CMS Engagement in CBD Processes Including the Global Biodiversity Framework" adopted by the 14th Conference of the Parties to CMS in February 2024 reinforces the contributions of CMS toward achieving the KMGBF. This includes facilitating action for conserving ecological connectivity for migratory species and their habitats,[4] and Parties acknowledging therein the importance of strengthening cooperation with CBD, as well as other multilateral environmental agreements to more efficiently and effectively implement common aims.

Connectivity links not only species, places, and processes, but is fostering greater cooperation across multilateral environmental agreements. It is fundamental for functioning ecosystems, can maximize the effectiveness and health of protected and conserved areas within larger landscapes and seascapes, and is an important component of restoration and spatial planning.[5] To help maximize consideration and application of these aspects, scientists have developed effective approaches to provide decision support for expanding the existing ecological network to meet related objectives. **Systematic Conservation Planning** is a strategic approach used to identify and prioritize new or increasing coverage of PAs as part of more comprehensive protected area systems in any region or at any scale based on ecological, biological, and socioeconomic factors. It involves analyzing data on species distributions, habitat types, and human activities to create comprehensive conservation plans. By considering various criteria and employing specialized algorithms, SCP aims to maximize conservation outcomes while minimizing costs and conflicts (Margules and Pressey 2000; Sinclair et al. 2018). **Connectivity modeling** uses computer algorithms and analytical techniques to represent and predict the movements of organisms within a landscape. The resulting maps are a fundamental tool to visualize, analyze, and communicate ecological interactions within landscapes. Combining SCP and connectivity modeling is a powerful approach to provide decision support for planners

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[4]UNEP/CMS/Resolution 14.3 "CMS Engagement in CBD Processes Including the Global Biodiversity Framework". https://www.cms.int/sites/default/files/document/cms_cop14_res.14.3_cms-engagement-in-cbd-processes-including-kmgbf_e_.pdf.

[5] "Brief: Ecological Connectivity in Global Policy". https://conservationcorridor.org/wp-content/uploads/Brief_Ecological-Connectivity-in-Global-Policy.pdf.

tasked with expanding a country's or region's ecological network to meet the requirements of ecological representation and connectivity spelled out in Target 3 of the KMGBF.

These guidelines lay out how to undertake assessment and planning that can maximize representation and connectivity when adding or increasing coverage of protected and conserved areas to promote the persistence of biodiversity.

3. Systematic Conservation Planning

SCP is a strategic, comprehensive, and scientific approach that has been utilized for over 20 years by governments and non-governmental organizations around the world to formulate effective conservation strategies and manage landscapes and seascapes, including for mobile species in terrestrial,[6] marine,[7] and freshwater[8] ecosystems, as well as across realms.[9] Its goal is to achieve the most beneficial outcomes for both biodiversity and people (Margules and Pressey 2000; Sinclair et al. 2018) by identifying sets of sites that conserve a full spectrum of biodiversity and important social-ecological features in a cost-effective manner (Margules and Pressey 2000). SCP objectives are to identify new areas for protection and to provide decision support to land managers for mitigating the impacts of development and other anthropogenic activities.

SCP is underpinned by the CARE principles—Connectivity, Adequacy, Representation, and Efficiency—which guide the identification of areas important for conservation (Kukkala and Moilanen 2013; McGowan 2021). **Connectivity** in the context of SCP emphasizes the importance of maintaining or enhancing ecological connectivity within and between PAs and OECMs. More information on connectivity in a broader context is shared below. **Adequacy** refers to ensuring that the size and distribution of PAs and OECMs are sufficient to maintain viable ecosystems and populations of target species. It involves assessing the minimum area requirements for species and ecosystems to thrive and designing PAs and OECMs that meet or exceed those requirements. Adequate PAs and OECMs can support viable populations, reduce the risk of extinction, and maintain ecosystem functions and services. **Representation** focuses on ensuring that the full range of biodiversity, including species, ecosystems, and ecological processes, is adequately represented within PAs and OECMs. It involves identifying and protecting representative examples of different habitats, ecosystems, and species assemblages, including those that are rare, unique, or of high conservation value. Representing biodiversity comprehensively enhances the resilience of PAs and OECMs and conserves evolutionary and ecological processes. **Efficiency** is about optimizing the allocation of resources to achieve conservation goals cost-effectively. It involves prioritizing areas for conservation based on ecological significance, threats, and feasibility, as well as considering socio-economic factors and stakeholder preferences. By identifying priority areas for protection and management, conservation planners can maximize conservation outcomes with limited resources and minimize trade-offs between biodiversity conservation and other societal needs.

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[6] See for example: Smith, Robert J., et al. Designing a transfrontier conservation landscape for the Maputaland Centre of Endemism using biodiversity, economic, and threat data. Biological Conservation 141.8 (2008): 2127-2138. https://www.sciencedirect.com/science/article/abs/pii/S0006320708002176?via%3Dihub.

[7] See for example: Dwyer, Ross G., et al. Using individual-based movement information to identify spatial conservation priorities for mobile species. Conservation Biology 33.6 (2019): 1426-1437. https://conbio.onlinelibrary.wiley.com/doi/abs/10.1111/cobi.13328.

[8] See for example: Allan, J.R., et al. Navigating the complexities of coordinated conservation along the River Nile. Science Advances 5 (2019). https://www.science.org/doi/10.1126/sciadv.aau7668.

[9] See for example: Hermoso, Virgilio, et al. Conservation planning across realms: Enhancing connectivity for multi-realm species. Journal of Applied Ecology (2020). https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/1365-2664.13796.

Following the four principles will ensure that biodiversity is sustained over time (Possingham et al., 2006; Sarkar et al., 2006), because the conservation network solution will be connected, adequately protect species and habitats, represent the diversity of species and ecosystems, and accomplish conservation goals efficiently without undue cost or impact on human activities (McGowan 2021).

A strength of SCP is that it allows the users to consider different costs, including economic, social, and environmental costs, to ensure a balanced approach to conservation (Naidoo et al. 2006). Furthermore, in addition to conservation features, planners can include cultural features and ecosystem services, as these elements can have intrinsic value in the focal landscapes (Chan et al. 2012). An important aspect of SCP is its transparency—it is not a black box. The steps, data, and decisions involved in the SCP process are clearly documented and communicated, ensuring that stakeholders understand how and why certain areas are prioritized for conservation.

The conservation network solutions generated by SCP processes can be implemented with a comprehensive approach to biodiversity conservation that may include a combination of PAs, OECMs, and other means. OECMs are geographically defined spaces that are governed and managed in ways that achieve positive and sustained long-term conservation outcomes (IUCN, 2019). Having a toolbox of flexible and inclusive conservation strategies is key to successful implementation of SCP-designed ecological networks.

The SCP approach extends beyond ecological considerations, incorporating critical elements such as stakeholder engagement, financial considerations, and adaptive management. These elements ensure the practical implementation and long-term sustainability of the resulting conservation plans. Key steps in the SCP process are (1) engaging with rightsholders and interested parties for consultation, (2) defining clear and measurable goals, and (3) conducting iterative analyses and developing and testing various network configurations that meet predefined targets. Various software tools are available to conduct the complex spatial analyses necessary for SCP. These include Marxan, Zonation, C-Plan, ResNet, and the R package 'prioritizr'. Here, we are focusing on Marxan, a widely used tool. Information about the alternative tools is in Appendix 1.

Several versions of Marxan have been developed, including Marxan with Zones and Marxan Connect. **Marxan** uses mathematical algorithms to identify the most cost-effective combination of sites for conservation while meeting specified targets for biodiversity or habitat representation. Marxan helps conservation planners prioritize areas for protection and allocate limited resources efficiently. **Marxan with Zones** is an extension of the Marxan software that allows for more complex spatial planning by incorporating zoning considerations into the conservation planning process. It enables users to designate different management zones within the planning area, each with its own set of conservation objectives and constraints. Marxan with Zones can be particularly useful for managing multiple land uses or addressing specific management needs within PAs and OECMs (Marxan Solutions, n.d.). **Marxan Connect** allows users to include areas identified as important for connectivity as conservation features. Alternatively, connectivity data can be included as spatial dependency amongst sites in the prioritization process (Daigle et al. 2020). Marxan Connect facilitates the use of estimates of demographic connectivity, derived from various sources such as animal tracking data, dispersal models, genetic tools, or structural landscape connectivity.

In the context of SCP, targets refer to the specific conservation goals that the planning process aims to achieve. These targets can be defined in terms of the amount and distribution of biodiversity features (such as species or habitats) that need to be conserved. For example, a target might be to protect at least 30% of the original extent of each habitat type, or to ensure the survival of viable populations of certain key species. Targets are an essential component of SCP as they provide a clear and measurable objective for the conservation planning process. They help to guide the selection of sites for conservation and enable the effectiveness of the conservation plan to be evaluated. Targets are typically set based on scientific knowledge about the needs of the biodiversity features of interest, but they can also be influenced by policy directives or stakeholder preferences.

