WILDLIFE CONSERVATION SOCIETY

ASSESSMENT & PLANNING FOR ECOLOGICAL CONNECTIVITY: A PRACTICAL GUIDE

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Acknowledgements

This document is a synthesis of current knowledge based on experts views expressed in a WCS workshop, April, 2009 and a review of current literature. In this document we hope to provide practical guidance to those designing assessment projects and implementing conservation plans to advance connectivity conservation. We want to thank those who contributed information and ideas through our WCS Best Science for Connectivity Workshop. Steering committee members included Jodi Hilty, Michael Soule, Barbara Dugelby, Fraser Shilling, and Keith Aune. Workshop participants included Paul Beier, Evan Grivetz, Craig Groves, Kim Heinemeyer, Pete Singleton, Dave Theobald, Bruce Thompson, Beatrice van Horne, Gillian Woolmer, and Greg Eckert. We wish to thank Michael Scott and the William and Flora Hewlett Foundation, New York Community Trust and Dr. Lucy Waletzky for funding support.

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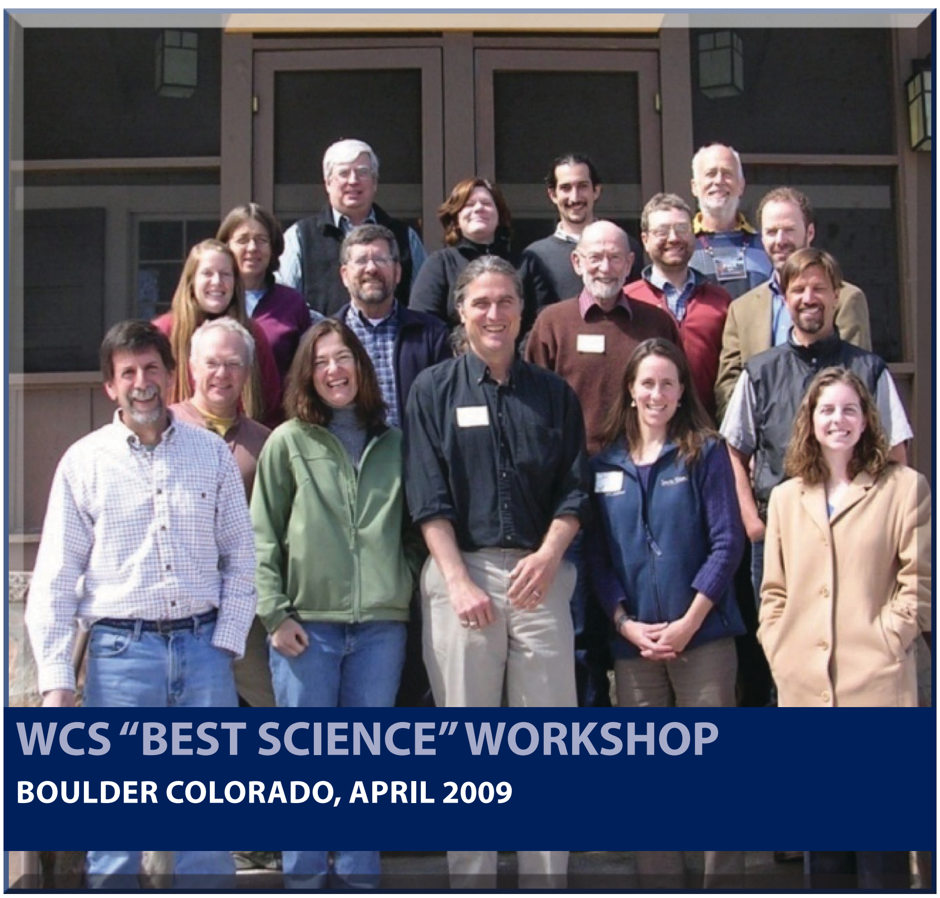

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The Wildlife Conservation Society saves wildlife and wild places worldwide. We do so through science, global conservation, education, and the management of the world's largest system of urban wildlife parks, led by the flagship Bronx Zoo. Together these activities change attitudes towards nature and help people imagine wildlife and humans living in harmony. WCS is committed to this mission because it is essential to the integrity of life on Earth.

Over the past century, WCS has grown and diversified to include four zoos, an aquarium, over 100 field conservation projects, local and international education programs, and a wildlife health program. To amplify this diverse conservation knowledge, the WCS Institute was established as an internal "think-tank" to coordinate WCS expertise for specific conservation opportunities and to analyze conservation and academic trends that provide opportunities to further conservation effectiveness. The Institute disseminates WCS' conservation work via papers and workshops, adding value to WCS' discoveries and experience by sharing them with partner organizations, policy-makers, and the public. Each year, the Institute identifies a set of emerging issues that potentially challenge WCS' mission and holds both internal and external meetings on the subjects to produce reports and guidelines for the institution.

Cover image: ©2011 Joel Berger - The Path of the Pronghorn in northwest Wyoming is one of the last remaining long distance pronghorn migrations in North America.

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Introductory Comments

The evolution of conservation, in theory and practice, has been dramatic over the past several decades. We have witnessed a rapid shift in conservation thought from the advent of simple island biogeography theory to the ascent of a more complex connectivity science. Although connectivity science dates back to the 1970's it has only recently come into its own (Chester and Hilty 2010). A new consensus has emerged that biodiversity conservation requires maintaining and restoring connections within landscapes (Worboys et al. 2010). Furthermore, the specter of climate change has heightened the call for connectivity conservation across the globe. Large scale connectivity is a prudent precautionary strategy for ensuring the sustainability of species and ecosystems (Chester and Hilty 2010).

Although connectivity conservation is widely discussed and routinely practiced there are many gaps in our understanding of how to conserve ecological connectivity. In addition, technologies and theory are rapidly developing as the conservation of ecological connectivity is being practiced. Several reviews of the art of connectivity conservation have been produced and provide significant counsel on how to identify and conserve connecting landscape to protect biodiversity (Heller and Zavaletta 2008, Worboys 2010). The guidance in this document was derived from extensive literature review and the collective wisdom of participants in the Wildlife Conservation Society's (WCS) "Best Science" for ecological connectivity held in Boulder Colorado. It is our intention to provide a quick summary of the current state of connectivity science and offer practical guidance on the best practices, tools and important considerations for conducting a science based connectivity assessment and integrating that into conservation planning. The focus of our guidance is toward terrestrial ecosystem management but many of the principles apply to conserving aquatic connectivity which is extremely important from a global and regional perspective

The Context Behind Connectivity Conservation

Ecosystem function and integrity is a global concern (Graham and Witt 2001, Bennett 2004, Bennett and Mulongoy 2006, MEA 2005, a and b). Everyone in the world depends completely on Earth's ecosystems and the services they provide, such as food, water, disease management, climate regulation, spiritual fulfillment, and aesthetic enjoyment (MEA 2005a). Healthy ecosystems provide a multitude of ecological services to humanity and that as such they represent its "life insurance" and the world's largest development agency (MEA 2005a). Unfortunately according to the *Millennium Ecosystem Assessment* "… over the past 50 years humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history" resulting in the degradation of more than 60% of ecosystem services. The consequences of human induced fragmentation of native fauna and flora are extensive (Hilty et al. 2006).

Around the globe natural landscapes are undergoing drastic change due to anthropogenic pressures; which include habitat loss and fragmentation. (Kindlman and Burel 2008, Crooks and Sanjayan 2006, Worboys et al. 2010). Natural habitats are rapidly being lost and what remains is becoming increasingly fragmented.

Although species vary greatly in their response to fragmentation it is invariably destructive to natural biotas (Laurance and Bierregaard 1997, Johnson and Klemens 2005). Fragmentation decreases the size of habitat blocks and increases isolation of these patches one from another (Bennett 1999, Fisher and Lindenmeyer 2007, Kupfer et al. 2006, Johnson and Klemens 2005). Increased fragmentation dramatically alters species and landscape relationships and usually increases the risk of extinction (Fisher and Lindenmeyer 2007, Kupfer et al. 2006, Johnson and Klemens 2005). Fragmentation results in isolated populations with decreased resiliency to changes in landscapes that are either human induced or caused by a changing climate (Bennett 1999, Fahrig and Marriam 1994, Laurance and Bierregaard 1997). The long term effect of increased landscape fragmentation is the decline of biodiversity, ecosystem resilience and ecosystem services.

To counteract habitat fragmentation global conservation efforts have been increased to protect natural landscapes. As of January 2009 UNEP identified 138,000 protected areas in 233 countries and territories (UNEP WCMC 2010). Although protected areas remain the anchor for biodiversity conservation (CBD 2000, 2001) they are insufficient to protect earth's biodiversity (Worboys et al. 2010). There is a limit to the area which can be set aside as protected, and those areas have geographically fixed, legally defined boundaries. Protected landscapes within fixed boundaries also remain subject to significant external forces impacting the biodiversity within them. Furthermore, the vast majority of the world's biodiversity is found outside protected areas (Franklin and Lindenmayer 2009, Whitelaw and Eagles 2007). Consequently, we must take into account the biodiversity found within a larger area (MEA 2005).

As areas of natural habitat are reduced in size and continuity by human activities, the degree to which the remaining fragments are functionally linked becomes increasingly important. The strength of those linkages is determined largely by a property known as "connectivity" (Noss 1991, Bennett 1999, Calabrese and Fagan 2004, Hilty et al. 2006, Worboys et al. 2010, Spring et al. 2010). The most significant impacts of humans on biodiversity involve changes in connectivity (Noss 1991). Consequently one of the most frequent recommendations for protecting biodiversity is to increase connectivity and establish ecological networks that connect natural habitats (Heller and Zavaletta 2009). This conservation practice becomes even more relevant in the face of impending climate change (Carroll et al. 2009, Spring 2010). Under all future scenarios, with or without climate change impacts, ecological networks will play a vital role in the conservation of biodiversity through improving resilience of ecosystems and natural dispersion of species.

Matrix is a term often used to describe the physical and biotic dimensions of human modified (unprotected) connecting landscapes in an ecological network (Hilty 2006, Lindenmayer and Franklin 2002). Consequently matrix habitats form the largest portion of critical connecting habitat and their management is critical for maintaining biological diversity (Franklin and Lindenmayer 2009, Prugh et al. 2008). Matrix management matters because formal reserve systems will never cover more than a fraction of the globe and human modified land—the matrix—overwhelmingly dominates the world's terrestrial ecosystems (Taylor et al. 2006). On the other hand, we should not substitute matrix management for the retention of existing protected areas or the establishment of additional ones (Lindenmayer and Franklin 2002).

Connectivity conservation can be expected to be part of a global response to climate change (Heller and Zavaletta 2009, Spring et al. 2010, UNEP 2009). Climate change is likely to exacerbate the effects of extractive land-uses on ecosystem structure, composition, and function. Climate change will also place significant pressures on protected areas as future management regimes of matrix habitats change. As a consequence of climate change and development pressures we anticipate new emerging ecosystem structure and function, new assemblages, and entirely new ecosystems which is already occurring (UNEP, 2009).

There is a critical need for a strong science platform to support the emergence of connectivity conservation. Improved capability to predict the consequences of changes in drivers for biodiversity, ecosystem functioning, and ecosystem services, together with improved measures of biodiversity, would aid decision-making at all levels (MEA 2005b). However, it must be remembered that even the best science will likely be revised as conservation decisions are made and management lessons are learned. We are fortunate that the pendulum is swinging in favor of recognizing the value of scientific research to conservation practice (Stein 2007). Conservation science and conservation practice are inextricably linked (Hilty et al. 2006).

Although an improved science platform can help ensure that decisions are made with the best available information the future of biodiversity will ultimately be determined by society (MEA 2005b). The laws governing natural systems are somewhat fixed therefore the best opportunities to improve resource management outcomes will depend on our ability to modify social systems to serve interests of the natural world (Brunckhorst et al. 2006). Connectivity conservation, a potentially transforming concept for saving biodiversity in nature, will only become possible if societies can understand and embrace its practice.

Principles Behind Ecological Connectivity

Definitions

Like any new emerging science, the literature for connectivity conservation is replete with a range of commonly used terms because the terminology has not been standardized. We have examined the terminology of many key resources and recommend a variety of literature including: Hilty et al., 2006, Kindelman and Burel 2008, Crooks and Sanjay 2006 and Worboys et al. 2010. We generally follow terminology of Worboys et al. 2010 as the most recent and comprehensive summary of referenced terminology in connectivity conservation.

Connectivity refers to the ease with which organisms move between particular landscape elements; the number of connections between patches, relative to the maximum number of potential connections (Lindenmayer and Burgman 2005). Determining what is meant by connectivity for a species or landscape is a critical initial step in developing any conservation assessment for connectivity. Worboys (2010) further refines the concept of connectivity very well and defines four major types of connectivity commonly expressed in conservation science. These include:

1. **Habitat Connectivity** which is defined as connecting patches of suitable habitat for a particular species or species group (Lindenmeyer and Fischer 2006).
2. **Landscape Connectivity** which is defined as the connectedness of patterns of vegetation cover in a landscape (Lindenmeyer and Fischer 2006).
3. **Ecological Connectivity** is the connectedness of ecological processes across landscapes at varying scales. Ecological processes include trophic relationships, disturbance processes, nutrient flows and hydro-ecological flows (Soule et al. 2006).
4. **Evolutionary Process Connectivity** maintains the natural evolutionary processes including evolutionary diversification, natural selection and genetic differentiation operating at large scales. Typically evolutionary processes require movement of species over long distances, long time-frames and management of unnatural selection forces (Soule 2006).