In the SCP process, different scenarios can be run based on varying conservation targets, socio-economic factors, and potential threats to biodiversity. By running these scenarios, planners can explore a range of possible outcomes and identify the most effective strategies for achieving conservation goals. The outcomes of these scenarios are often represented as maps, which are invaluable tools for land-use planners (Box 1). These maps can highlight priority areas for conservation and illustrate the impacts of different land-use decisions on biodiversity. They provide a visual representation of where new or increased coverage of PAs and OECMs could be located to create a representative and socially responsive PA network. Moreover, these maps can also be used to engage stakeholders, including local communities, government agencies, and conservation organizations. They can help facilitate discussions about conservation priorities, land-use trade-offs, and strategies for managing PAs and OECMs.

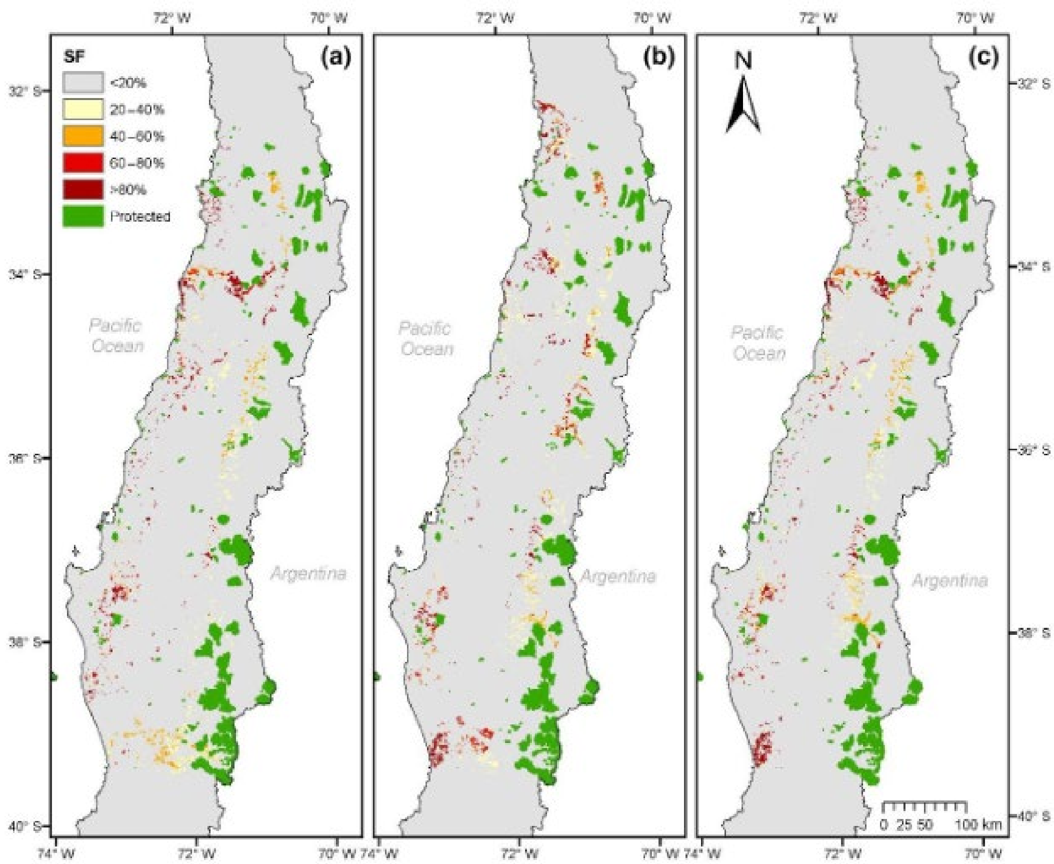
Box 1: Understanding Conservation Features, Scenarios, and SCP Outcomes

A case study assessed conservation planning for people and nature in a Chilean biodiversity hotspot.

- Goals: Extend and optimize the protected area system to balance ecological conservation with social accessibility and economic feasibility.
- **Conservation features used**: 34 forest ecosystem types based on detailed vegetation classification.
- **Outputs**: the maps below show the already established protected areas in green, and the selection frequency, which refers to the number of times a planning unit was selected across various (often 100) iterations of the spatial prioritization tool for finding the most optimal new locations for protection.

Scenarios Compared:

1. Baseline: Current protected areas (both public and private) as per the Chilean Ministry of Environment database.
2. Minimize Land Acquisition Cost: Focus on reducing financial expenditure for land acquisition.
3. Maximize Social Accessibility: Aim to enhance access to protected areas from socially disadvantaged municipalities.
4. Combined Cost and Accessibility: Seek an optimal balance between minimizing costs and maximizing social accessibility.



Selection frequency maps, ranging from yellow/low frequency to red/high frequency, for sites achieving a 17% protection for each of the 34 forest ecosystem types (a) scenario to minimize land cost, (b) the maximum penalty for social access scenario, and (c) combined land cost and social access scenario. (Martinez-Harms et al., 2021).

Conducting SCP is a complex process that requires careful planning and execution. Pressey and Bottrill (2009) identified 11 key stages that are undertaken in many SCP processes (Figure 1). The application of SCP is highly context-specific, the selection of conservation features, input layers, and spatial prioritization tools should be influenced by the unique characteristics of the landscape, the biodiversity present, the socio-economic context, and the specific conservation goals (Margules & Pressey, 2000; Sinclair et al., 2018). There are numerous resources available, including scientific literature, expert advice, and case studies, that can guide these decisions. We invite readers to consult the extensive resources on SCP for more information (Appendix 2).

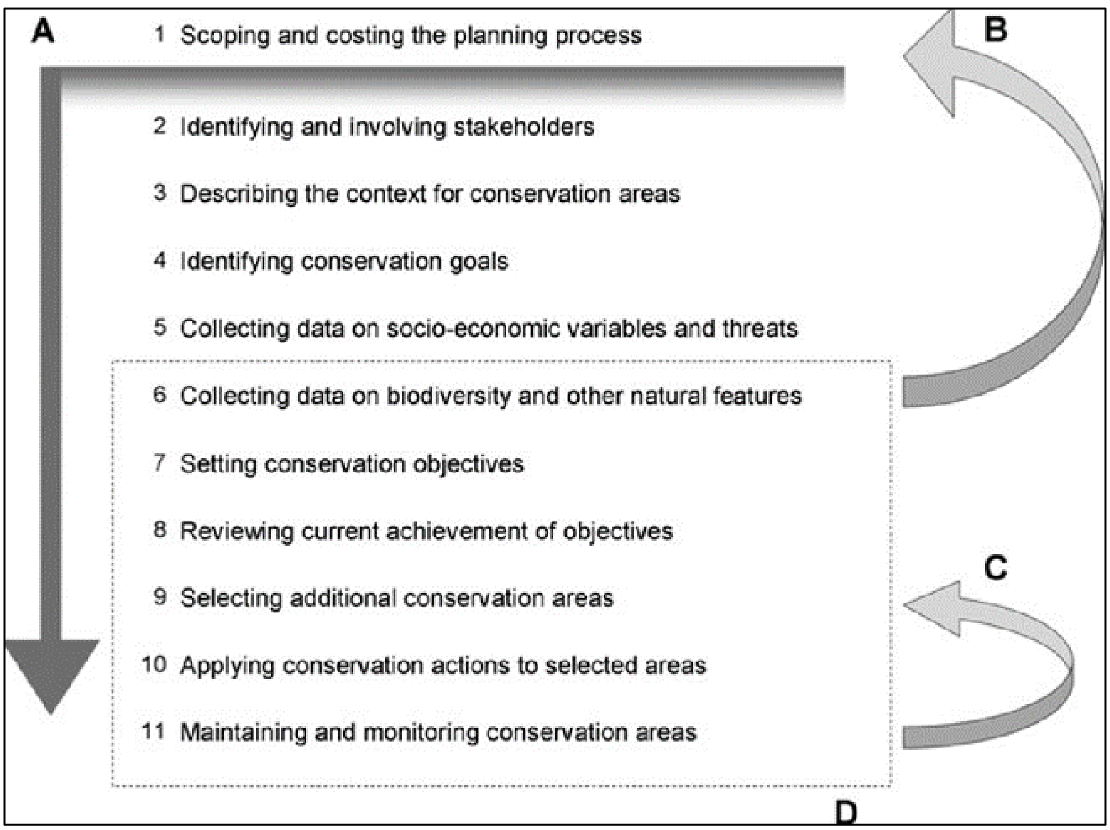


Figure 1: *11 steps of Systematic Conservation Planning proposed by Pressey and Bottrill (2019). A: Stakeholder engagement throughout the process. B: Revisions on boundaries of planning area based on data collection results. C: Lessons learned from management and monitoring. D: Spatial prioritization after the social, economic, and political context has been defined through steps 1 to 5.*

4. Ecological Connectivity

4.1 The importance of ecological connectivity

Well-connected ecosystems support a diversity of ecological functions such as migration, dispersal, gene flow, range shifts, pollination, surface and sub-surface hydrology, nutrient cycling, and disease resistance. Connectivity shapes species richness, food web structure, and most ecological functions, processes, and ecosystem services, both on land and at sea. Its conservation is thus essential for managing healthy and productive ecosystems, mitigating fragmentation, conserving biodiversity, and building resilience to human activities and climate change across all biomes and all spatial scales (Hilty et al., 2020). Ecological connectivity is especially important for migratory species across terrestrial, freshwater, and marine ecosystems. Throughout their lifecycles, migratory species rely on networks of habitat, pathways between these core habitats, and a host of dynamic and diverse ecosystem processes.

The State of the World's Migratory Species reports that one in five CMS species are threatened with extinction and 44% are facing population declines, with fragmentation and loss of ecological connectivity a major driver of these declines (UNEP-WCMC, 2024). The report underscores that coherent, well-connected ecological networks are crucial for migratory species.

Fragmentation by linear infrastructure like roads, railways, and fences is a major threat to ecological connectivity, especially for migratory species (UNEP-WCMC, 2024; CMS, 2023; MSU ILR, 2023). These barriers disrupt natural wildlife movements, fragment habitats, and increase conflicts such as wildlife-vehicle collisions that can injure and kill both humans and wildlife. By identifying and mitigating these barriers, efforts can be directed towards enhancing ecological connectivity such as supporting the migratory needs of species, enhancing safety, and ensuring successful long-term conservation outcomes (Ament et al., 2023). CMS is working extensively to protect migratory species during the lifecycle of linear infrastructure development, especially through impact assessment (Slootweg, 2021).

Overall, ecological connectivity underpins a landscape and seascape approach for achieving the multiple goals of environmental, social, and economic priorities. A sound understanding and set of tools to address ecological connectivity is essential for conservation at broader scales and sustainability of key economic sectors, including agriculture, infrastructure, extractive industries, fishing, shipping, urban development, and others that both impact and are supported by well-functioning ecosystems and the services they provide (CMS, 2024b).

4.2 International policy mandates for connectivity

In light of growing threats to biodiversity and ecosystem services from habitat degradation and fragmentation, ecological connectivity is increasingly recognized as a priority for conservation, sustainable development, and climate change adaptation (CCSG, 2024). Its importance is reflected in major scientific assessments and global policy commitments, including the IPBES

Global Assessment (2019),[10] the UN Decade on Ecosystem Restoration,[11] The UN Convention to Combat Desertification,[12] and the Agreement under the UN Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement).[13] Ecological connectivity is a pillar of the CMS Samarkand Strategic Plan for Migratory Species[14] and its critical role for CMS was most recently highlighted at COP14 with adoption of Resolution 14.16 on Ecological Connectivity,[15] Resolution 7.2(Rev.COP14) on Impact Assessment and Migratory Species,[16] and Decision 14.201 on Infrastructure Development and Migratory Species.[17] The global importance of connectivity and transboundary conservation is further underpinned by UN General Assembly Resolution 75/271 "Nature knows no borders: transboundary cooperation a key factor for biodiversity conservation, restoration and sustainable use".[18]

Finally, and as already mentioned, the KMGBF emphasizes the fundamental contribution that ecological connectivity makes to healthy functioning ecosystems and species, and its benefit to people. This includes explicitly or implicitly addressing the importance of ecological connectivity in a number of goals and targets to be advanced globally by the 196 signatory countries, especially Goal A, and Target 1 on spatial planning, Target 2 on restoration, Target 3 on

[10] In addition, IPBES-10 agreed to undertake a fast-track methodological assessment on biodiversity-inclusive spatial planning and ecological connectivity. See: https://www.cms.int/sites/default/files/027_IPBES10_Connectivity_Assessment.pdf.

[11] The United Nations Decade on Ecosystem Restoration Strategy (2021-2030) highlights activities necessary for catalyzing large-scale restoration,and discusses "the importance of ecological connectivity in restoring ecosystem functioning and how to incorporate this concept into natural resource planning and management." See: https://wedocs.unep.org/bitstream/handle/20.500.11822/31813/ERDStrat.pdf?sequence=1&isAllowed=y.

[12] The 15th Conference of the Parties to the United Nations Convention to Combat Desertification (UNCCD) meeting in Abidjan (Côte d'Ivoire) in May 2022 adopted the Land, Life and Legacy Declaration. The declaration encourages Parties to take into account the "connectivity of ecosystems" to accelerate commitments to achieve land degradation neutrality by 2030. This is the first-ever formal inclusion of connectivity in UNCCD policies. Prior to the conference, UNCCD's Global Land Outlook 2 was released and ecological connectivity was highlighted throughout as an important process, catalyst, and action for large-scale land restoration.

[13] The UN Convention on the Law of the Sea (UNCLOS) adopted the Agreement on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction (BBNJ Agreement) in 2023 and includes "ecological connectivity" among the indicative criteria for identifying marine protected areas in the high seas. https://treaties.un.org/doc/Treaties/2023/06/20230620%2004-28%20PM/Ch_XXI_10.pdf.

[14] See especially: Goal 2 "The habitats and ranges of migratory species are maintained and restored, supporting their connectivity"; and Target 3.2. "By 2032, the direct mortality of migratory species caused by human-made infrastructure is significantly reduced to levels that are not harmful to species' viability" https://www.cms.int/en/document/new-strategic-plan-migratory-species-0.

[15] https://www.cms.int/en/document/ecological-connectivity.

[16] https://www.cms.int/en/document/impact-assessment-and-migratory-species-4.

[17] This decision includes requests to Parties, the Scientific Council, and Secretariat to identify and take specific actions to avoid and mitigate impacts of various forms of infrastructure, while taking into account ecological connectivity. https://www.cms.int/sites/default/files/document/cms_cop14_decisions_e.pdf.

[18] https://documents.un.org/doc/undoc/gen/n21/096/15/pdf/n2109615.pdf?token=iErodj0Pp6jFeCdshB&fe=true.

conservation, Target 12 on cities, and Target 14 on policy integration.[19] CBD Parties are working to prepare requisite National Biodiversity and Strategic Action Plans (NBSAPs) in time for the 16th Conference of the Parties. At time of this publication, there are eight countries (Austria, China, France, Hungary, Ireland, Japan, Luxembourg, and Spain) and the European Union that have submitted revised or updated NBSAPs.[20] Based on initial review, all of the plans include objectives for "ecological connectivity", "ecological corridors", or "ecological networks", and/or measures for maintaining, enhancing, and restoring connectivity. With focus now on implementation of these Goals, Targets, and plans, policymakers and conservation practitioners are eager for concrete guidance on how to proceed with planning and eventually managing for ecological connectivity at the landscape scale. This guidance is responding to the need for clear best practices for incorporating ecological connectivity into the existing and expanding area-based conservation estate (WWF & IUCN WCPA, 2023), and therefore can help countries to meet their international conservation commitments more efficiently and effectively, including especially Target 3 of the KMGBF.

4.3 Ecological connectivity in the context of area-based conservation (PAs & OECMs) and restoration

Ecological connectivity is vital for sustaining ecosystems and conserving biodiversity within and between PAs and OECMs. This is the "well-connected" element of Target 3 of the KMGBF, and work continues to address the widely acknowledged fact that PAs are the cornerstone of area-based conservation (Dudley & Stolton, 2020), but insufficient in isolation (Foden and Young 2016; Gross et al. 2017; Tabor 2019).

While PAs and OECMs are critical for biodiversity conservation, they currently encompass only 17% of terrestrial ecosystems and 8% of the ocean (UNEP-WCMC & IUCN, 2024; SpringerLink, 2023). As such, ecological processes such as dispersal, gene flow, and range shifts in response to climate change (Heller and Zavaleta 2009; Keeley et al. 2019) need to continue outside of PAs and OECMs for biodiversity to endure in the long term.

Ecological corridors serve as an essential strategy to maintain, enhance, or restore connectivity in both currently intact and fragmented landscapes (Hilty et al. 2019). Defined by IUCN as a "clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity," they play a vital role in facilitating species movement, promoting gene flow, and supporting ecosystem resilience in the face of environmental challenges (Hilty et al., 2020). The establishment and maintenance of ecological corridors are essential components of connectivity conservation efforts to ensure the long-term viability of ecosystems and species across various landscapes. Restoration actions can be targeted at re-establishing the lost or degraded connectivity of natural processes. In some cases, improving ecological connectivity may be the primary purpose of a given restoration scheme.

[19] See: https://conservationcorridor.org/wp-content/uploads/CCSG-Guidance-for-NBSAPs-and-GBF-Implementation.pdf.
[20] See: https://www.cbd.int/nbsap/search/default.shtml.