These definitions of connectivity provide an important framework for much of the guidance provided in this document.

Guiding Principles for Connectivity Conservation

The following synthesis of guiding principles for connectivity come from extensive review of the literature from the past two decades and collective thoughts from participants at the WCS Best Science Workshop in Boulder Colorado, April 2009 (Reed Noss 2003, Beier et al. 2008, Beier and Noss 1998, Groves 2003, Groves et al. 2002, Hilty et al. 2006, Soule and Noss 1998, Halpin 1997, Kindlmann and Burell 2008, Heller and Zavaleta 2009, Calabrese and Fagan 2004, Crooks and Sanjayan 2006, Worboys et al. 2010). These principles form a conceptual framework for the conservation practitioner assessing landscape connectivity or designing conservation plans that incorporate connectivity conservation. These guiding principles are followed with more specific guidelines and technical recommendations, covering many other aspects of connectivity assessment and planning.

- Connectivity ecology emerged from earlier ecological precepts of island biogeography, metapopulation theory and landscape ecology (Hilty et al. 2006, Chester and Hilty 2010 in Worboys et al. 2010). The theoretical base for connectivity ecology is well vetted among the science community and recently gained wide acceptance in conservation practice around the globe (Worboys et al. 2010).
- Connectivity is fundamentally important and should be integrated into conservation planning (Noss and Daly 2006, Worboys et al. 2010). While there is little debate about the importance of connectivity to preserve biodiversity there remains considerable discussion about how to connectivity conservation and integrate best practices into existing planning and management frameworks.
- Connectivity conservation management has moved beyond a theoretical construct and is already being undertaken in nearly all of Udvardy's (1975) eight biogeographic realms of the earth (Bennett and Wit 2001, Worboys et al. 2010). Although the benefits from early connectivity conservation efforts were debated or not readily evident (Beier and Noss 1998, Bennett and Wit 2001, Hodgson et al. 2009) recent case studies have identified some of the specific benefits of practicing connectivity conservation in landscapes around the world (Worboys et al. 2010, Gilbert-Norton et al. 2010).
- Connectivity fundamentally depends on interaction of species and landscape (Calabrese and Fagan 2004). This dynamic interaction is primarily expressed through the relationship of species, habitats and human impacts within those habitats (Kindelmann and Burell 2008). Different landscapes may have different connectivity values to the same species and certainly to different species. The connectivity property of a landscape may even be different for the same species at different times (Kindelmann and Burel 2008). With advancing knowledge of species biology, habitat relationships, and human disturbance regimes then connectivity for individual species becomes a measurable property of the landscape (Kindelmann and Burel 2008).
- Many human dominated landscapes are not considered core areas but are functional habitat at some level. Resource management practices that maintain or improve the suitability of human dominated matrix habitats are fundamentally important for linking protected areas and conserving biodiversity (Franklin and Lindenmayer 2009, Prugh et al. 2008).
- Sufficient movement of individuals between isolated extinction-prone populations can allow an entire network of populations to persist via metapopulation dynamics (Hanski 1991, Moilanen and Hanski 2006). Connectivity conservation can be deemed successful when movement across all spatial and temporal scales is possible, for a given species or suite of species in a given landscape (i.e. the landscape is permeable).

Some level of permeability can be retained outside of protected areas or reserves by managing human activities and impacts to habitat.

- A large scale interconnected landscape of natural lands with embedded protected areas can provide opportunities for many species to respond to climate change and increasing human pressures (Heller and Zavaletta 2009, Carroll et al. 2009, Spring et al. 2010,Worboys et al. 2010). However, conserving connectivity conservation areas is not a substitute for continued establishment of reserves or protected areas around the world (Worboys et al. 2010).
- Two basic types of connectivity can generally be defined: structural (based on landscape structure) and functional (based on organismal behavior and ecological processes) (Kindlmann and Burel 2008). Although structural connectivity is easiest to quantify and map, functional connectivity is more important (Taylor et al. 2006). Recent studies show that structural measures of landscape intactness are inconsistent predictors of connectivity for all species and in all situations (Olden et al. 2004, Baguette and Van Dyck 2007, Hannon and Schmeigelow 2000, Selonen and Hanski 2003).
- The ecological literature is awash with different connectivity metrics. Measures of connectivity differ in their data requirements and information yield (Calabrese and Fagan 2004, Kindelman and Burel 2008). Connectivity metrics can be classified according to their different strengths and weaknesses.
- Outside of special cases the vast majority of landscapes are composed of a gradient of conditions (Fischer et al. 2004). These gradients challenge the polygon-based prioritization of lands for conservation and contribute to the recent finding that changing the spatial scale (extent and grain) of analysis changes the areas identified for protection (Rouget et al. 2006, Fischer et al. 2004).
- Connectivity conservation does not represent the whole of biodiversity conservation. Landscape connectivity is a necessary but not an entirely sufficient condition for species conservation (Taylor et al. 2006). Other factors affecting species and population persistence may over-ride positive or negative aspects of the degree of connectivity (Olden et al. 2004, Baguette and Van Dyck 2007).
- Connectivity is essential to conservation regardless of a changing climate. (Heller and Zavaleta 2009, Chester and Hilty 2010). Connectivity principles should hold true with or without climate change (Hodgson et al. 2009)
- Conserving connectivity is likely to be most difficult in working landscapes (e.g. agricultural, forestry, extractive industry) because of human domination of these landscapes. Facilitating wildlife movement is likely to be contested if it is perceived to or actually reduces economic activity and productivity, threatens public safety, or leads to present or future regulatory problems.
- Assessment of and design for connectivity are activities that precede but should be linked to conservation planning efforts (Worboys et al. 2010). There is some danger in doing them independently. Linking assessment to specific planning efforts can make conservation targets and goals clear and products from the connectivity assessment relevant to the management framework for landscape, region or ecosystem.
- The nature context-what nature needs-should be the principle driver for initiating and maintaining connectivity conservation (Worboys et al. 2010). Although it remains uncertain how much connectivity is enough we contend that nature needs extensive connectivity. There is little conservation risk in providing extensive connectivity while there is great risk for providing too little. We must strive to escape the minimalist trap in conserving connectivity (Sanderson et al. 2006).

- If adverse effects of climate change are to be minimized connectivity assessment should establish priorities for preserving connecting landscapes and reserve protection. High priority should be given to conserving connecting habitats that are irreplaceable and highly threatened (Noss et al. 2002, Spring et al. 2010). Spring et al. (2010) indicates that corridors where delay cost is highest should be an immediate priority. Such corridors make relatively large contributions to regional connectivity and are more easily fractured.
- Connectivity characteristics are dynamic and change over time as a result of system dynamics, conservation actions or habitat loss/fragmentation due to development (Spring et al. 2010). Landscape connectivity will change over both short and long timescales (Taylor et al. 2006).
- To meet the challenge of a changing and uncertain world we must consider future threats as well as current threats (Spring et al. 2010, Pressey et al. 2007, Coulston and Riiters 2005). By considering the implications of conservation strategies into the future higher levels of connectivity will be achieved when compared to reactive approaches that consider only immediate threats (Spring et al. 2010).
- A guiding vision for connectivity conservation is central to all connectivity management functions and strong leadership is important in any connectivity management endeavor (Worboys et al. 2010).
- There is mounting evidence that conserving connectivity has increased animal movement and biodiversity while reducing impacts associated with ever increasing fragmentation (Gilbert-Norton 2010, Beier and Noss 1998, Worboys et al. 2010, Beckmann et al. 2010). A robust connectivity assessment designed with adequate thought and applying best science tools will successfully address connectivity conservation needs.

Part I

Assessing and Mapping Connectivity

To conserve connectivity in large landscapes ecologists and managers need coarse-grained maps for decision support and fine-grained maps for site-specific interventions (Beier et al. 2012). To develop these connectivity maps an effective process for delineating and prioritizing connectivity areas is essential. Several authors have attempted to outline such a process (Figure 1). There are critical similarities and some unique inclusions in the steps described in this literature for designing corridors and connectivity in landscapes. In this document we concentrate our guidance toward the following critical steps for assessing and mapping connectivity including:

- creating a vision for extensive connectivity
- scoping purpose and structuring goals.
- identifying conservation targets
- establishing collaboration and partnerships
- identifying information needs
- gathering critical data
- defining an appropriate conservation area
- designing robust mapping and assessment analysis

We also present some practical guidance around meeting the major challenges associated with connectivity assessment based on the discussions at the WCS Best Science Workshop and from a review of the published literature.

Creating a Vision for Extensive Connectivity:

Assessment and planning for connectivity is usually a subset of a larger conservation vision and plan. As such the vision for extensive connectivity will often be nested within a larger conservation plan that embraces many facets of species and habitat conservation. For this document we are focusing discussion only within the context of assessing and planning for connectivity conservation knowing well that there may be broader conservation needs for a landscape or species.

A conservation vision with well defined conservation targets, clear purpose and achievable goals is important for implementing effective connectivity conservation as it is correlated with organizational and individual commitment, motivation and achievement of outcomes (Lockwood in Worboys et al. 2010). The literature is replete with appeals to practicing conservationists regarding the importance of identifying clear targets, objectives and setting goals for connectivity (Groves et al. 2003, Anderson and Jenkins 2006, Worboys et al. 2010). However, connectivity conservation initiatives frequently do not present a clear conservation vision, with conservation targets, objectives

HILTY ET AL. 2006 ***Corridor Ecology***	**ANDERSON & JENKINS 2006** ***Network Designs***	**BEIER ET AL. 2012** ***(also see www.corridordesign.org)***
PREPARATION • Assemble a planning team • State purpose of project • Define geographic extent • Determine if habitat is sufficient or restoration is needed	**IDENTIFY INFORMATION NEEDS** • Identify characteristics and quality of information • Proceed from coarse scales to finer scales • Determine strategic indicators	**STATE THE GOAL OF THE MAP** • Goal clearly stated • Potentially measurable
IDENTIFY NETWORKS • Acquire relevant data • Integrate data into GIS • Perform land mapping • Identify developed areas and barriers • Map available information for special features and focal species	**UNDERSTAND CONSERVATION GOALS AND REGIONAL CONTEXT** • Conservation targets as part of large scale or ecoregional plan • Identify scale and type of corridor needed • Identify special opportunities and threats	**ESTABLISH COLLABORATIVE ARRANGEMENTS** • Interest groups are involved from the beginning • Stakeholder input and review is critical
PRIORITIZATION • Map corridors • Estimate cost • Perform vulnerability assessment • Weigh benefits, costs and threats of corridor options	**IDENTIFY CORRIDOR OBJECTIVES AND DEFINE GENERAL CORRIDOR AREAS** • Be specific as possible • How do various objectives interact • Define criteria for candidate areas to assess for connectivity	**DEFINE THE REGION TO BE ASSESSED AND DELINEATE NATURAL LANDSCAPE BLOCKS** • Can be ecologically or politically defined • Larger areas and/or subsets of that area can be assessed and mapped • Defining larger areas has advantages • Buffer the core assessment area
ASSESSMENT • Evaluate site characteristics and quality • Biological survey • Identify potential limiting factors • Gather feedback from the community	**SELECT CANDIDATE AREAS AND DETERMINE CORRIDOR CONFIGURATION** • Gather more specific data • Social, political and economic factors become important • Stakeholder participation and conflict resolution will be necessary	**DETERMINE WHICH BLOCKS NEED TO BE CONNECTED AND DEPICT CONNECTIVITY AREAS ON MAP** • What needs to be connected • Seven options to consider (see this document) • Be detailed as resources allow • May need to start coarse, then refine at scale
	DEFINE STRATEGIC INTERVENTIONS • Umbrella plan for a larger landscape or region become important • Short term versus long term interventions should be identified	**PROVIDE GUIDANCE TO END-USERS** • Supporting documentation • Descriptive statistics • How the map should be used

Figure 1. Steps for completing a connectivity assessment.

or SMART (specific, measurable, attainable, realistic and timely) goals. In the absence of clear conservation targets, defined objectives and measurable goals many connectivity assessment and planning efforts become tools or data driven losing track of their original purpose. We recommend very careful initial steps to brainstorm the purpose for connectivity assessment and to define clear conservation targets before embarking upon this journey.

It is also very important to create consensus around the vision for connectivity conservation (Lombard et al. 2010). Without consensus different stakeholders or project team members will hold different expectations and there will be disagreement over the desired products and their implementation. Strong leadership, representative of all stakeholders, is required to achieve vision consensus and guide implementation. In the event that vision consensus is not possible, participatory processes can provide a forum to express differences and contribute to problem solving.

Scoping and Selecting Conservation Targets

When describing the context behind connectivity conservation, Worboys and others (2010) defined the four types of connectivity as listed above. It is within the context of this typology that clear conservation targets and project purpose can best be derived. In most cases, connectivity conservation will not be framed by just one of these types but will likely conserve more than one type of connectivity at once. Understanding the type or types of connectivity desired in a conservation program will shape the discussion of conservation targets for robust connectivity assessment.