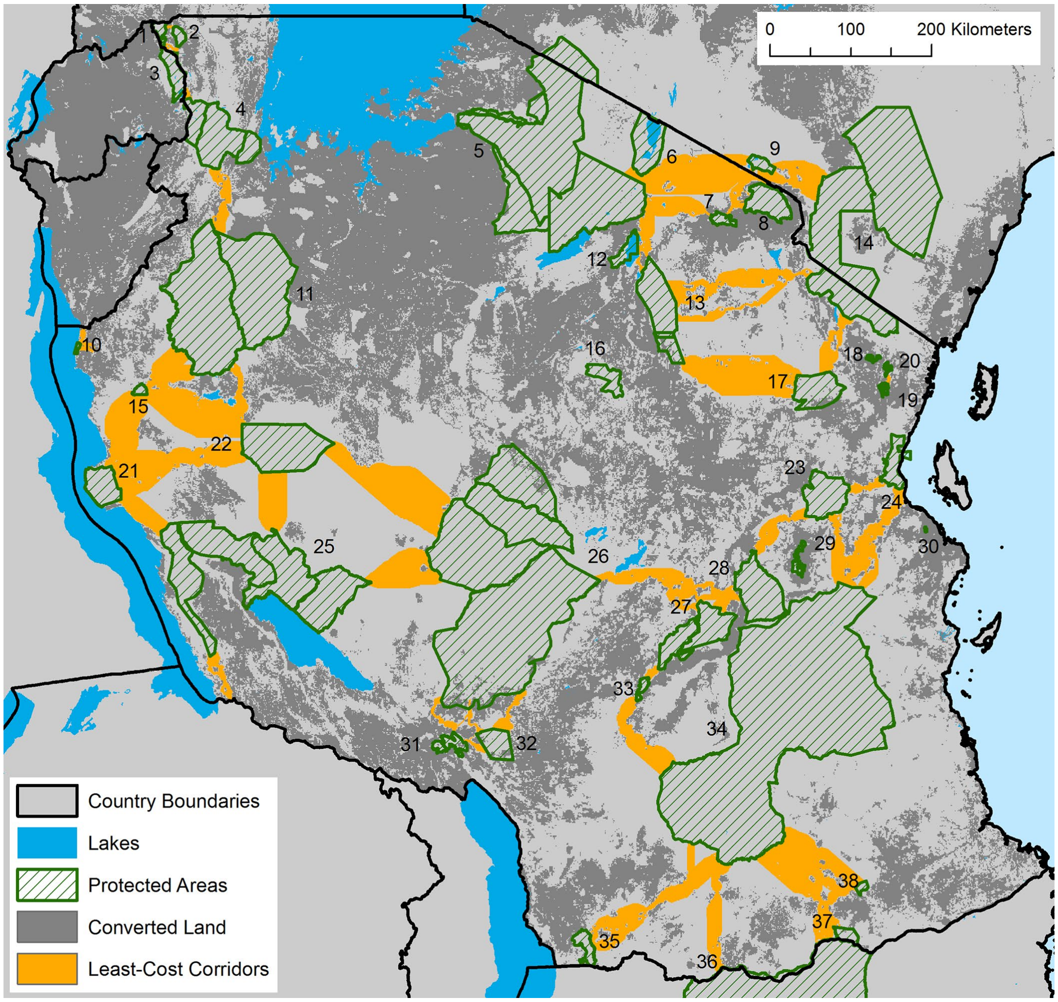
In certain instances, ecological corridors may consist of separate patches of habitat, often referred to as "stepping stones," especially when facilitating the long-distance movement of wildlife like marine mammals, sea turtles, and birds (Hilty et al. 2020). For instance, in the case of migratory birds, minimizing the distance between these sites may not always be necessary unless they are very far apart or if the target species faces metabolic limitations (Klaasen, 1996). Instead, the priority lies in ensuring that these sites fulfill the specific natural requirements of the species, such as access to food, minimal disturbance, and suitable roosting locations, particularly during key stages of migration.

4.4 Ecological Connectivity Modeling

Connectivity models produce maps of landscape connectivity that identify features such as conservation corridors, barriers to movement, or areas of high gene flow. Connectivity models can focus on either functional connectivity - a description of how well genes, gametes, propagules, or individuals move through lands, freshwater and seascapes - or structural connectivity - a measure of habitat permeability based on the physical features and arrangements of habitat patches, disturbances, and other land, freshwater or seascape elements presumed to be important for organisms to move through their environment (See example in Box 2). An elegant approach of structural connectivity modeling that focuses on climate change adaptation is the land facet connectivity analysis (Brost and Beier 2012). The resulting land facet corridors are expected to facilitate movement of a landscape's species communities into the future despite the effects of climate change. Several methods for identifying corridors or connectivity areas have been developed (See Table 1). It is beyond the scope of this guidance to describe them in detail; rather, we refer the reader to the key publications (Bunn, Urban, and Keitt 2000; Urban and Keitt 2001; McRae et al. 2008; Beier et al. 2011; Zeller, McGarigal, and Whiteley 2012; Adriaensen et al. 2003; Rayfield et al. 2016; Rayfield, Fortin, and Fall 2011; Pinto and Keitt 2009; Hilty et al. 2019; Jackson et al. 2016).

Box 2: Corridor Modeling

Resulting maps provide decision support for implementing connectivity conservation actions.



Using a structural connectivity modeling approach based on the naturalness of the landscape, researchers identified 52 least-cost corridors linking protected areas in and adjacent to Tanzania (Riggio and Caro, 2017).

Table 1: Overview of common methods for identifying and mapping habitat corridors. (Modified from Hilty et al. 2019, Box 7.2)

Model Type	Brief Explanation
Least-cost corridor analysis	This model identifies the optimal route for an individual animal moving between habitat patches or other important locations, for a species, based on minimum-cost distance which is a function of distance traveled and the costs of traversing. These corridors show the path that requires the least amount of energy or resources.
Circuit theory	This model estimates movement probability based on cost-distances and path redundancy which highlights locations throughout the landscape of high movement probability and potential bottlenecks.
Omniscape	Builds on circuit theory to measure current flow (i.e., probability of movement) from all grid cells (i.e., locations on the landscape) within a window to the central target cell, with the window moving systematically across the landscape to measure current flow from all like-cell types to all target cells on the landscape. This model helps us understand how species might move across a landscape towards specific locations from various starting points.
Resistant kernel	Calculates the expected relative density of dispersing individuals around source habitats; based on least-cost dispersal from a defined set of source habitats. This predicts how animals are likely to spread out form their natal home ranges based on the easiest path of movement.
Individual-based modeling	Simulates movement paths of individuals by following movement rules to map the estimated relative frequency of use for movement across landscape. Estimated relative frequency refers to the predicted likelihood of an individual moving through a particular area or cell in the landscape.

5. Technical Guidance: Combining Systematic Conservation Planning and Ecological Connectivity Modeling

5.1 Overview

In the past, connectivity considerations have not been commonly included in PA planning (Balbar and Metaxas 2019; McIntosh et al. 2018; Beger et al. 2010). In recent planning projects in Saudi Arabia and Jordan, CLLC combined the well-developed science-based approaches of SCP and connectivity modeling to provide decision support maps for expanding the PA networks according to the KMGBF Target 3 criteria. We incorporated modeled conservation corridors or areas important for connectivity as features in the SCP analysis, ensuring that the resulting conservation plan presents a connected, representative ecological network for conservation. Applying lessons learned from the two projects, in the following section, we outline the steps necessary to conduct SCP with connectivity features. **This guidance is particularly relevant for governments, conservation organizations, land planners, and any entity aiming to expand their PA networks in a systematic way while meeting KMGBF Target 3.**

5.2 Methodological Steps for combining Systematic Conservation Planning and Ecological Connectivity Modeling

The region requesting an SCP and connectivity analysis will determine the appropriate SCP and connectivity specialists to conduct the work. There are many decisions points throughout the connectivity and SCP analyses. To streamline the process and make the analyses more effective it is important for project partners to have a clear understanding of the methodology and the information required. Therefore, taking some time in the beginning to explain SCP and connectivity modeling to all involved is a good investment.

Ideally, the analyst will have in-depth knowledge of the region. If not, it is beneficial if people from the region are available for regular communication and decision-making support throughout the project period. The following steps are designed to be adaptable to various circumstances.

5.2.1 Initiate the project

a. Identify a steering committee, i.e. a small group of advisors with a keen interest in the project. Members may come to the project-funding entity but may also include, for example, representatives from government agencies or conservation non-profit organizations.
b. Appoint a specialist with expertise in SCP and connectivity modeling. The specialist should conduct a comprehensive study of the area, utilizing data provided by regional experts.
c. Establish communication channels, set expectations, and define a timeline.
d. Identify relevant rightsholders and interested parties to consult the project.

5.2.2 Conduct a workshop (preferably in person) with the steering committee and relevant rightsholders and interested parties

a. Provide an overview of SCP and connectivity modeling.
b. Agree on methods and direction for the project.
c. Define the study area with a buffer and decide on core areas as corridor endpoints.
d. Select a suite of focal species and/or decide to take a structural connectivity approach.
e. Decide on the type of connectivity analysis (see section 4.4).
f. Describe the context for conservation areas, for example current threats and institutional capacity.
g. Decide on spatial prioritization software to use (see Appendix 1 for a summary of the different options).
h. Discuss conservation features and the availability of relevant datasets
    i. Consider selecting biodiversity and other features for which data are available, such as cultural sites, ecosystem services, etc. (Table 2).
    ii. To create a representative PA network, it is ideal to have wall-to-wall data on ecosystem types, Species Distribution Models (SDMs) for species of interest, locations of rare or irreplaceable plants, cultural features, and ecosystem services (e.g., important hydrological features). If creating a network for specific features, knowledge about the different areas that are important to a species from experts combined with the SDM or ecosystem maps can be useful (e.g., protect more of the birthing grounds and migratory routes).
        - Note: There are many options for features but having species distribution models (SDMs) or habitat suitability models (HSMs) for species of interest is critical for model focal species connectivity and for understanding species habitat locations as SCP features.
        - Obtaining available data can take longer than expected.