In addition to the connectivity typology described above conservation targets are often identified at a variety of levels of biological organization and spatial scales from local to regional (Groves et al. 2002) (Figure 2). Conservation targets may be

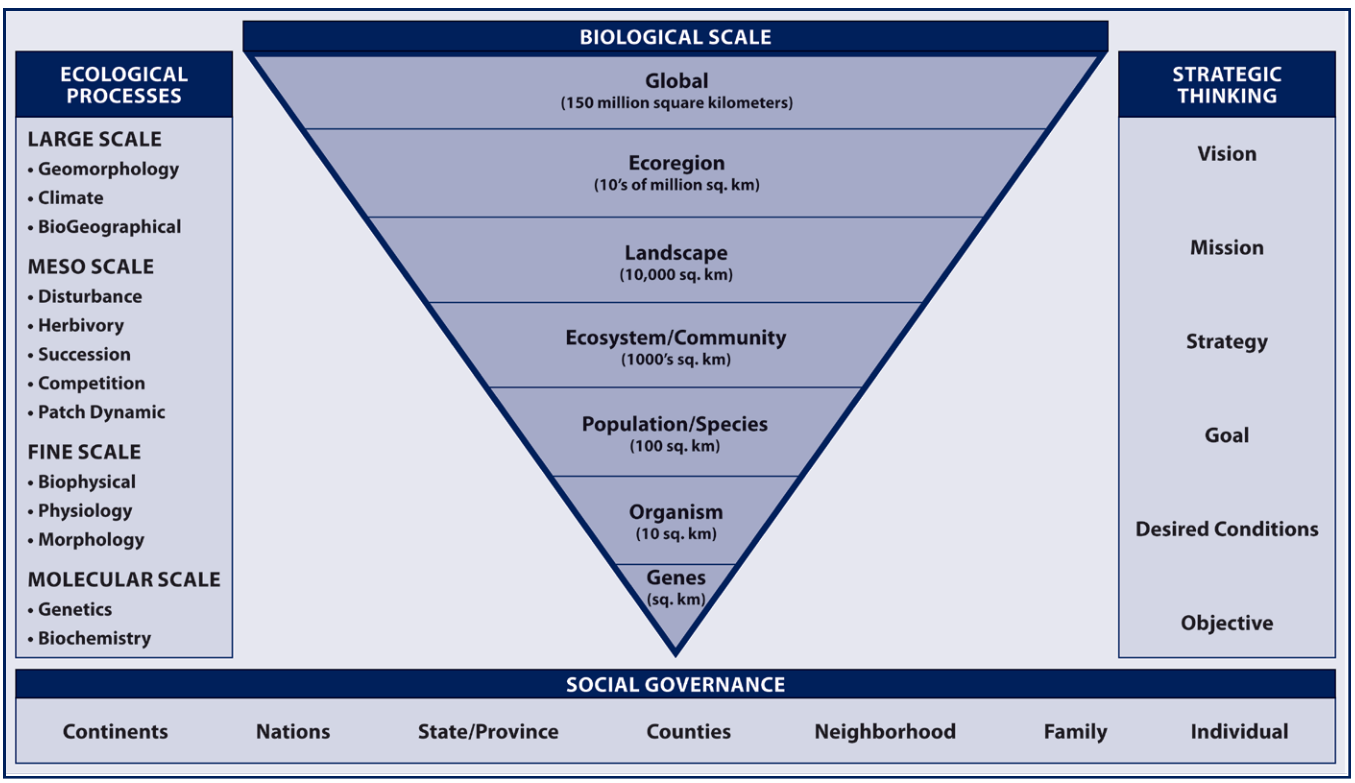


Figure 2. The levels of biological organization compared to ecological processes, strategic thinking and various levels of social governance. Conservation targets can be viewed as occurring at multiple scales from global to individual animals. Social governance and conservation strategies influence biology and ecological processes at various spatial scales.

selected based on their biological features (e.g., species and communities), physical features (e.g., soils, geology, climate), or a combination of both biotic and abiotic features (Groves et al. 2003). Groves indicates that by focusing conservation on clear conservation targets there will be a higher likelihood of conserving the vast majority of living organisms in a region, both those known to science and the many yet to be discovered. Some common reasons for protecting connectivity presented in the literature vary with geography, data limitations, institutional capacity, conservation mission, and political jurisdictions. Most contemporary connectivity assessments primarily aim to:

1. Protect specific migratory pathways or movement corridors for a species or suite of species.
2. Protect or increase biodiversity on a landscape or region.
3. Enhance species or communities resilience to disturbance, especially climate change.
4. Preserve ecological processes such as nutrient flow, disturbance processes, trophic relationships.
5. Maintain natural evolutionary processes
6. Mitigate impacts due to human disturbance such as transportation, highways or railways.

Selecting the right connectivity conservation targets is a difficult task. Ecologists have long faced the dilemma between targeting ecological processes, landscape attributes or species when conserving biodiversity (Unasch et al. 2009). To overcome this tension ecologists have proposed several solutions (Unasch et al 2009). One focuses on the selection of a set of focal species to represent the full suite of biodiversity within a conservation landscape. The second solution, emphasizing ecosystems, has been termed the "coarse filter/fine filter" approach. A third recently emerging approach, targets ecosystem integrity and the conservation of ecosystem processes, resilience and resistance [Unnasch et al. 2009, Beier and Brost 2010, Beier et al. (in press)].

Selecting focal species as conservation targets builds upon the concept of an umbrella effect where focal species requirements are believed to encapsulate the needs of other species. This method identifies a set of species as proxies for different spatial and ecological attributes that must be present in a landscape to ensure persistence of biodiversity (Lambeck 1997). It is believed that in planning for the most wide-ranging, and hence most habitat-area demanding species, a conservation plan built around a few, well selected focal species will sufficiently encompass requirements of all other species (Soule et al. 2003, Unnasch et al. 2009).

The alternative, "coarse filter/fine filter" approach was originally proposed by scientists from The Nature Conservancy (Noss 1987) and focuses primarily on ecosystems, only secondarily on species. Coarse-filter focal ecological resources are identified first, and typically include all of the major ecosystem types within the conservation landscape. Ecologists then consider whether individual species of concern, such as those that vulnerable, rare, or endangered, are adequately "captured" by the coarse filter. Those species that are not adequately addressed through ecosystem-scale conservation are included as additional foci for planning and conservation action – the "fine filter."

Finally, recent efforts to target ecological integrity are based on the central tenet that ecosystems with greater integrity will be more resistant and resilient to change and disturbance (Peterson et al 1998). This approach has gained more relevance as anthropogenic transformation of the earth has intensified and climate change more evident. For example, Spencer and others (2010) applied different thresholds of naturalness based on land use intensities to define target landscapes for conservation and to be ecologically connected. In another example Woolmer and others (2008) identified patches of high ecological integrity based on the inverse of the human footprint. Furst and others (2010) recently developed a spatial planning tool to rapidly visualize changes in land use patterns.

We recommend selecting conservation targets that operate at the intended level of biological organization and at the appropriate spatial/

temporal scale. This can best be derived through a careful scoping process to clearly define conservation targets and explain the purpose for selecting those targets. That scoping process should address three important questions:

1. What is important to conserve?
2. How is it currently doing?
3. What is the desired condition?

Species as Biological Targets

Species populations are in a state of flux due to the cumulative and interacting impacts of climate change and human stressors across landscapes therefore are commonly used as ecological indicators (Crabtree et al 2011). Crabtree and Sheldon (2011) describe three reasons why species are often used as an indicator in conservation. First, species constitute the longest standing indicator within the ecological/biological management profession. Second, the legacy of species as ecosystem indicators has created long-term, time series data sets. Thirdly, they are strongly linked to human management systems and have socio-economic importance.

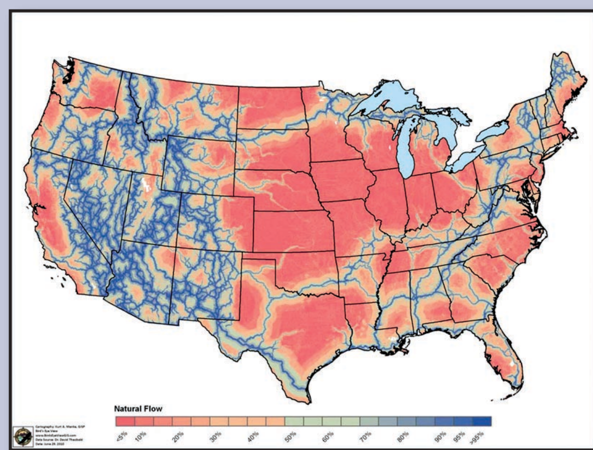
Connectivity is an important property that results from the interaction between animal movement behavior and landscape structure, and is influenced directly by the animal's perceptual range (Olden et al. 2004). Choosing the right species as targets is a critical step in conducting a comprehensive connectivity assessment. Species selection should be intimately linked to the conservation purpose described for the project and a process should be well designed to make that selection. Groves (2003) reviews and discusses several key aspects of establishing species as conservation targets. Based on his work and that of others we recommend that the following considerations be weighed when considering focal species for connectivity assessment:

- We recommend corridor design that serves more than one species (Bier et al. 2008)
- Design and apply a focal species selection process (Lambeck 1997)
  - Consider species umbrella effects and representation
- Be certain some species move across environmental gradients and have high mobility
- Select highly interactive species - One who's virtual or effective absence leads to significant changes in some feature of its ecosystem(s) (Soule et al. 2003).
- Include climate indicator species to monitor effects of changing climate.

The strategy of using focal species has been tested in several circumstances (Carroll 2001, Suring et al. 2011) but widely criticized by a number of authors (Franklin 1993, Noss 2002). Much of the criticism has been aimed at the selection of primarily vertebrate focal species which may not well represent insects, other invertebrates or plant communities (Unnasch et al. 2009). Lindenmayer et al. (2002) also points out that a focal species approach is data-intensive and, unfortunately, scientific information is lacking for many species. Finally, Furst et al. (2010) points out that poor selection of or inappropriate indicators can send ambiguous signals to conservationists leading to faulty decision making. Despite these challenges we believe that species remain a valid and useful target for connectivity conservation but should be used in conjunction with other useful ecological indicators.

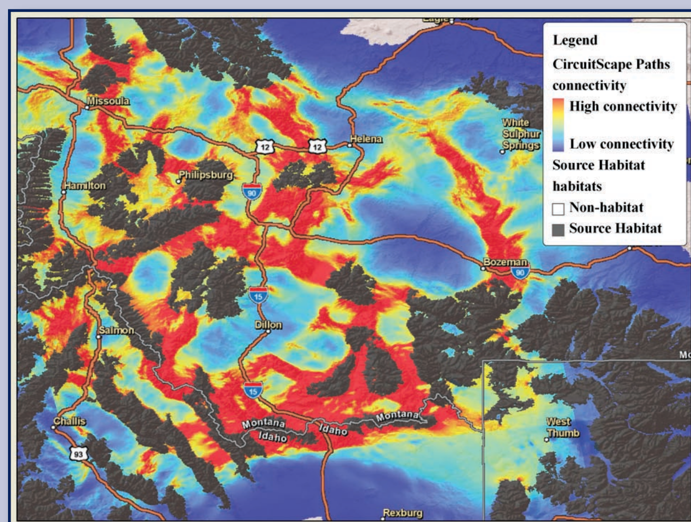
Matching Scale and Purpose When Assessing Connectivity

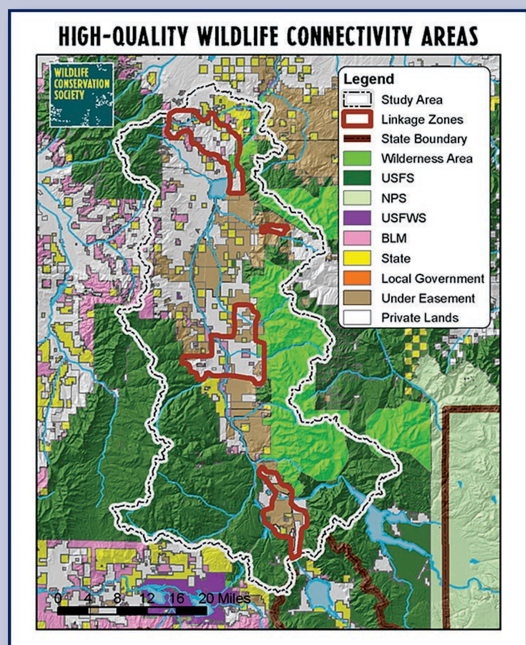
Spatial scale and grain are two important concepts in defining a connectivity assessment (Hilty et al. 2006, Figure 3). Spatial scale is more easily understood concept whereas grain is more complex idea. Grain is typically defined in the literature as the finest level of spatial resolution possible given a data set (Hilty et al. 2006). However, the functional importance of grain in connectivity is driven not just by the patchiness of landscapes and resolution of data but also by the dispersal capacity of species (Prugh et al. 2008). Dispersal capacity varies according to the



Wild LifeLines™ depict potential movement pathways in the U.S. between the Mexican and Canadian borders that emphasize the least human modification and highest extant connectivity for wildlife. These pathways are the result of a novel modeling approach that is based on a map of Natural Landscapes.

A regional perspective is important for identifying connecting landscapes at that management scale. The graphic to the left illustrates a circuitscape analysis for wolverine occupying the High Divide landscape linking the Greater Yellowstone and Central Idaho areas.





At the local level a fine scale analysis was applied using least cost path methods to identify key corridors for wildlife in the Madison Valley, Montana.

Figure 3. Examples of Connectivity Assessment at Various Scales

perceptual range of the species (Baguette and Van Dyck 2007). The interaction between landscape and species is defined as the functional grain. Functional grain size is then the smallest spatial scale at which an organism recognizes spatial heterogeneity according to its perceptual range, which is the basic limitation of animal perception (Wiens 1989; Kotliar and Wiens 1990; Lima and Zollner 1996). It has been hypothesized that the interaction between organisms and landscapes should depend on whether or not the grain of resource patches matches the spatial scale of the perceptual range (Baguette and Van Dyck 2007).

Spatial scale is one of the most important defining attributes of an ecological connectivity assessment (Hilty et al. 2006). Connectivity conservation is currently applied at many scales for a variety of purposes ranging from designing urban greenways, planning appropriate highway crossings, and identifying mega-linkages at a continental scale. Frequently, the scale at which planning and management occur is a key driver in determining the best scale for connectivity assessment. In many cases, the region is defined based on political boundaries, such as a nation, state, county, community or transportation district. In other cases, ecological transitions, or the decision of a funder, can define the region. Any of these delineations can lead to a successful effort. Furthermore, mapping of a state or other large extent is complemented, not undermined, by maps for subsets of the larger area. For instance, the 2006 Arizona Wildlife Linkage Assessment stimulated efforts to map linkages in 6 of Arizona's 15 counties. This advances conservation because in the US, the counties – not the states – develop land-use plans and make decisions about development of private land. Similarly, the 2001 California Missing Linkages Map stimulated a regional plan for the south Coast Ecoregion, which quickly led to linkage designs for 11 critical connectivity areas.

Defining a relatively large region has some advantages. As extent increases, edge-to-area ratio decreases, so that relatively few linkages are left unconsidered along the margin of the region. Thus a map at a large spatial extent better depicts a meaningful network of landscape blocks and connectivity areas. On the other hand, as extent increases, environmental and planning contexts may become heterogeneous (Woolmer et al. 2008). Such heterogeneity can be addressed by modifying strategies for particular subregions. For instance, Spencer et al. (2010) applied different thresholds for recognizing natural landscape blocks in different areas of California to reflect variation in degrees of habitat loss, habitat fragmentation, and land protection. A single, state-wide threshold that would discriminate areas to be connected in the relatively pristine eastern deserts would identify no natural landscapes in the Great Central Valley, thus excluding important habitat areas that deserve connectivity. Conversely, a statewide threshold that adequately discriminated natural landscape blocks in the Central Valley would coalesce the entire Desert into a single block, failing to recognize areas where connectivity should be enhanced. We recommend that connectivity targets should be prescribed at both coarse and fine scales and adequately matched to the geographic and time scales for the planning project or program. We also recommend that the analysis area extend beyond the conservation area, state or ecoregion of interest so that linkages to adjacent natural landscape blocks can be included on the map (Spencer et al. 2010, Jongman 2004). For instance, Spencer and others (2010) analyzed the state of California plus and 80 km. buffer and Washington's assessment extended 200 km beyond the state boundaries. Woolmer and others (2008) applied a 20 km area buffer around their planning area when evaluating the "Last of the Wild" in the Northern Appalachian Mountains. These buffer areas around the area of interest help coordinate management decisions across boundary areas and avoid strict jurisdiction based decisions that thwart conservation efforts.

Establishing Collaboration and Partnerships

Connectivity conservation is an attempt to manage a complex socio-ecological system that is beset with "wicked problems" therefore connectivity conservation is dependent upon people working together (Lockwood 2010). A fundamental characteristic and very important step for any successful conservation program in the U.S. is building necessary partnerships and encouraging collaboration among these partners to overcome these wicked problems. Beier and others (2012) suggest that stakeholders should be involved in each step of the assessment process from its conception to implementation. Stakeholders should be engaged in crafting the conservation vision, identifying conservation targets, defining the assessment region, determining what areas need to be connected, approving the work plans and reviewing the products. In many cases this can be accomplished by forming a steering committee and/or technical workgroups with all stakeholders seated at the table.

Collaboration is dependent upon building a trusting and open environment for participation. Lockwood and others (2009) identifies 8 principles of good governance that we believe will create a better atmosphere for collaboration in connectivity conservation. These principles include:

- **Establishing Legitimacy** - Authority to govern accepted by the stakeholders.
- **Maintaining Transparency** - visibility and clarity of decision making
- **Practicing Accountability** - allocation and acceptance of responsibility
- **Inclusiveness** - opportunity for stakeholders to participate in and influence decision making
- **Fairness** - respect and attention given to stakeholders
- **Encouraging Integration** - connection and coordination across different governance levels
- **Establishing Capability** - systems, plans, resources, skills, leadership and knowledge that enable organizations
- **Demonstrating Adaptability** - ability to incorporate new knowledge and learning.

When all these principles are applied then true partnerships can form and collaboration can thrive assuring that connectivity assessment products will be accepted by most stakeholders. A useful report titled *Beyond the Hundredth Meeting: A field guide to collaborative conservation on the West's Public Lands* can be consulted to begin the collaborative process (Cestero 1999). Many web resources such as the Center for Collaborative Conservation at www.collaborativeconservation.org can be helpful in crafting your process for building collaboration around connectivity conservation. Finally, Conley and Moote (2003) discuss methods for evaluating the effectiveness of a collaborative process and identify useful criteria for evaluating collaboration. We recommend consulting specialists, published literature and on-line resources to develop a process to establish good collaboration and engage partners in connectivity conservation. In addition, a subsequent evaluation process should be established to determine if the collaborative process was effective in gaining support for connectivity conservation.

Conservation Areas to be Connected:

A crucial step in any connectivity analysis is deciding what needs to be connected. There have been a wide variety of approaches used. Two often-used and complementary ones for wildlife and plants are: Approach 1) to describe taxonomic group movement needs and disturbances to those needs using a connectivity gradient across a landscape (e.g., Shilling et al., 2002; Shilling and Girvetz, 2007) and Approach 2) to define core areas and corridors or linkages among core areas across the landscape to meet focal species' needs (Shilling et al., 2007; Spencer et al., 2010). The approaches – or combinations of them – can be used to define connectivity needs across these complementary approaches:

Hold an expert workshop at which knowledgeable participants describe species' needs for movement and sensitivity to disturbance (Approach 1), or draw polygons on a map by hand (Approach 2).

Select areas of high ecological integrity, such as low road density, and low proportion of area converted to urban, agricultural, or industrial use (Approaches 1 & 2).

Analyze connectivity as a gradient across the landscape to reflect connectivity needs for multiple species and processes (Approach 1).

Select protected areas – areas where biodiversity and natural landscape character are protected by law or landowner mission (Approach 2).

Use simulated annealing to identify areas that meet quantitative biodiversity targets in a compact area (Approach 2).

Use one of the several methods for delineating "corridors" or "linkages" among core areas (Approach 2).

Compare findings from Approaches 1 & 2 to a map that another agency has already developed to conserve biodiversity (e.g., biodiversity hotspots, The Nature Conservancy's ecoregional priorities, Critical Habitat for listed species) to include as "core areas", or to test the results of your analysis and the other agency.

Compare findings from Approaches 1 & 2 with maps of modeled or known habitat for a suite of species.

Use highways either to estimate disturbance to connectivity needs (Approach 1) or to delineate natural landscape blocks or to modify preliminary blocks developed by one of the above procedures (Approach 2).

In both California (Shilling et al., 2002; Shilling and Girvet, 2007; Spencer et al. 2010) and Washington, most stakeholders initially argued for and eventually used focal-species, habitat-based approaches (#8). Washington eventually defined blocks on the basis of a combination of core habitats for 16 focal species (#8) and areas of high ecological integrity (#2). After long discussion, California stakeholders in one process (Spencer et al., 2010) came to believe that state-wide maps of modeled habitat for over 25 focal species would likely be inaccurate and insignificantly better than an analysis based on naturalness. Once they fully appreciated that the map would be a decision-support tool, not a collection of several hundred implementable linkage designs, they settled on a hybrid approach that identified preliminary natural landscape blocks as areas of high ecological integrity (#2) or areas of high protection status (#4), with a small ―bonus‖ for mapped biodiversity areas (#7). They further modified the natural landscape blocks by splitting them at each highway crossing (#9). In another California process, at the scale of the Sierra Nevada/Modoc/Cascades bioregions (Shilling et al., 2002; Shilling and Girvetz, 2007), stakeholders agreed to a combination of modeled focal species habitats (#8) and ecological integrity (#2) as foundations for modeling a gradient of connectivity, followed by simulated annealing to identify core areas (#5), corridor identification (#6), and identification of conflicts with highways with highway volumes of traffic (#9). We believe both Approaches were good ones because they respected the range of stakeholder values. To help inform future discussions, we describe the advantages and disadvantages of each option.

Option 1: Expert Workshops

An expert workshop is an efficient way to draw on the knowledge of the many people who know the status of biodiversity across the region. Much of their knowledge comes from unpublished information and personal familiarity with the land. The approach is efficient, in that large areas can be discussed and mapped in a short time at low cost. On the other hand, the process is not transparent, quantitative, and repeatable, and the outputs tend to be vague, making it difficult to see what was at stake if a particular linkage was lost.

Option 2: Areas of High Ecological Integrity & Gradients of Connectivity

In this approach, ecological integrity or naturalness of each pixel is calculated as a function of attributes that are mapped for every pixel in the analysis area. Pixel attributes related to ecological integrity may include landcover, land use, distance to nearest paved road, population density, or road density. The result of this process is calculation of a gradient of connectivity (Fischer et al., 2004). Then contiguous clusters of pixels that are good enough (above a certain threshold ecological integrity) and big enough (above a minimum area threshold) can be identified as natural landscape blocks. An elongated strip of natural land, such as power line right of way in an urban area, may be too narrow to contribute to a true core area; conversely small holes within a natural area may not disrupt its integrity. To define blocks that ignore these spurs and gaps, analysts should use PatchMorph (Girvetz and Greco 2007) or other simple shape algorithms (Shilling et al., 2007; Spencer et al. 2010).

We recommend ecological integrity as a primary determinant of natural landscape blocks, because it efficiently identifies large natural areas, even if they are unprotected. The approach is transparent, repeatable, and relatively simple. Hoctor et al. (2000), Carr et al. (2002), and Marulli and Mallarach (2005) used Ecological Integrity to define natural landscape blocks.

The analyst must work with stakeholders to select the attributes that will define ecological integrity. We recommend using a small number of easy-to-grasp attributes, such as proportion of land in natural land cover and measures of disturbance, such as a road-proximity variable. Models with many attributes lack transparency and risk becoming black boxes that stakeholders distrust. If housing density is a variable, analysts should be aware that the US Census Bureau does not report where houses occur within the Census Block. When a heavily-populated Census Block extends into an unpopulated natural area, all pixels in the Census Block, even those in pristine areas, will be assigned the average housing density of that Block.

The attributes are combined to yield an overall ecological integrity score using some combination of Boolean functions, mathematical operations, arithmetic mean, or geometric mean. The Boolean ―AND, mathematical operator ―MINIMUM, and geometric mean reflect situations where deficiency in one attribute cannot be compensated by good values for other attributes. The analyst should develop maps reflecting alternative rules and alternative minimum size thresholds to qualify as high integrity, or as a natural landscape block and let end users choose the rule and threshold that provides a useful, readable map. The map of ecological integrity will reflect the gradient of likely connectivity across a landscape. When combined with an understanding of connectivity needs of animals, plants, and natural processes at scales appropriate for each, the map increasingly reflects functional connectivity.

Option 3: Protected Areas

In this approach, the analyst selects all parcels that meet a certain level of protection, such as all lands in certain GAP protection classes (Crist 2000) or IUCN protected area classes (IUCN 1994). Contiguous parcels above the threshold protection status and above the minimum size threshold are designated as Natural Landscape Blocks. The approach is straightforward and unambiguous. The resulting connectivity map connects only to existing conservation investments, precluding ―corridors to nowhere– i.e., mapped connections to lands that could be developed in the future. The downside of the approach is that it writes off natural landscapes that are not currently protected. In some regions, most large natural landscapes may be unprotected and still have functional connectivity. Some of these areas may be at low risk of development due to rugged terrain or lack of access to water, and others could be conserved in the future. Because using protection status as the sole determinant of a Natural Landscape Block would fail to recognize some valuable wild landscapes, we recommend using protection status in conjunction with ecological integrity.