Table 2. Examples of conservation features and data sets needed.

Conservation Features	Relevant Dataset	Ideal Use
Ecosystem type 1 (e.g. Riparian vegetation)	Land cover map: Wall-to-wall data on different types of ecosystems present in the area.	Ideal for a representative PA network.
Ecosystem type 2 (e.g. Evergreen oak forest)		
Ecosystem type 3 (e.g. Acacia woodland)		

Habitat of focal species	Species Distribution Models or Habitat Suitability Models for species of interest.	Useful for understanding species habitat locations for SCP features and for focal species connectivity models.
Rare or Irreplaceable Plants	Data on the locations of rare or irreplaceable plant species.	Useful for prioritizing areas that contain unique biodiversity.
Cultural Features	Data on the locations of important cultural sites.	Can be included as a feature to ensure cultural heritage is considered in the conservation planning.
Ecosystem Services	Data on ecosystem services, such as important hydrological features.	Useful for ensuring that areas providing key ecosystem services are included in the conservation network.
Connectivity Models	Outputs from connectivity models, such as those produced by tools like Circuitscape or Linkage Mapper.	Useful for ensuring that the resulting conservation plan addresses connectivity concerns.

iii. Once conservation features are identified, workshop participants collaboratively decide on which datasets to use. Please note that deciding on exact datasets may need to occur a few weeks later once the steering committee and specialist have had time to search for data. If no datasets are available, consider holding off on SCP and connectivity analyses until more data are available. Alternatively, at this stage, decide on proxy datasets.
   - Proxy datasets are used when direct measurements or data are not available. They are indirect measures that can be used to infer values of interest. For instance, if data on the distribution of a particular species is not available, a proxy dataset such as the presence of a type of vegetation known to be suitable for the species could be used instead. Similarly, if data on animal movement needs are not available, a proxy such as structural connectivity based on naturalness (lack of human modification) can be modeled.
   - It's important to note that while proxy datasets can provide valuable information, they come with uncertainties because they are not direct measurements. The choice of a proxy should be based on a strong understanding of the ecological relationships and processes in question. The use of proxy datasets should be clearly documented and acknowledged in the analysis (Pullin and Stewart 2006).

iv. Discuss planning units and constraints: In SCP, the study area is divided into planning units. These units are often uniform (square or hexagonal), depending on the specific needs and characteristics of the study area.

- Decide on the size of the planning units (e.g. 1 km^2, 5 km^2, 10km^2). Choose a resolution that balances computational feasibility with ecological relevance. Also consider what planning unit size makes sense from a planning or management perspective and at what resolution are the input data.

v. Decide on what projection to use: The choice of map projection can impact the spatial relationships and distances between planning units. It is essential to select a projection that accurately represents the study area and minimizes distortion.

vi. Discuss which areas to lock in: Locked-in areas must be included in the final conservation plan due to their high conservation value or legal protection status. For example, areas with endangered species habitats, critical ecosystems, or legally protected areas are commonly locked in.

vii. Discuss which areas to lock out: Locked-out areas cannot be included in the conservation plan due to constraints such as urban development, private property, or areas with conflicting land uses. For instance, industrial zones, agricultural lands, or populated urban areas are commonly locked out.

viii. Consider other important areas that are not locked in/out: These are areas that hold potential conservation value but are not strictly protected or excluded. For example, a Key Biodiversity Area (KBA) may not be formally protected, but it could be a priority area for conservation. In such cases, the spatial prioritization software can be configured to start looking for solutions in these areas, thereby increasing their likelihood of being included in the final conservation plan.

ix. Discuss costs: This can include, for example, the actual cost of land, the loss incurred from not being able to develop extractive industry, or the distance to roads as a proxy for the likelihood of development. Given equal conservation targets on a planning unit, the SCP algorithm selects areas with a lower cost over areas with a higher cost.

x. Discuss targets: Targets can also be set to a standard value (e.g., protect 30% of each target). However, creating custom targets based on results of a gap analysis is more informative. Note that users of Zonation can select the top 10%, 20%, 30% etc. of the priority ranked areas output; this is not an option in Marxan.

xi. Discuss scenarios: Scenarios may differ in the targets set for each conservation feature. At this stage, scenarios should be considered preliminary; the preliminary outputs can provide a basis for understanding the tool capabilities and limitations.

5.2.3 Gather and process data

a. The specialist together with partners in the focal landscape collect and process spatial data as identified in step 5.2.2h.

5.3.4 Conduct connectivity modeling

a. This step involves using specific modeling approaches to understand and map the connectivity in the landscape (Zeller, McGarigal, and Whiteley 2012).

b. Core areas and focal species should already be defined from the previous steps.

c. Develop resistance surfaces: These are landscape maps that quantify the degree of resistance to species movement, with higher values indicating greater resistance (McRae et al. 2012) (See Appendix 3 for a list of spatial data resources to consider).
d. Identify optimal movement paths among core areas using tools like Linkage Mapper or Circuitscape, and/or structural connectivity (McRae & Kavanagh, 2011).

5.3.5 Perform a gap analysis

a. Measure the representativeness of the current PA network for each of the conservation features, including the outputs from the connectivity models. This involves using GIS software to measure the extent and/or presence of conservation features within the existing PA network. The aim is to determine to what extent the current conservation network already meets the defined targets of the selected conservation features. The gap analysis is a critical step for optimizing solutions for SCP analyses (Sharafi et al. 2012; Zhang et al. 2016). An example of conducting a gap analysis as part of an SCP project can be found in a case study looking at the Republic of Korea (UNEP-WCMC and Korea National Park Service).

5.3.6 Prepare for the spatial prioritization analysis

a. Create the input files specific to the spatial prioritization software being used.
    i. For Marxan, this includes a planning unit file and three main input files (consult latest version of the Marxan User Manual for most up-to-date information):
        - spec.dat file, contains information about conservation features, targets, and species penalty factors.
        - pu.dat provides information about planning units including their ID, status, and cost.
        - puvspr.dat contains information about the distribution of conservation features within each planning unit.
        - Additionally, the bound.dat file is crucial as it provides information on what planning units are adjacent to other planning units and the weight of the boundary relationship between them (ArcMarxan Toolbox).
    ii. For Zonation, the input files include biodiversity features (defined in 01.spp) and input parameters (defined in 01.dat). All the configuration files needed for a run are specified in a Windows batch file (01_core_area_zonation.bat) (Moilanen, Kujala & Leathwick, 2009).
    iii. Marxan with Zones is an extension of Marxan that allows for the allocation of planning units to multiple zones (i.e., marine PAs of various protection levels) and incorporates multiple costs into a systematic planning framework (Watts et al. 2009). There are seven fundamental input files used in Marxan with Zones (Watts et al., 2009). This tool is useful when you need to allocate resources to multiple-zone configurations (Watts et al., 2009).
    iv. For Prioritizr, the input files are typically derived from your existing data sets. For example, you might have a multi-layer raster where each layer describes the spatial distribution of a feature, such as different bird species (Hanson et al., 2023). Prioritizr

can also read input data formatted for the Marxan conservation planning program and find much cheaper solutions in a much shorter period than Marxan (Hanson et al., 2023).

v. For C-Plan, this includes a set of input files that describe the planning region, the conservation features, and the targets. The software uses these inputs to identify priority areas for conservation action (Pressey et al., 2009).

vi. For ResNet, the input files typically include a raster of habitat suitability for each species and a raster of current land use. The software uses these inputs to identify a network of conservation areas that maximizes the representation of each species while minimizing conflict with human land use (Lechner et al., 2016).

5.3.7 Run the spatial prioritization

a. Run spatial prioritization for a set of targets. We recommend using the results of the gap analysis to create an initial custom scenario.
b. Make the necessary calibrations for the spatial prioritization. For instance, in Marxan, adjust the Boundary Length Modifier to influence the compactness of the resulting design. This can be decided quantitatively (refer to Box 12 in the Marxan User Manual), or qualitatively based on aesthetic preferences.
c. Map both the optimal and frequency solutions based on a custom target (or two different targets) with various BLM options.

5.3.8 Hold a steering committee meeting

a. Present the results of the first preliminary scenario.
b. Decide on the custom targets and the Boundary Length Modifier.
c. Discuss the smallest size of newly identified PAs or OECMs for potential protection.
d. Agree on scenarios to run for multiple map outputs:
    i. Suggest one scenario with no costs, locked in/out, just features to visualize the "ideal" situation—although this is ultimately unrealistic, it helps to get a sense of the landscape and software.
    ii. Suggest one or two scenarios with custom targets.
    iii. Build off custom target scenarios with the addition of connectivity outputs to see how the connectivity models shift the ideal network design.

5.3.9 Rerun the spatial prioritization and create maps

a. Rerun the SCP based on the decisions made in the steering committee meeting and create maps.