Option 4: Simulated Annealing

Simulated annealing (Ball and Possingham 2000, Possingham et al. 2000) depicts the landscape either as a grid of cells, or as a group of irregularly-shaped polygons (e.g., watersheds, ownership parcels). The analyst must have an estimate of how much each grid cell or polygon can contribute to biodiversity targets. The goal is to achieve a certain number of occurrences of each species, or each type of natural vegetation community, at the smallest cost. Two aspects of cost are considered, namely total land area (expressed in ha or dollars) and the amount of edge (because the cost of managing a protected area and ensuring its integrity becomes more difficult as edge increases). The combination of cells or polygons that achieves all targets at the lowest cost is the optimal solution. Before high-speed computing, finding the optimal solution was difficult; with 100 polygons, there are over a trillion quadrillion possible combinations of polygons to evaluate. Fortunately, the software MARXAN (Ball & Possingham 2000) efficiently identifies optimal or near-optimal solutions. Other versions of MARXAN are SITES, used by The Nature Conservancy in many of its ecoregional assessments in the US, and CLUZ. Shilling et al. (2002) used SITES to identify "core areas" that met conservation goals, using ecological integrity and focal species needs as a value surface. These core areas were later linked using a corridor method to create a network of protected and connection areas.

We suggest caution in using simulated annealing to define core areas because connectivity should not be limited solely to the smallest landscape areas needed to meet biodiversity goals. Such a procedure may be appropriate when one is allocating scarce dollars for acquisition or easements. But connectivity planners typically want to maintain or improve connectivity to all core areas – not just those that contain high biodiversity in a small area. Therefore we recommend procedures that identify large, intact natural landscape areas in their entirety, rather than the smallest portion necessary to meet specified goals.

Option 5: Corridor and Linkage Analysis

Corridors are delimited areas on the landscape that a planner either selects for constrained connectivity purposes, or is a strip of remnant, un-developed vegetation. Linkages are wider corridors. Both are designed to link patches of un-developed habitat and are useful under that rubric. Most contemporary connectivity mapping projects use some form of corridor or linkage to delineate connections among core areas. We caution that, although the authors and other conservation scientists have used these methods in the past, this approach has not been tested fully in terms of actual benefits to biodiversity. Where testing has occurred, landscape corridors and linkages have species-specific and scale-specific utility. Because of the lack of general application of the concept of corridors and linkages, connectivity mappers should include information about ecological integrity and gradients of disturbance and connectivity.

Option 6: Existing Conservation Maps

Many agencies have developed maps to conserve biodiversity that cover broad regions. For example, The Nature Conservancy has developed maps of conservation priorities in most states and ecoregions. As part of their Strategic Wildlife Action Plans, most states have identified areas of conservation emphasis. The US Fish and Wildlife Service has designated Critical Habitat for many species listed under the Endangered Species Act. All such maps depict areas with documented value to biodiversity, and thus seem appropriate for designation as core areas. This approach has two disadvantages. First, it can fail to recognize biodiversity —coldspot – that is, those large, functioning ecosystems that lack high biodiversity or special status species (Karieva and Marvier 2003) but may nevertheless be important to conserving natural communities, biodiversity, and ecological functions. Second, some designated Critical Habitat and some rare species occurrences occur in highly degraded, un-natural landscapes, and some rare endemic plants or insects may occur in small, naturally-isolated populations that do not need connectivity.

In light of these disadvantages, we recommend against giving a major role to these areas in defining a core area. Both Shilling et al. (2002)

and Spencer et al. (2010) reasonably assigned a small —bonus to the ecological integrity score for pixels that fall in areas of mapped biological value.

We caution against using a biological value map layer that covers less than the entire region. For example BLM designates Areas of Critical Environmental Concern, but only on federal land; using this map to help define blocks would disfavor non-federal lands. Maps of designated critical habitat under the US Endangered Species Act are problematic because the law requires designation to minimize economic impact and avoid private lands. Instead of or in addition to critical habitat maps, we recommend using maps of areas that support habitat features essential to survival and recovery of a species, as determined by USFWS prior to consideration of economic impacts and land ownership. Other layers that may be available in some regions include wetlands and vernal pools, rarity-weighted hotspots of biodiversity, successional stage of the vegetation, susceptibility to disturbance, and presence of invasive species.

Option 7: Habitat Cores for a Suite of Species

For a relatively small region (2,500 km2) in northern Italy, Bani et al. (2002) defined core areas for a suite of forest birds and carnivores as areas above a minimum size and minimum number of detections in over 1,000 point counts and transects of the area. They used these cores as start- and end-points for a regional network of corridors. Because empirical species distributions are expensive to determine for planning areas 10 or more times larger than this, other planners were compelled to use modeled or expert-based species distributions. For example, the Southern Rockies Ecosystem Project (2005) convened expert workshops that produced hand-drawn habitat core areas for 27 focal species in Colorado, and 176 hand-drawn linkage areas among these core areas; these were never joined into a single statewide map. In 2008-2011, Washington analysts selected 16 focal species to represent five major vegetation biotypes, developed a map of modeled core habitats and modeled least-cost corridors for each species, and joined the 16 maps into a statewide map of habitat cores and linkages.

There are advantages to this approach. Most end-users are comfortable with species conservation as a goal, and federal and state agencies have regulatory authority to protect and manage species. Furthermore, linkages are ultimately intended to serve particular species; a linkage based on ecological integrity could fail to include a good linkage for some species.

On the other hand, it is difficult to select focal species that represent the entire biota of a state or region, reliably model each species‘ core habitat, and overlay the maps for individual species to produce a coherent set of core areas. In addition, there is a bias in information accuracy and completeness toward larger, or well-studied species. This large extra effort (compared to an approach based on ecological integrity) may be worthwhile if the product is a better decision support tool or vision statement. In addition, the habitat and permeability models for each focal species can provide a good basis for individual linkage designs. Nonetheless, fine-scale linkage designs will need to consider additional focal species, site-specific interventions such as wildlife crossing structures, and other local conditions.

Option 8: Linear Barriers as Block Boundaries

Unless mitigated by crossing structures integrated with fencing, a single highway can block gene flow for mammals, reptiles, and even sedentary birds (Delaney et al. 2010, and citations therein). Therefore, it is reasonable to split a preliminary core area into smaller blocks using highway, canal, railroad or other linear barrier as the dividing line. In the context of visualizing connectivity as a gradient across a landscape, a highway can mark an extreme limitation to connectivity. This divide formed by linear barriers will have variable but often limited permeability based upon the ability of species to cross the line from one side to the other.

Robust Approaches to Assess Connectivity:

There are an increasing number of science approaches and many new tools for assessing and mapping ecological connectivity. Every science based approach models some aspect of connectivity and there is no single approach that is best for all tasks. Effective connectivity assessment requires that managers clearly define their goals, match the assessment approach to desired outcomes and then attend to a specific set of tasks (Worboys et al. 2010).

There are several important examples of connectivity assessment at the state or regional scale that warrant review. The California Missing Linkages report (Penrod et al. 2001), Arizona Wildlife Linkage Assessment (Nordhaugen et al. 2006), and the California Essential Habitat Connectivity report (Spencer et al. 2010) changed the way connectivity is treated in each of those states. For example, federal, state, and local transportation agencies began to consider the impact of new highway projects early in the planning process, and collaborations between state transportation and wildlife agencies increased dramatically. Arizona, for example, experimentally tested the effectiveness of different wildlife overpass designs and different types of roadside fences, and is using the information in new projects. Moreover, Arizona is now building its first two wildlife overpasses, and is committed to build three more. The statewide plans in California and Arizona promptly stimulated county or ecoregional connectivity maps, and 11 linkage designs in California (South Coast Wildlands 2007) and 16 linkage designs in Arizona (www.corridordesign.org/arizona), each of which is being actively implemented. Over 100,000 ha (250,000 acres) of natural lands have been conserved in the 11 California linkage designs.

There are also many examples of mega-linkage assessments that have deeply impacted conservation around the world (Worboys et al. 2010). Around the globe there are a myriad of connectivity initiatives for implementing large scale ecological networks such as the Pan-European Ecological Network (PEEN) and the Natura 2000 network in Europe; Yellowstone to Yukon, Two Countries-One Forest, the 'Alps to Atherton'; Great Barrier Reef Marine Park and 'Gondwana Link' in Australia; the Terai Arc in Nepal and India; the Mesoamerican Biological Corridor; the Vilacamba-Amboró in South America and many others; (See Graham and Wit 2001, Shadie and Moore 2009). Most recently Wildlands Network introduced a new connectivity initiative titled Wild Lifelines™ which modeled broadscale wildlife movement pathways in the continental United States. These large scale approaches can help identify critical landscapes needing protection or special management prescriptions to accommodate animal movement in the face of human impacts and pending climatic changes. However, these large scale assessments should be accompanied by appropriate regional or small scale assessments to prescribe finer scale management. These statewide, regional and mega-linkage connectivity initiatives have captured the imagination of thousands of citizens, leading to better consideration of connectivity in countless local planning efforts.

The explosion of modeling approaches and new assessment tools has led to some confusion about which tools are robust and provide the best science base for connectivity conservation. We reviewed the literature and consulted experts in the field to derive some guidance about these tools and to help the practitioner decide which assessment approach or toolkit will best serve their conservation needs. There are several tools and best approaches for assessing connectivity and we have chosen not to select a single approach but rather catalog the current methods and offer our best guidance regarding advantages and disadvantages of each approach (Table 1).

Current robust approaches for assessing and mapping connectivity are listed and described below:

- **Least Cost Path:** Least-cost modeling was first applied to corridor design by Walker and Craighead (1997). This approach calculates a

Table 1. Advantages and Disadvantages of Connectivity Assessment Approaches

Approach	Description	Theoretical Basis / Assumptions	Advantages	Disadvantages	Comments / Considerations	
Least Cost Path	• Path of least resistance (cost) between habitat patches for an individual species • Functional Connectivity (Potential)	Species will move where the landscape provides the least resistance	• Incorporates influence of matrix and individual species behavior • Modest data need: resistance map of the matrix • A good tool for coarse scale linkage design	• Costs assigned to landscape are often subjective – "subjective translation" • Pixel-wide paths are not a realistic conservation intervention. • Effectiveness of corridors often not confirmed • It is NOT a predicted path (animals do not have perfect knowledge of the landscape)	Common approach, could be improved by: • Using empirical data to determine costs • Using genetic relatedness to determine endpoints • Evaluating with movement data • Including species perception information to examine the influence of scale on resistance	Increasing data requirements >>>>>>>>>>
Graph Theory	• Graphs a network of habitat patches incorporating species-specific dispersal data • Functional Connectivity (Potential)	Habitat patches and linkages create a network that can be examined to understand overall landscape connectivity and linkage value	• Simplest form requires little data • Allows for multi-scale examination of patch/linkage configuration and the effects of changes on the landscape • Excellent for prioritization of linkages identified and mapped by another approach	• Does not incorporate matrix effects • Produces tinker-toy, not a 'real map' – each linkage is a non-spatial 'stick'	Can be used to rank corridors based on their contribution to landscape-level connectivity	
Landscape Networks	• Combines least cost paths with graph theory to visualize landscape level connectivity • Functional Connectivity (Potential)	Same as least cost path and graph theory	• Incorporates matrix effects • Allows for landscape level examination of patch/linkage configuration and the effects of changes	Same disadvantages as LCP	Can be used to rank corridors based on their contribution to landscape-level connectivity	
Circuit Theory	• Applies circuit theory to graphs but further defines linkages relative to resistance, conductance, current, voltage and other metrics	Current voltage and resistance in electrical circuits have precise relationships with random walks.	• Metrics generated from models are process based • Easily parameterized from raster grids • Robust to changes in scale (cell size)	• Can suffer from "subjective translation" • Not useful for movement that is unidirectional or biased in one direction. • Pinchpoints ("hot" areas of constricted flow) are not the same as corridors or linkages.	• Can be used to predict dispersal rates based on simple landscape data and for modeling processes that depend on dispersal (gene flow, community diversity) • Ideal for identifying areas of high threat (prioritizing), and comparing alternatives	
Individual Based Movement Model	• Detailed tracking of movement via telemetry, mark-recapture • Patch level immigration or colonization rates • Functional Connectivity (Actual)	No assumptions, actual movement is mapped	Most direct estimate of actual connectivity.	Data intensive, usually limited to small spatial extents. • Required data: travel speed • Turning angles • Energy costs • Mortality risk in each habitat	Patch level movements may help inform landscape level movements	
Network Flow / Dispersal Chains	Bioclimatic envelopes will shift with climate change	Landscape attributes will shift with climatic change affecting ecological processes in predictive ways	Does not depend on the resistance map	Huge data needs & assumptions	• An emerging approach in development • Identifies Climate Change Corridors	

resistance or travel cost for a pixel resulting from the pixel's internal characteristics, which is simply the inverse of the pixel's permeability or habitat suitability. In contrast, cost-distance (sometimes called effective distance or cost-weighted distance) is a pixel attribute resulting from the pixel's resistance plus the resistance of a chain of pixels reaching to each terminus of a pathway. Thus in moving from resistance to cost-distance, you are moving from a single pixel's content to its landscape context. LCP is not a prediction of the movement path of an animal but identifies a potential travel route that minimizes the cost of movement. Theobold (2006) provides a review of this approach and offers refinements.