5.3.10 Hold a validation workshop

a. Share maps and findings for both SCP and connectivity models.
b. Decide if specific additional locations should be "locked in" for rerunning connectivity models.
c. Gather input from rightsholders/shareholders – participants can draw on maps and fill out worksheets to bring into the next stage of revisions.

5.3.11 Rerun SCP Based on Validation Workshop Results

a. Rerun the SCP based on the feedback and decisions made during the validation workshop.

5.3.12 Deliver the final report

a. Compile all the findings, decisions, and maps into a comprehensive report and deliver it to all relevant stakeholders.
b. Compile all spatial data and code to share with partners.
c. Point to boxes for outcomes and how the products are used to reach Target 3 of the KMGBF.

6. Example: Turkmenistan and Uzbekistan - Transboundary Mountain Ecosystems of Koytendag

The methods provided in this Guidance are generalizable, adaptable globally, and can be applied to diverse landscapes (i.e., mountains, wetlands, deserts, forests). To show opportunities for application, this example takes a closer look at a subset of protected and conserved areas in the transboundary Mountain Ecosystems of Koytendag (MEK). It centers around how SCP and connectivity modeling could be undertaken to identify opportunities to bolster the ecological network for Koytendag State Nature Reserve (SNR) in Turkmenistan, Surkhan State Nature Reserve (SNR) in Uzbekistan, and the wider ecosystems (See Figure 2). Moreover, applying these approaches would be an important step in enhancing each country's implementing activities to meet and exceed global conservation commitments, such as the CMS Samarkand Strategic Plan for Migratory Species and KMGBF. Parts of both countries and the larger region are currently experiencing rapid urban, agricultural, and infrastructure development, which underscores the region's strategic and economic significance and brings with it an array of challenges and opportunities for local ecosystems and biodiversity. Some efforts have already been made by CMS to respond and provide support, including adoption of Resolution 11.24" The Central Asian Mammals Initiative"[21] adopted by CMS/CoP-11 in 2014 and subsequent guidance for ameliorating the barrier effect and direct mortality impacts of linear infrastructure,[22] wildlife disease, wildlife management, and other conservation issues.

The MEK is part of the western boundary of the Mountains of Central Asia Global Biodiversity Hotspot, as defined by the Critical Ecosystem Partnership Fund (Critical Ecosystem Partnership Fund, 2017). Overall, this region is renowned for its rich biodiversity, ecosystems, and cultural heritage (Critical Ecosystem Partnership Fund, 2017) and is also included as an area of significance for conservation of urial (*O.v. bocharensis*), as well as being potential habitat for goitered gazelle (*Gazella subgutturosa*) and Persian leopard (*Panthera pardus saxicoloras*) as documented in the CMS study "Mapping Transboundary Conservation Hotspots for the Central Asian Mammals Initiative".[23] The MEK and wider region holds myriad genetic resources, hosting the wild relatives of various domesticated plants such as wheat, apples, pears, almonds, walnuts, and pistachios, along with migratory wildlife species such as lynx (*Lynx lynx isabellinus*), urial (*O.v. bocharensis*), markhor (*Capra falconeri*), and kulan (*Equus hemionus kulan*) (Rosen et al., 2023).

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[21] See: https://www.cms.int/sites/default/files/document/Res_11_24_Central_Asian_Mammals_Initiative_En.pdf.

[22] See: Guidelines for Addressing the Impact of Linear Infrastructure on Large Migratory Mammals in Central Asia https://www.cms.int/sites/default/files/publication/cms-cami_pub_linear-infrastructure_wcs_e.pdf and Central Asian Mammals Migration and Linear Infrastructure Atlas https://www.cms.int/cami/sites/default/files/document/cms_cami2_inf.4_cami-migration-and-infrastructure-atlas_e.pdf.

[23] See: Mapping Transboundary Conservation Hotspots for the Central Asian Mammals Initiative https://www.cms.int/sites/default/files/document/cms_awars1_inf1_transboudnary%20hotspots_draft7_en.pdf.

Taking this information into account, Central Asia, including Turkmenistan and Uzbekistan, is home to unique ecosystems and important species. Ungulates, such as urial and markhor migrate throughout and across the landscapes each spring and autumn to access the most nutritious plants and avoid deep snow (Rosen et al., 2023). The region also contains desert and mountain ecosystems that are increasingly under anthropogenic pressure compounded by climate change impacts that manifest themselves in the form of prolonged drought and increased frequency of extreme weather events. The migratory behavior of species in this area, and around the world, is an adaptation to avoid such weather extremes and other adverse conditions and to follow temporal and spatial changes in resource availability. Therefore, the pressure on wildlife and the ecosystems they inhabit is making it even more compelling to maintain large scale movements which enable them to survive in their natural environment. Connectivity between existing and future protected and conserved areas is essential as they may already be, or prove to be, insufficient to protect migratory species and their movements. Thus, SCP and connectivity modeling are powerful tools for identifying and implementing more comprehensive solutions.

A view of Turkmenistan's highest mountain Ayrybaba from the Koytendag State Nature Reserve (SNR) headquarters. (Courtesy: John Linnell)

The western part of Turkmenistan and southern part of Uzbekistan around Koytendag SNR and Surkhan SNR has been selected as the example because this area is part of MEK and the focus of an ongoing project that started in 2021 titled "Improving Capacity and Connectivity Between Reserves in Turkmenistan and Uzbekistan" funded by the Critical Ecosystem

Partnership Fund (CLLC & CEPF 2023). The area is a unique and biodiverse landscape that is especially important for storing and releasing water. Rising from caves to hot plains, through diverse forests and to snow-capped mountains, it is home to small towns and communities, and cultural and sacred sites. It is also a crucial habitat for vulnerable and endangered wildlife such as lynx, urial, and markhor that are increasingly threatened by agricultural expansion, overgrazing, illegal hunting, and unmanaged tourism. Throughout the project, transboundary collaboration continues to improve the information and knowledge base, including evaluating the presence of important species, increasing monitoring and data-gathering, and better understanding the connectivity of the area. Overall, this example provides insights into how information and data is already being brought together, and could be harnessed for eventual application in SCP and connectivity modeling to inform long-term, durable conservation of the surrounding landscape.

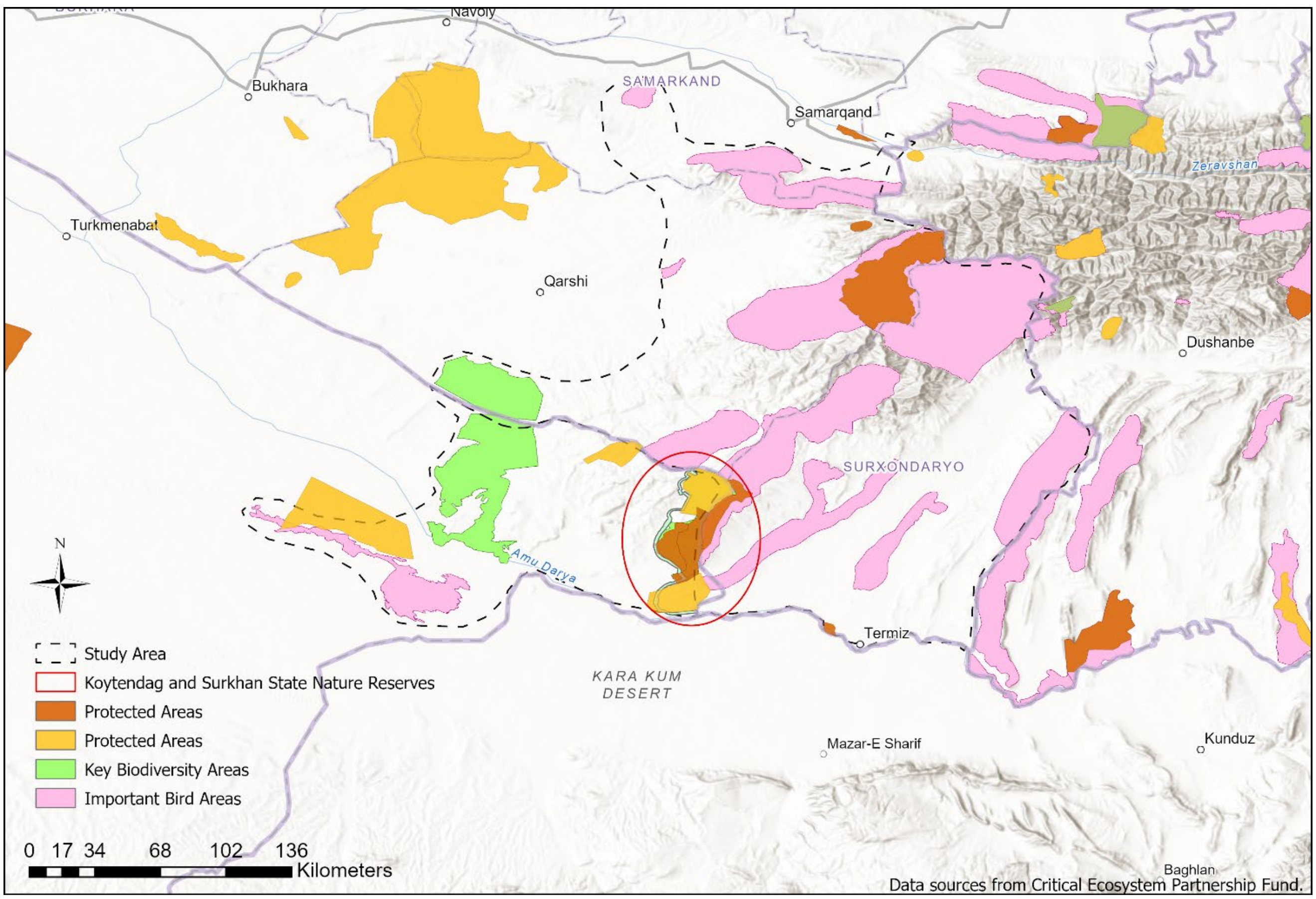

Figure 2. *Map of example study area. Protected areas are shown in orange hues, Key Biodiversity Areas are shown in green, and Important Bird Areas are shown in pink. Koytendag and Surkhan SNRs are circled in red. Data on boundaries shared by the Critical Ecosystems Partnership Fund.*