- **Individual-Based Movement Models (Hargrove et al. 2004, Tracey 2006):** These models simulate animal movement, consider the impact of mortality (ignored by other procedures) on successful movement, and identify multiple paths that are less linear than those produced by other procedures. Because of these virtues, this approach is potentially an ideal tool to produce both coarse-scale connectivity maps and fine-scale linkage designs for focal species. It has not yet been used to produce connectivity maps because ecologists lack data to estimate the required parameters, such as turning angles and mortality risks in each cover type or each edge type. New GPS radio-tags will yield sufficient volumes of the types of data needed to estimate these parameters reliably. At that time, these models will become more widely used for connectivity mapping.
- **Circuit Theory (McRae 2006, McRae et al. 2008):** The key innovation of circuit theory is that it considers the ability of the entire landscape (rather than a path or corridor) to support animal movement. It requires exactly the same data as least-cost modeling, namely a resistance map and can often be used to complement least-cost modeling. It is probably the best single tool for comparing the overall connectivity of alternative landscape configurations, and for identifying narrow pinchpoints. These vulnerable areas should be targeted for conservation interventions such as land acquisition and habitat restoration. Circuit theory was developed to describe movement and gene flow, and has not yet evolved into an approach that can map optimal connectivity.
- **Graph Theory:** Graph theory underlies all raster-based GIS operations, including least-cost modeling, individual-based movement models, and circuit theory. Confusingly, "graph theory" has also come to refer to a set of descriptors such as *between-ness*, *centrality*, and *minimum spanning tree* (Bunn et al. 2000, Urban & Keitt 2001, Theobald 2007, Minor & Urban 2007) that describe a graph consisting of the x-y locations of the centroids of patches (such as natural landscape blocks), some of which are connected by sticks (called "edges" in graph theory). FunConn (http://www.nrel.colostate.edu/projects/starmap) and the Connectivity Analysis Toolkit (http://www.connectivitytools.org) are software packages that perform these operations. The metrics can be used to describe and compare networks or to assign priority to certain blocks or linkages (but see Pascual-Hortal & Saura 2006, 2008 for examples of how poorly some of these metrics perform). These descriptors have never been used to create mapped connector polygons.
- **Dispersal Chain Models and Network Flow Models:** These 2 approaches produce corridors that track how a species' bioclimatic envelope (suitable temperature and moisture regime) moves across the landscape during climate change. Both approaches rely on predictions of future emissions of greenhouse gasses, models of how the atmosphere and oceans respond to these gasses to produce new seasonal patterns of temperature and precipitation at each grid cell in a landscape, and bioclimatic envelope models. Then a dispersal chain model (Williams et al. 2005) or a network flow model (Phillips et al.

2008) identifies cells of suitable habitat that are spatially contiguous for a long enough time that a species could establish new populations in cells that are transitioning into the bioclimatic envelope as fast as currently occupied cells are becoming unsuitable. Although the dispersal chain and network flow models are conceptually sound, the utility of the overall approach is limited by massive uncertainty in emission scenarios, global air-ocean circulation models, and climate envelope models (Beier & Brost 2010). Ensemble modeling (building dozens of corridors based on various combinations of emission scenarios, circulation models, and climate envelope models) might identify corridors robust to these uncertainties. Until ensemble modeling occurs, we do not recommend using corridors produced by these models in a regional connectivity map.

- **Land Facet Models:** To plan for climate change without relying on projected emissions, air-ocean circulation models, and climate envelope models, Hunter et al. (1988), Beier and Brost (2010), and Anderson and Ferree (2010) advocate designing reserves for land facets, defined as recurring landscape units with uniform topographic and soil attributes. The key assumption is that land facets serve as arenas of biological activity that will not change with future climate, and are thus appropriate entities for long-term conservation planning. Brost and Beier (Northern Arizona University) are preparing a paper describing how to use land facets to design corridors for climate change, and a second paper describing how land facet corridors overlap focal species corridors. This may be a promising approach for both coarse-scale connectivity maps and fine-scale linkage design. The limitation of this approach is that one may end up protecting the stage, but not the actors (species) or the play (interactions among species and with their environment).

There are many advantages and certain disadvantages to the various approaches described above (Table 1). We recommend the conservation practitioner examine the literature in more detail to carefully match the best connectivity assessment approach to conservation targets and scale of conservation area or region. Since 1997 there have been considerable improvements in modeling tools and we recommend reviewing and selecting the right modeling tool fitted to your purpose and capacity (Figure 4).

Meeting Challenges Associated with Connectivity Assessment:

There are significant issues and challenges to be addressed when assessing ecological connectivity in a conservation area (Appendix Table 1). These will necessarily vary with the geography and scale of the project. Each challenge imparts unique considerations and the conservation practitioner should evaluate and integrate these into the assessment process. The challenges we present here are only the most prominent we have identified through a search of published literature and the experience of workshop experts who have attempted connectivity assessment in recent years. Within unique geographies and various management jurisdictions many others challenges can be expected.

Data Availability, Quality, and Limitations

One of the most difficult but easily overlooked challenges affecting connectivity conservation is gathering and evaluating the quality of data used in assessment then managing the large quantities of data available. In many cases the volume and/or reliability of available data are weak thereby limiting the ability to identify habitat patches and assess connectivity needs for a species or landscape. A fundamental step in assessing connectivity is completing a comprehensive inventory of available data and documenting the data source, quality, and reliability. Criteria are needed to determine which data to include or exclude from the disparate sets of information available for assessment. The assessment

Corridor Design - http://www.corridordesign.org
A team of ecologists and GIS Analysts in the school of Forestry at Northern Arizona University have designed over 20 wildlife corridors in Arizona and California. They developed GIS tools to develop corridor designs and a toolbox that any GIS savvy user can use. The CorridorDesigner ArcGIS tools are best suited for designing corridors in a heterogenous landscape at a regional (e.g. 2 - 500 km long) scale. They have found GIS-based corridor modeling to be a useful tool which helps design the best corridors. The website offers alternative approaches and encourages exploration using various tools and methods.

FunConn - http://www.nrel.colostate.edu/projects/starmap/funconn_index.htm
FunConn is a functional connectivity modeling toolbox for ArcGIS, distributed by Dave Theobald and the Natural Resource Ecology Laboratory at Colorado State University. The goal of the functional connectivity model is to allow landscape connectivity to be examined from a functional perspective. Functional connectivity recognizes that individuals, species or processes respond functionally (or behaviorally) to the physical structure of the landscape. From this perspective, landscape connectivity is specific to a landscape and species/individual/process under investigation.

CircuitScape - http://www.circuitscape.org
CircuitScape is a stand-alone Python program which borrows algorithms from circuit theory to predict patterns of movement, gene flow, and genetic differentiation among populations in heterogeneous landscapes. It uses raster habitat maps as input, and predicts connectivity and movement patterns between user-defined points on the landscape. Circuitscape is distributed by Brad McRae of the National Center for Ecological Analysis and Synthesis (NCEAS) at University of California, Santa Barbara.

Connectivity Analysis Toolkit - http://wwwconnectivitytools.org
The Connectivity Analysis Toolkit is a software interface that provides conservation planners with newly-developed tools for both linkage mapping and landscape-level ‘centrality’ analysis. Centrality refers to a group of landscape metrics that rank the importance of sites as gatekeepers for flow across a landscape network. The Toolkit allows users to develop and compare three contrasting centrality metrics based on input data representing habitat suitability or permeability, in order to determine which areas, across the landscape as a whole, would be priorities for conservation measures that might facilitate connectivity and dispersal. The Toolkit also allows application of these approaches to the more common question of mapping the best habitat linkages between a source and a target patch. The software is free and available at www.connectivitytools.org. A detailed manual included in the download gives more background on the methods, and may also be useful to those who are not GIS modelers but are interested in conservation planning.

Figure 4. Connectivity Assessment Websites

processes must be iterative in nature so data systems also need to be capable of integrating new and better data to improve the performance of assessment tools. Data limitations need to be clearly articulated in the metadata documentation and measures to incorporate new and better data should be built into the information management system. This need demands a flexible architecture in the data management system.

It is important to develop a dynamic data needs assessment as the project moves forward to identify information gaps in currently available data for the project. Important and significant gaps may require modification in the assessment process including modeling tools, conservation targets, and project goals or, more dramatically, a complete restructuring of assessment and planning efforts. An analysis of important information gaps is essential for directing new research and designing monitoring to produce new information in the future.

Systems to manage large volumes of complex data are essential to the success of a comprehensive connectivity project. Many new data management tools are readily available and should be incorporated into a connectivity project (Figure 5). An example is the existing network system employed by NatureServe and called Biotics 4. This is NatureServe’s 8th generation of biodiversity data

Environmental Systems Research Institute (ESRI) - http://www.esri.com

ArcGIS Data Appliance - http://www.esri.com/software/arcgis/data-appliance/index.html
Maps and Tasks for ArcGIS Server. ArcGIS Data Appliance is a unique combination of hardware and data. The enterprise scalable server plugs right into your organization's internal network and serves terabytes of worldwide reference map data including imagery, street, and topography.

ArcGIS Online Map Services - http://www.esri.com/software/arcgis/arcgisonline/standard-maps.html
ArcGIS Online provides a common platform to find, share, and organize geographic content and to build GIS applications. Through ArcGIS.com, the Web interface for ArcGIS Online, you can access maps, apps, and tools published by ESRI and other GIS users, and share your own content with a broad community of users. These include:

- Basemaps - World Imagery, World Street Map, World Shaded Relief, World Physical Map, and USA Topographic Maps
- Demographic Maps - Twenty maps providing details about the U.S. population, including average household size, median age, population density, retail spending potential, and more.
- Reference Maps - World Boundaries and Places, World Reference Overlay, and World Transportation.
- Specialty Maps - DeLorme World Basemap, World Navigation Charts, and Soil Survey Map.

ESRI Demographic Data - http://www.esri.com/data/esri_data/index.html
Accurate and comprehensive demographic, lifestyle segmentation, consumer spending, and business data to help you profile customers, analyze markets, evaluate competitors, and identify opportunities.

Geospatial Data Wiki (Yellowstone Ecosystem Research Center) - http://www.yellowstoneresearch.org/projects_wiki.html
The Geospatial Data Wiki is an end user product that was born out of our NASA funded RRSC grant. This type of product came up in discussion with early adopter working groups as a valuable way for researchers to have access to a list of many of the different data types available to them.

COASTER (Yellowstone Ecosystem Research Center) - http://www.yellowstoneresearch.org/projects_coaster.html
The Customized Online Aggregation & Summarization Tool for Environmental Rasters (COASTER) system is being developed by Yellowstone Ecological Research Center in response to the data needs of research collaborators. The primary intent of COASTER is to greatly reduce the data storage and computational capabilities required to create customized environmental covariates. Notable features of COASTER include a conceptually simple and yet extremely flexible design, and easy to use output (i.e., results from COASTER are in a format (.tif) amenable for use in most GIS and remote sensing software packages).

Ecosystem Based Management (EBM) Tools - http://www.ebmtools.org
The EBM Tools Network is an alliance of EBM tool users, providers, and researchers to promote the use and development of EBM in coastal and marine environments and the terrestrial environments that affect them (watersheds). The EBM Tools Network works with technology tools, primarily software, which can facilitate a variety of EBM processes including:

- Collecting, managing, and processing data about ecosystems and human communities
- Generating and visualizing scenarios of potential consequences of different management decisions on natural resources and the economy
- Facilitating communication with the public and stakeholder involvement in planning and management processes.

NatureServe - http://www.natureserve.org/getData
NatureServe and its network of member programs are a leading source for reliable scientific information about species and ecosystems of the Western Hemisphere. This site serves as a portal for accessing several types of publicly available biodiversity data.

NatureServe Explorer - http://www.natureserve.org/explorer
Authoritative conservation data on more than 70,000 plants, animals, and ecological communities of the United States and Canada.

InfoNatura - http://www.natureserve.org/infonatura
Learn about more than 8,500 common, rare and endangered species and 788 ecosystems.

NatureServe Web Services for Application Developers - http://services.natureserve.org
Using NatureServe Web Services you can access and download detailed spatial and tabular data on at-risk plants, animals, and natural communities and import it into your application.

DataBasin - http://databasin.org/about
Data Basin is a free, online system that connects users with spatial datasets, tools, and expertise. Individuals and organization can explore and download a vast library of datasets, upload their own data, create and publish analysis, utilize working groups, and produce customized maps that can be easily shared. The building blocks of Data Basin are:

Datasets: A dataset is a spatially explicit file, currently Arcshape and ArcGrid files. These can be biological, physical, socioeconomic, (and soon to be imagery) that can be uploaded, downloaded or visualized.
Maps: Maps are visualized datasets created with easy-to-use tools in Data Basin. Maps, customized by users, can be kept private, shared with groups, or published for everyone. Users can critique maps with provided drawing and commenting tools.
Galleries: Galleries are meaningful collections of datasets and/or maps created by Data Basin users. Users and organizations can publish galleries (including studies, atlases and books) that others can easily find and use.

National Biological Information Infrasctructure - http://www.nbii.gov
The National Biological Information Infrastructure (NBII) is a broad, collaborative program to provide increased access to data and information on the nation's biological resources. The NBII links diverse, high-quality biological databases, information products, and analytical tools maintained by NBII partners and other contributors in government agencies, academic institutions, non-government organizations, and private industry.