As part of the aforementioned project, a workshop was held in in the capital city of Ashgabat, Turkmenistan on 17-18 April 2023. With 30 participants, this meeting drew together expertise and new information toward enhancing capacities, addressing threats, and building collaboration for more consistent conservation across the landscape. Based on operationalizing the IUCN *Guidelines for ecological corridors in the context of ecological networks* (Hilty et al. 2020), staff from protected areas, agencies, ministries, and related conservation associations worked with staff from the Center for Large Landscape Conservation to integrate field data and practitioner expertise to begin considering practical solutions in and around Koytendag SNR, transboundary with Surkhan SNR, and the larger Koytendag-Hissar Corridor. Over the course of multiple breakout and full group meetings, participants discussed and accumulated input about specific connectivity values around the reserves, and recorded potential actions for the design, governance, and management of specific areas. The meeting concluded with outlining shared visions and preliminary plans for seven areas important for the connectivity of habitats and species in and around the reserve, including lynx, urial, markhor, goitered gazelle, rare bird species, and Bukhara deer (*Cervus elaphus bactrianus*).

Box 3. Summarized 12 steps of SCP and ecological connectivity modeling

1. Initiate the project
2. Conduct a workshop
3. Gather and process data
4. Conduct connectivity modeling
5. Perform a gap analysis
6. Prepare for the spatial prioritization analysis
7. Run the spatial prioritization
8. Hold a steering committee meeting
9. Rerun the spatial prioritization and create maps
10. Hold a validation workshop
11. Rerun SCP based on validation workshop results
12. Deliver the final report

This project is providing key collaboration and information that can be especially useful if there is interest, political will, and funding to undertake all 12 steps of the SCP (See Box 3) and connectivity modeling methodology for PAs, OECMs, and corridors across the larger area and region. Based on outcomes identified in the Ashgabat workshop report (CLLC & CEPF 2023), Table 3 details some of the information already gathered that could inform in-depth analysis in this region. Presenting this in the context of some of the initial methodological steps of the SCP and connectivity modeling process is intended to show the types of information already gathered in existing processes, what additional actions would still be necessary, and that Koytendag SNR, Surkhan SNR, and the wider example study area are especially primed for undertaking such a process. Moreover, many area and species-focused projects around the world have similar information that could be harnessed in SCP and connectivity modeling to provide a more balanced approach that helps to identify key conservation areas and develop innovative strategies that enhance ecological connectivity across landscapes.

For this example, Table 3 shows that the initial Step 1d is already well-underway with 11 initial categories of rightsholders and interested parties identified as either current or potential partners that could contribute to successful analysis and application in decision-making. For Step 2d, an initial suite of nine focal species has been compiled from the input provided during the workshop in Ashgabat. Based further on the information provided for each of the seven areas identified as important for connectivity, a list of 18 specific threats, issues, and needs is included under Step 2f to inform consideration of the situation and opportunities for the analysis. Where there is no specific data yet for many of the steps, a set of selected recommendations is provided in Box 4 based on experiences using this approach and knowledge of the region (Box 4). Completing the entire set of steps outlined in section 5.2, considering the factors mentioned above, has the potential to identify where to add new or increase coverage of PAs, OECMs, and corridors. This underlines the capability of SCP and connectivity modeling to create conservation network solutions using a holistic method toward biodiversity preservation, which could encompass a mix of PAs, OECMs, and alternative protection methods.

Table 3: Alignment of methodological steps with ongoing project activities in Turkmenistan and Uzbekistan

Methodology	Existing/available information identified	For further action
Step 1: Initiate the project		
Step 1a: Identify a steering committee		Still needs to be undertaken
Step 1b: Appoint a specialist		Still needs to be undertaken
Step 1c: Establish communication, etc.		Still needs to be undertaken
Step 1d: Identify rightsholders and interested parties	• Ministries of agriculture, environment, transport, tourism, etc. • Wildlife, environmental protection, and other natural resource agencies and departments • Border security agencies and services • Law enforcement agencies • Non-governmental organizations (NGOs) • Local governments, including town and county administrations	

	• Gas, oil, mining, and other extractive companies • Private farms and businesses • Grazing lease holders • International experts • International organizations • Etc.	
Step 2: Conduct a workshop		
Step 2a: Provide an overview of SCP and connectivity modeling		Still needs to be undertaken
Step 2b: Agree on methods and direction for the project		Still needs to be undertaken
Step 2c: Define the study area		Still needs to be undertaken
Step 2d: Select a suite of focal species	• Urial • Markhor • Rare bird species (sociable lapwing, bustard, steppe eagle, lesser white-fronted goose, etc.) • Lynx • Bukhara deer • Goitered gazelle • Etc.	
Step 2e: Decide on type of connectivity analysis		Still needs to be undertaken
Step 2f: Describe the context for conservation areas, for example current threats and institutional capacity	• Lack of migration between wildlife populations • Lack of genetic exchange between populations • Lack of conservation status, pressures from oil and gas fields and other anthropogenic pressures • Insufficient representativeness for the existing reserves • Grazing, pollution, unorganized tourism, degradation of cultural sites and monuments	

	• Lack of full protection status • Decrease in subspecies numbers • Lack of protection and local enforcement • Lack of protection and monitoring • Degradation of habitats • Flooding of rivers • Border zones, barriers, and lack of access • Burning of vegetation • Lack of communication between reserves and other protected and conserved areas • Lack of transboundary monitoring and joint cooperation • Lack of data sharing and more reliable wildlife population numbers • Inaccessibility of territory, especially border areas • Hunting bans versus licensed hunting • Etc.	
Step 2g: Decide on spatial prioritization software		Still needs to be undertaken
Step 2h: Discuss conservation features and the availability of relevant data sets		Still needs to be undertaken
Steps 3-12		Still needs to be undertaken

Box 4: Selected recommendations for the example: Turkmenistan and Uzbekistan - Transboundary Mountain Ecosystem of Koytendag

Step 2g: Marxan with Zones could be particularly beneficial for large land areas like the MEK region where different land uses coexist. For instance, the most important areas for both conservation features and connectivity could be identified for only certain allowable or seasonal uses, such as rotational grazing. This allows for a nuanced and realistic conservation plan that considers the various competing land uses in the region although this approach is more data intensive.

Step 2h/viii: Identify and compile a list of protected areas, Key Biodiversity Areas (KBAs), Important Bird and Biodiversity Areas (IBAs), and OECMs in the study area. These areas represent regions of high biodiversity value and should be prioritized for conservation. While KBAs, IBAs, and OECMs may not be locked in for the PA network solution, they could be set as starting points for the algorithm.

Step 2h/ix: Collect (or identify existing) data on grazing value and use it as a cost layer in the SCP process. This would help identify areas where conservation efforts might conflict with grazing activities, allowing for a more balanced and sustainable conservation plan. Identify areas of high human modification and lock them out of the conservation network. These areas are less likely to hold high conservation values and more likely to conflict with conservation efforts.

Step 2h: Include species distribution models (SDMs), ecological corridors from models, and ecosystem types as conservation features. Prioritize the rarest ecosystems for higher protection to help preserve biodiversity and maintain ecosystem health in the region. Consider other features such as the genetic resources of wild relatives of various domesticated plants such as wheat, apples, pears, almonds, walnuts, and pistachios, along with animals including sheep and goats. Include the 30 distinct ecosystems as distinct features. These unique ecosystems and species add to the biodiversity value of the region and should be prioritized for conservation. Consider the semi-desert lowlands of the region in the conservation planning.

Step 2h: Understand hydrological processes such as infiltration as it plays a key role in water filtration. Conduct hydrological mapping to provide a better understanding of where these processes are happening. It can help identify key water sources, understand the flow of water within the landscape, and assess the impact of human activities on water resources. This is another important conservation feature that directly impacts human well-being and sustainability in the region.

Next steps: Develop strategies for implementing the conservation plan, including securing funding, engaging local communities, and coordinating with government agencies and other organizations. Establish a monitoring program to track the progress of the conservation plan and assess its effectiveness. Follow the Conservation Standards to develop a relevant monitoring plan. Adapt the conservation plan based on feedback and additional analyses as needed.