Figure 5. Resource websites to support data gathering and integration.

management software. This is a desktop based application for integrating tabular and spatial biodiversity data. It manages local and range-wide information for both species and ecosystems. It is built with Oracle database and ESRI spatial components.

Integration of data from various sources and in various formats can be a formidable challenge. Often data used in assessment are derived for various purposes and differ significantly in their quality and resolution. This become particularly problematic as the scale of a project is increased. With a broad scale connectivity analysis it is common to cross various jurisdictions and intersect a variety of data collection protocols, data management systems and formats. There are several organizations or groups that have experience in the area of broad scale data integration (e.g. NatureServe and ESRI) and should be consulted in the beginning of the assessment process (Woolmer).

The wide use of data sets from different domains has created a demand for processes to extract and understand data from them (Cristina et al 2003). This demand has opened a whole new field of data exploration and visualization. Data exploration before, during and after ecological modeling serves a vital role in testing assumptions (Crabtree and Sheldon 2011, Zuur et al 2010). Data exploration and visualization toolsets are emerging and should be utilized routinely to acquire insight into useful information embedded in underlying data or define limitations in its appropriate use.

The concept of an Information Value Chain was developed as a deliberate model of strategy formation by Schwolow & Jungfalk (2009). NatureServe has developed an example of a Conservation Information Value Chain (Figure 6). Because there are so many sources of complex data and various qualities of data understanding the value changes in the information as it moves to applications and decisions is an important concept.

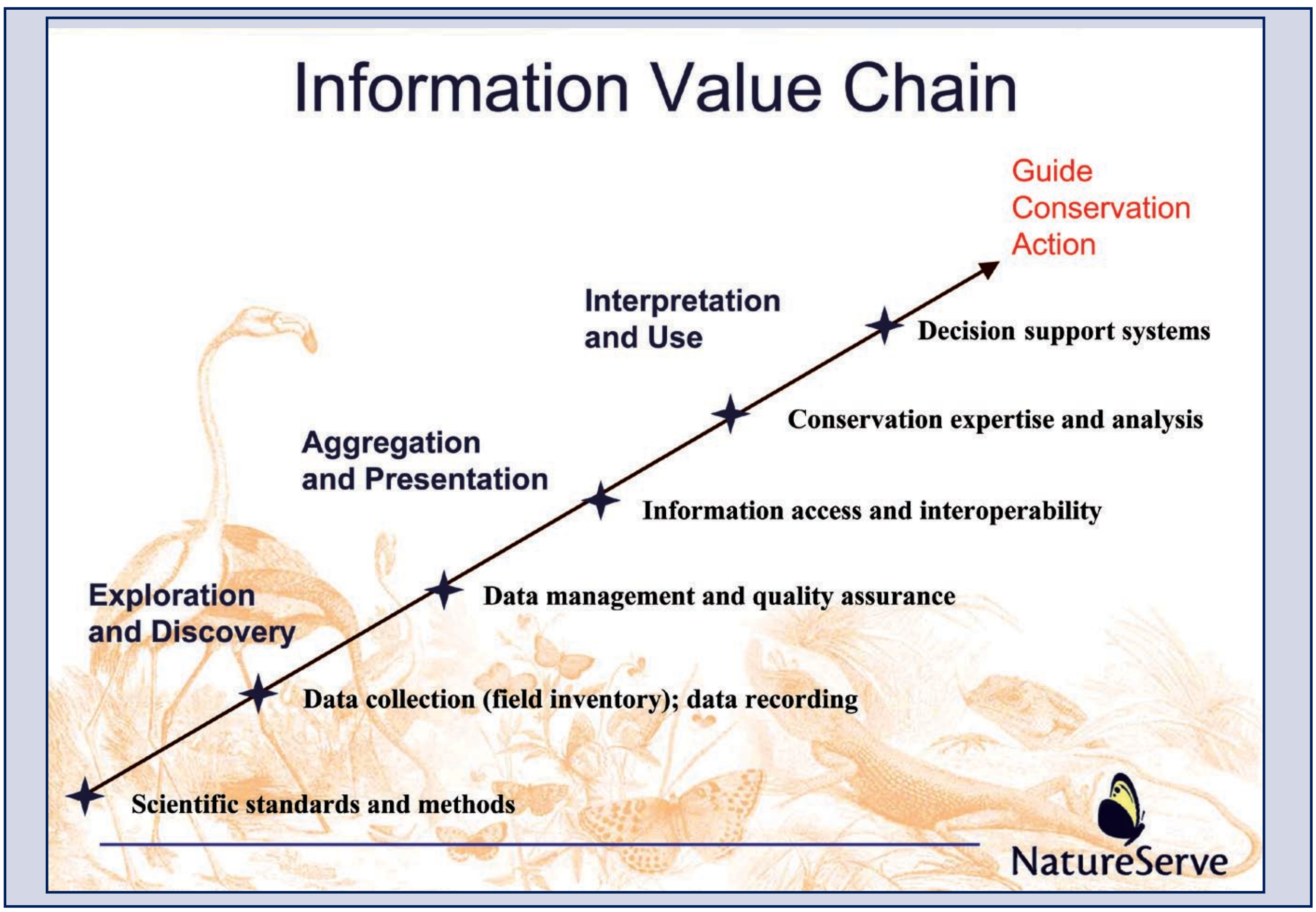


Figure 6. The NatureServe data management architecture and information value chain.

Structural Versus Functional Connectivity

Connectivity has two dimensions: landscape and the organism considered and only a combination of these two will yield a meaningful value of connectivity (Kindelman and Burrell 2008). A robust connectivity assessment should integrate both structural and functional aspects of connectivity. Although functional connectivity is most important there will be structural elements important for ecological connectivity. Structural connectivity is often emphasized because it demands less data, is cheaper to analyze, and conceptually simpler than observing and measuring the complex interaction of species and landscapes. However, we caution against the tendency to drift toward structural connectivity measures in a robust analysis.

A major challenge in connectivity research today is to developing functional connectivity measures that incorporate both species-specific movement behavior and landscape structure that are relatively simple to calculate (Kindelman and Burrell 2008). Many modeling approaches are capable of evaluating functional connectivity (Theobold et al. 2006, McRae et al. 2008, Carroll et al. 2009, Schwartz et al. 2009). However, functional connectivity assessment remains somewhat elusive because of limited data and specific knowledge about species and their movements. Collecting comprehensive dispersal data on the population-landscape study system should be the first step toward analyzing functional connectivity in landscapes (Baguette and Van Dyck 2007). These authors argue that we need individual-based movement models with behavioral rules that ultimately explain the underlying behavioral processes and hence connectivity. However, this will require detailed studies in more than one landscape configuration and is costly and time consuming. In the meantime connectivity assessment may need to build adaptable hybrid systems that can easily incorporate new species specific data as it is acquired but can derive important movement corridors with existing but much coarser data.

Temporal Scale

A fundamental question we must ask is, on what scale should connectivity be defined? The spatial and temporal scale of a connectivity assessment is probably the most defining aspect of the project (Hilty et al. 2006). The issue of spatial scale is well discussed in the ecological literature while temporal scale is largely ignored (Bennett 1999, Hilty et al. 2006, Worboys et al. 2010). Considerable time must be spent in evaluating the proper temporal scale for connectivity assessment and conservation planning.

The temporal scale of a connectivity project is very important but is seldom well explained or integrated into connectivity assessment processes. Fahrig (1992) compared the relative effects of temporal and spatial scales upon metapopulation persistence of a species and found that the effect of temporal scale far outweighed the effect of spatial scale on population persistence. Connectivity assessments tend to approach analysis under a static temporal framework and reflect the existing situation for landscapes and species because dynamic analysis is too difficult and complex. If temporal considerations are integrated into analysis at all they typically consider a dichotomous approach thinking in terms of short and long term time frames (Hilty et al. 2006).

Time proceeds in a one way linear dimension and its influence on connectivity is always framed in a forward direction (Hilty et al. 2006). This demands some capacity and ability to forecast events. Unfortunately these are very uncertain features in even the most robust assessment tools and current connectivity assessments remain somewhat limited given the natural system dynamics, human dominance of landscapes and impending climate change. Nonetheless new tools are always underdevelopment and some level of flexibility and adaptability are essential to the analysis of connectivity.

The temporal scale for a connectivity project will be influenced by the spatial scale of conservation areas, species selected, management purpose, planning schedules and human activities. We have identified the following critical considerations to weigh when considering the temporal scale for a robust connectivity assessment:

- Species lifecycles are an essential consideration when thinking about connectivity.
- Species lifecycles will shift over time with trends in climate and human disturbance patterns on landscapes.
- Species interactions occur over a variety of time-scales and will change over time
- Management planning frameworks are an important consideration and the assessment methodology and process should be temporally aligned.
- Human activities happen on temporal scales, will shift with land use policies and are usually unpredictable in near and long term.
- Wildlife habitats within a conservation area will change over time according to both natural and human disturbance regimes.

It is important that assessment and planning processes for connectivity conservation be dynamic and operable at various time scales. Assessment tools and analysis procedures should be easily updated and reviewed on defined time schedules to accommodate system dynamics and changes in science.

Evaluating the Economic, Social and Cultural Landscape

Connectivity conservation is critically dependent upon people working together (Lockwood 2010) Determining the social, cultural and economic factors that influence connectivity, both positive and negative is an essential step (Worboys et al. 2010). Although social, economic or cultural factors are not specific connectivity attributes gathering this information is important for building social-political support for a future vision of connected landscapes and helps inspire potential partners to bring about that vision.

Creating and integrating an appropriate set of anthropogenic and community values layers in a connectivity assessment provides the social, economic and cultural context for many other sets of data and enhance the analysis of connectivity. Several recent conservation efforts have employed a community values mapping process that helped local communities define, in a spatial context, why they value specific geographic areas (Brunckhorst et al. 2005). In Montana, WCS has developed important community values maps for the Bighole Valley (Figure 7). In the Northern Appalachians community values mapping is being implemented to support connectivity planning in Vermont (Vermont Town Forest Stewardship Guide, http://www.vtfpr.org/urban/documents/TownForestStewardshipGuide.pdf). Another example of mapping values is the Montana Sportsman Values Map that Theodore Roosevelt Conservation partnership has developed showing geographies that are important to hunters as described by them (http://www.trcp.org/issues/2-energy/294-energy-svm-1208.htmlwebsite).

Climate change will significantly impact the social and economic conditions in North America and the world. Many climate change adaptation strategies for humans may conflict with wildlife conservation efforts. In many cases adaptation approaches geared to safeguard economic interests run contrary to options for biodiversity conservation (Hulme 2005). For example, current management practices, such as the construction of sea defenses, flood management and fire exclusion are often detrimental to biodiversity conservation but deemed essential to protecting economic interests from the effects of climate change. Careful consideration and common sense integration of climate change adaptation strategies across various sectors of society will become increasingly important to connectivity conservation.

Uncertainty of the Science

There are several layers of uncertainty involved in the assessment of connectivity for conservation. These include uncertainty associated with predicting climate futures, understanding natural systems, human land-use patterns and the limitations of current modeling tools.

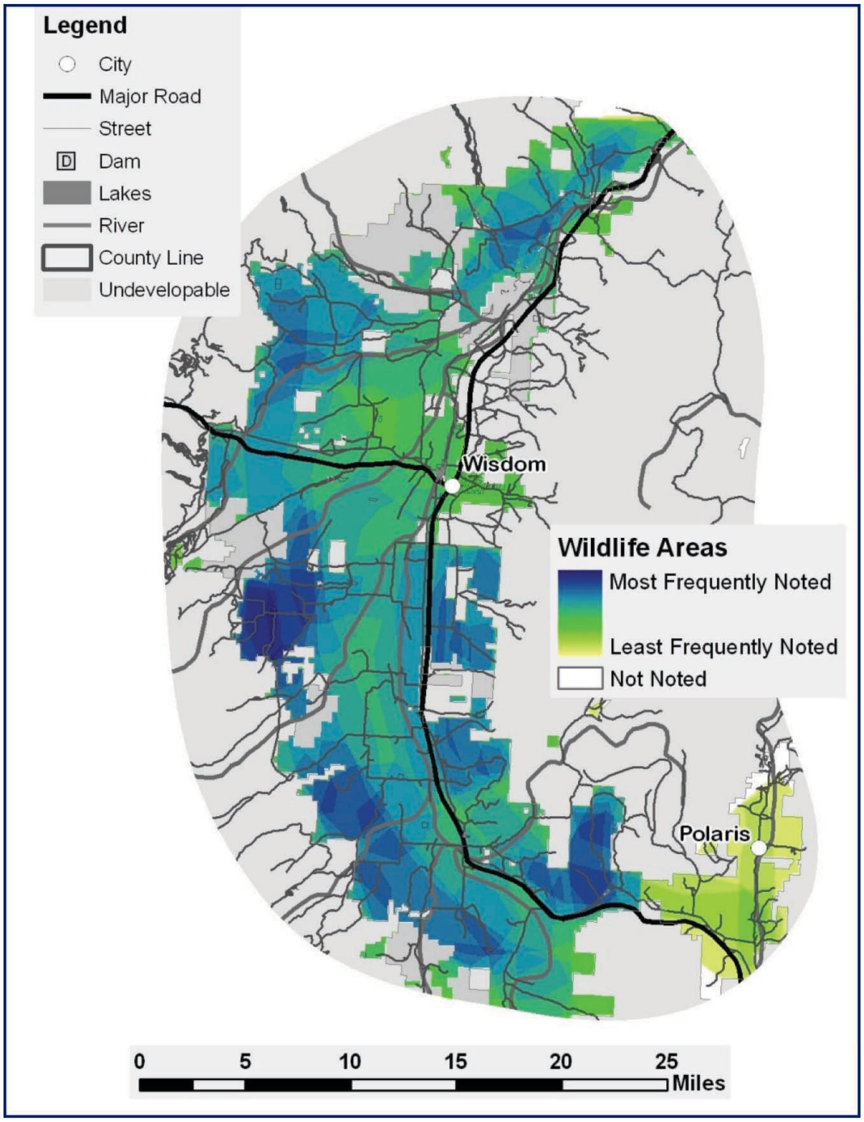


Figure 7. An example of community values maps showing the important wildlife habitat identified by local community partners in Bighole Valley, Montana.