7. Conclusion

This guidance underscores the strengths of utilizing SCP and connectivity modeling for achieving effective biodiversity conservation. The success of expanding protected and conserved areas to meet the ambitions of the KMGBF—particularly Target 3—relies on strategic and scientific solutions, one of which is outlined here in detail for those wishing to achieve a connected PA network. These tools not only facilitate the expansion of PAs but also ensure their ecological representation and connectivity, thereby enhancing the overall resilience and functionality of ecosystems.

The current status of protected terrestrial and marine areas significantly falls short of 2030 conservation targets. The pressing need to increase these areas calls for adherence to a structured approach to conservation planning that is responsive to ecological needs and sensitive to national and local socio-economic contexts.

The path towards effective conservation depends on the availability of robust data and active engagement from all stakeholders, including indigenous communities and local communities, governments at all levels, and the private sector. Moreover, given the complexities associated with conservation in diverse ecological and socio-economic landscapes, tailored approaches that consider local contexts and specific ecosystem characteristics are essential.

Looking ahead, the call to action for policymakers, conservation practitioners, and the global community is to prioritize funding and capacity-building initiatives that empower local actions. These efforts should align with the clear policy mandates and guidance provided by international bodies such as CMS, the IUCN, and others. Additionally, ongoing research and adaptive management practices are crucial in refining these conservation strategies, ensuring they remain effective under changing environmental conditions and advancing scientific understandings.

Conservation efforts at this juncture must strive not only for ecological results but also facilitate socio-economic benefits, fostering a harmonious balance between human activities and nature conservation. By leveraging SCP and connectivity modeling in this dual context there is a promising path forward towards achieving global biodiversity targets in a manner that is both ecologically sound and socially equitable.

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Appendix 1: Overview of Reserve Selection Software Packages

Deciding on a software package is a difficult choice to make. Marxan, Zonation, the Prioritizr R-package, C-Plan, and ResNet can all be used for reserve selection (Table A-1).

Marxan is appealing because it uses simulated annealing which is a powerful optimization technique (Ball et al. in 2009). It aims to maximize the representation of biodiversity features while minimizing the cost of conservation. Marxan allows users to set targets for the representation of biodiversity features, incorporate various constraints (such as cost, connectivity, and land use), and generate solutions that prioritize areas for conservation. The output consists of multiple maps of reserve networks.

Zonation's algorithm iteratively removes those cells whose loss causes the smallest marginal loss in the overall conservation value of the remaining landscape (Moilanen et al. 2009). There are alternative cell removal rules that can be applied depending on the data sets and goals. Core-area Zonation identifies a solution that includes high-quality core areas for all species, whereas additive benefit function Zonation gives higher value to species richness. Zonation provides flexibility in setting conservation targets, incorporating multiple conservation features, and generating zoning solutions that reflect both complementarity and representativeness.

Prioritizr uses integer linear programming (ILP) techniques to solve reserve selection problems. It formulates conservation planning as an optimization problem and identifies optimal solutions that meet specified conservation objectives while minimizing costs or other constraints (Hanson et al. 2023). Prioritizr offers a flexible framework for specifying conservation objectives, constraints, and spatial data inputs. It supports various optimization algorithms and allows for customization of conservation plans based on user-defined criteria.

C-Plan's output is similar to Zonation's output: it is a map of irreplaceability values (Pressey et al. in MWP). Irreplaceability is "a measure of the likelihood of needing any site within a planning region for achieving targets, varying from 1.0 to 0." (Pressey et al. 2009). C-Plan first estimates irreplaceability of each planning unit for each of the features occurring at that planning unit. The software then uses a statistical approach to combine all the individual irreplaceability values to one value per planning unit (Ferrier et al. 2000). As in Zonation, the top 5% most irreplaceable cells are nested within the top 10%, etc. The algorithm incorporates complementarity between already protected and unprotected sites by accounting for the number of occurrences of features in each site relative to the numbers of their occurrences in all other sites. C-Plan employs a simulated annealing algorithm similar to Marxan but with additional features for collaborative decision-making and uncertainty analysis. It integrates stakeholder preferences and uncertainty into the conservation planning process.

ResNet focuses on assessing the effectiveness of existing PA networks and identifying gaps in conservation coverage. It employs network analysis and spatial statistics to evaluate structural connectivity, fragmentation, and representativeness of PAs (Sarkar et al. 2009). In this program, the algorithm first selects cells on the basis of rarity. If there are ties between cells they are broken by complementarity. In a second stage the algorithm drops cells that have become redundant from the solution. Sarkar et al. (2009) argue that selection for rarity first and then for complementarity has produced the best spatially economical solutions with presence-absence data compared to similar algorithms.

Table A-1. Comparison of four reserve selection software programs.

	Marxan	**Zonation**	**C-Plan**	**ConsNet/ResNet**	**PrioritizR**
Algorithm	Minimize cost and boundary length while meeting targets, Complementarity	Removal of cells with smallest marginal loss in overall conservation value	Calculates irreplaceability of each cell	Cells are selected based on rarity, then complementarit, then adjacency	Prioritizes cells based on rarity, complementarity, and adjacency
Optimization technique	Simulated annealing	Warp factor	-	-	Integer linear programming (ILP)
Trade-offs	Trades off area with cost	Trades off species representation levels	-	Trades off conservation, societal, economic factors	Trades off conservation, societal, and economic factors to select areas for conservation.
Output	Maps of networks (best + alternatives)	Map of conservation priority rankings	Map of irreplaceability rankings	Maps of networks (best+alternatives	Maps of networks (best + alternatives)
Connectivity/ Compactness	Boundary Length Modifier -> compactness	**General:** removes cells from the edges, boundary length penalty, use of multi-cell planning units **Species specific:** Boundary Quality Penalty, distribution smoothing	Through manual, interactive manipulation	Graph theory, Minimum Spanning Trees -> real connectivity	Graph theory and Minimum Spanning Trees to evaluate real connectivity

Target based	yes	(yes)	yes	yes	Yes
Incorporates costs	yes	yes	no	yes	Yes
Advantages	Uses simulated annealing Gives a 'best' solution Can incorporate cost or threat Illustrates trade-offs Marxan with Zones: plans for multiple levels of conservation	Can handle huge data sets Illustrates trade-offs No 'hard' targets Transparent, repeatable	Speed of operation makes it a good tool for real-time negotiations Provides a lot of information on individual cells	Can incorporate real connectivity Multiple criteria analysis Analyzes surrogates	Can handle large data sets, transparent, repeatable, can incorporate real connectivity, multiple criteria analysis
Disadvantages	Computation time goes up as cell number goes up; Need to calibrate species weights	Output may depend on starting point	Does not address per unit area cost	Connectivity is not species specific	The algorithm does not address per-unit area cost, and the connectivity analysis is not species-specific.

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Appendix 2: Resources for Spatial Conservation Planning

Marxan:

Marxan Learn includes information on the fundamentals of Marxan, including a Marxan 101 course, advanced concepts, and details on Marxan with Connectivity and Marxan with Zones.

https://marxansolutions.org/learn/

Marxan User Manual: https://marxansolutions.org/download/marxan-user-manual-2021/

Marxan Good Practices Handbook: https://marxansolutions.org/download/best-practices-handbook/

Prioritizr:

Prioritizr - This is an R package that provides a flexible interface for building and solving systematic conservation prioritization problems. At the end of the vignette, there is a tutorial on getting started, package overview, connectivity tutorial, calibrating trade-offs tutorial, management zones tutorial, gurobi installation, and publication record.

https://prioritizr.net/

Zonation:

This is a spatial conservation planning software designed to offer solutions for reserve selection, land-use planning, and general conservation resource allocation problems. See the website link below for more information on zonation including links to the user manual, quick introduction, and software download.
https://www.syke.fi/en-US/Research__development/Nature/Specialist_work/Zonation_in_Finland/Zonation_software

https://zonationteam.github.io/Zonation5/

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Appendix 3: Spatial Data for Connectivity Analyses

Potential input data for ecological connectivity analyses

*Indicates data that can also be useful as inputs for SCP

Base Data

- [ ] Vegetation/land cover types*
- [ ] Hydrography – rivers, streams, lakes, wetlands, reservoirs, *
- [ ] Linear infrastructure (roads, rail, canals, pipelines, powerlines, etc)
- [ ] Protected areas *
- [ ] OECMs*
- [ ] Conservation easement data*
- [ ] Land jurisdictional boundaries (district, cities, etc)*

Species Movement/Occurrence Data

- [ ] Species Distribution Models/Habitat Suitability Models*
- [ ] Telemetry/GPS collar data
- [ ] Camera trap data, track survey data, pitfall trap data, etc.
- [ ] Wildlife crossing monitoring data
- [ ] Species occurrence data
- [ ] Landscape genetics gene flow mapping
- [ ] Seasonal use - persistence of use across space*

Mapping Threats & Challenges

- [ ] Hot spots for risk of vehicle/train collisions*
- [ ] Human-wildlife conflict hot spots/Livestock-wildlife conflict hot spots*
- [ ] Invasive Species*

Social data

- [ ] Social attitude surveys or interviews*
- [ ] Land Use/Zoning*

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