Knowing that there is uncertainty associated with connectivity assessment and it influences outcomes is important information in itself. Expressing uncertainty and error bounds is good scientific practice and a means of quantifying the accuracy and reliability of information.

Unfortunately, our understanding of the natural world is imperfect and conservation planners are often looking for definitive answers when qualified guidance is all we can provide (Stein, 2007). Conservation assessment and planning are sensitive to the uncertainties associated with natural systems (Wilson et al. 2005; McDonald-Madden et al., 2008) and species (Nicholson and Possingham 2007). Although uncertainty is prevalent we must learn to make good best practice decisions based on current knowledge and exercise feedback learning to meet changing conditions (Hansen and Hoffman 2010). A comprehensive connectivity assessment process should reflect the dynamic nature of natural systems and its susceptibility to both old and new forces both natural and human caused. Given the uncertainty of the best science and our ability to forecast future scenarios we recommend the most conservative approach that errs on the side of saving extensive and robust connectivity networks with as much redundancy as possible (Peterons et al. 1998, Hilty et al. 2006).

Climate Change

Climate change is likely to cause an extreme makeover on the face of the world. While climate will have a direct impact on the performance of many species, for others impacts will be indirect and result from changes in the spatiotemporal availability of natural resources (Hulme 2005). In addition, mutualistic and antagonistic interactions among species will mediate both the indirect and direct effects of climate change. Climate change is also likely to exacerbate the effects of extractive land uses on ecosystem structure, function and composition (Hulme 2005). New emerging ecosystem structures, new species assemblages, and entirely new ecosystems are already occurring (UNEP 2009). It’s important to acknowledge that there is substantial uncertainty regarding where or how species and communities will adapt to a changing climate, but providing a well connected, robust landscape will be important for maintaining opportunities for species to shift, even if we don’t know how it’s all going to play out (Heller and Zavaleta 2009, Krosby et al. 2010, Hansen and Hoffman 2010).

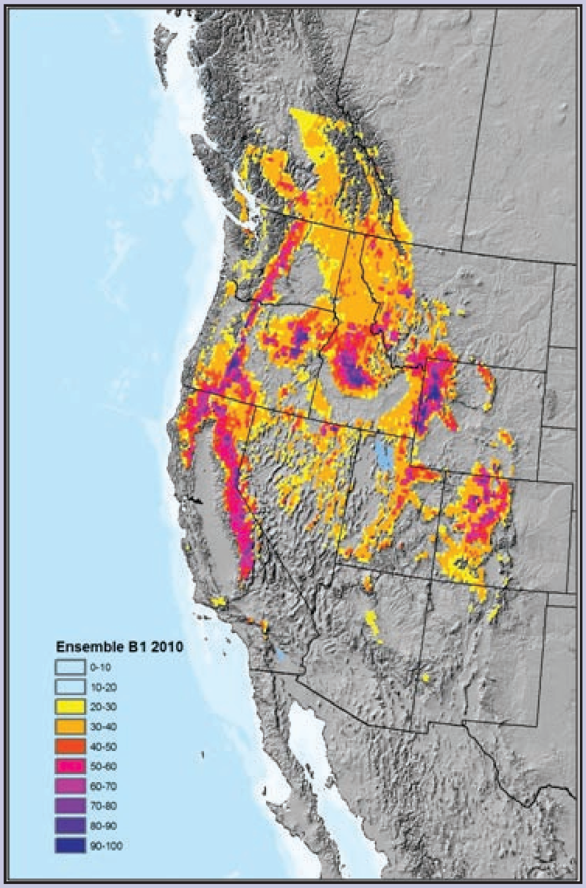
One commonly-proposed adaptation strategy is modeling structural connectivity under climate change scenarios using the climate range for a given species/group to estimate range changes over time (Carroll et al., 2009). Recent envelope modeling approaches have been applied to modeled or observed species distributions to forecast future climate impacts on a species (http://ecoclim.org, Figure 8). This approach has resulted in maps of future refugia for species such as wolverine. Two future climate surfaces are available under the A2 and B1 greenhouse gas emissions scenarios.

In another example, Philips et al. (2008) calculated the migration of species-specific ranges for the South African plant group Cape Proteacae through time using an approach called network flow, resulting in a minimal land-set that could meet the climate change-adaptation requirements of these plants. Although this study represents the cutting-edge of climate change adaptation research in regards to landscape connectivity and biodiversity protection, it lacks what most such studies lack – evaluation and inclusion of species-interactions and other ecological interactions that extend beyond structural considerations. In the case of Philips et al. (2008), seeds from Cape Proteacae plants can be dispersed by wind, rodents, and ants. Climate shifts may influence all three of these mechanisms and will add a layer of unpredictability on top of the already uncertain projections of range shifts due to changing species-specific climate spaces (Midgley et al., 2006). It is this uncertainty and unpredictability that is the most constant aspect of climate change adaptation research. Providing for biodiversity conservation under climate change and land-use pressure includes protecting connectivity as a landscape attribute to facilitate individual species and community migration.

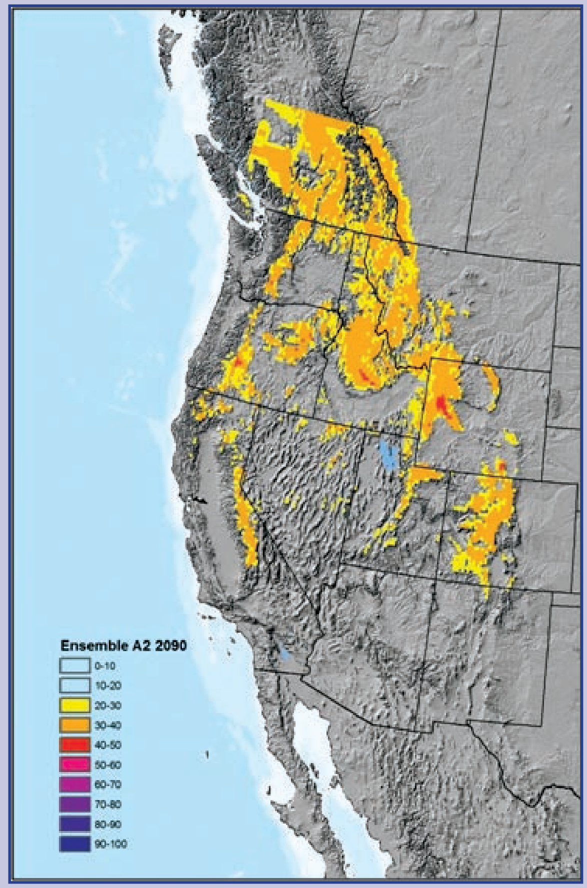
There is an urgent need to merge past, current and future data sources with new technologies to meet the challenge of modeling wildlife habitat and connectivity needs in the face of impending climate change. New modeling tools that demonstrate a diagnostic and prognostic capability are needed (Crabtree et al. 2011). Only recently have several new tools and approaches have been developed to enable ecologists to examine connectivity needs and species responses to a changing landuse patterns and climate. In one example the Yellowstone Ecological Research Center has created several new geospatial data products and linked software to conduct an ecological analysis for decision support in the Great Plains Landscape Conservation Cooperative (GPLCC) (Crabtree et al 2011). These linked Decision Support Tools (DSTs) are organized as an adaptable, unifying workflow architecture, collectively referred to as EAGLES (Ecosystem Assessment, Geospatial analysis, and Landscape Evaluation System). The goal of EAGLES is to lower the barrier of entry to allow scientists and practitioners the ability to understand the cause and consequence of environmental change using focal species data as key ecosystem indicators. This approach was initially applied to three focal species in the GPLCC including Arkansas Valley Evening Primrose (Oenothera harringtonii), Grasshopper Sparrow (Ammodramus savannarum) and Swift Fox (Vulpes velox). New and emerging tools are rapidly developing and to meet the demand for rapid assessment and analysis of ecological data in light of climate change. We recommend conducting a thorough search of existing efforts and the published literature before designing your connectivity project to identify the best available predictive modeling tools to integrate the effects of land use and climate change on species and other ecological connectivity indicators.

Potential Detrimental Effects Of Connectivity

Is connectivity conservation the most cost effective means for conserving biodiversity? Some propose that the uncertainties associated with the evaluation and estimation of effects of connectivity may render it less effective as a conservation measure (Hodgson et al. 2009). However, a recent meta-analysis by Gilbert-Norton and others (2009) showed that increased connectivity increased



A model showing predicted current climate envelope for wolverine habitat south of the boreal forest.



A projection of future distribution of the wolverine climate envelope under the A2 greenhouse gas emissions scenario. Note the loss of many highly suitable habitats and remaining refugia.

Photo Courtesy Larry Master

Figure 8. An example of the spatial scale and scope of climate envelope models for wolverine conducted by Dr. Healy Hamilton of the California Academy of Sciences

movement between habitat patches. They found that corridors were more important for the movement of invertebrates, non-avian vertebrates, and plants than they were for birds. Given that connectivity is shown to promote movement and dispersal we infer that there are significant benefits and recommend increasing connectivity as a suitable method to conserve biodiversity with or without climate change.

Several specific detrimental effects of connectivity have been described in the literature. A concern for the spread of invasive species, genetic impacts and introduction of disease has been repeatedly raised by many scientists (Crooks and Sanjayan 2006, Bennett 1999, Hilty 2006). The concern for the movement of invasive species and disease are most significant. However, to date no corridor created for restoration or conservation is known to have promoted the spread of invasive species (Haddad et al. 2010).

The detrimental effects from increased connectivity on population genetics are much less understood and certain. There have been examples of hybridization as an unintended consequence of connecting habitats (Hilty et al. 2006, Rhymer and Simberloff 1996). However, most examples are the inadvertent result of human activities that connect habitats and the circumstances in which such effects are likely are limited (Hilty et al. 2006).

It has been suggested that increased connectivity may alter the existing predator and prey relationships in a conservation area and create new source sink mortality dynamics that were not predicted (Crooks and Suarez 2006, Hilty et al. 2006). This is particularly problematic with the introduction of an exotic predator into a previously naïve population. When assessing connectivity it is important to recognize the presence of invasive species in each patch and to guard against movement of undesirable species that might introduce demographic impacts on native species.

Identifying potential detrimental effects of increased connectivity is important when assessing and planning for connectivity. Specific measures for mitigating these effects should be designed, integrated into the analysis and articulated throughout the process. Specific long term monitoring should be implemented to measure any potential negative effects of connecting habitats.

Elk migration Southwest Montana. Copyright © 2011 Terry N. Lonner

Part II

Integrating Connectivity Science into Planning and policy

There has been a growing interest in conserving biodiversity and ecological connectivity exposed through state, federal and regional plans (Wilkinson et al. 2005) and into local planning (Daly and Klemens 2005). Throughout the world there are many conservation areas now supported by conservation plans within an existing management framework. Unfortunately, in most instances connectivity assessments are accomplished with hope of integrating connectivity measures into this existing framework rather than establishing a new planning and management framework. However, bringing connectivity conservation into an existing planning and management framework produces some significant challenges (Appendix Table 2). Several key challenges to integrating biodiversity and connectivity into conservation plans include: lack of awareness, inclusion of stakeholders in the process, complex data and language, integrating science advice, rapidly advancing technology, and regulatory limits (Daly and Klemens 2005). These issues certainly apply to conserving connectivity and should be addressed in order to achieve connectivity conservation outcomes.

Worboys and Lockwood (2010) describe 3 important components of the management framework including; nature, people and management contexts. The existing management context and framework have significant affect on the selection of targets, the assessment process, planning process and the strategies employed to implement connectivity conservation. The challenge to conservation planners is intersecting these 3 components of a management framework to identify clear targets and strategies for the conservation of connectivity.

There are ample support resources and robust modeling tools available to help the conservation community exercise good connectivity planning [Groves 2003, Worboys et al. 2010, (Figure 9)]. In addition, there is excellent guidance for how to conduct excellent conservation planning. Bottrill and Pressey (2009) describe 11 stages in conservation planning (Figure 10) and Groves (2003) provides 7 habits for highly effective planning. We do not attempt to duplicate the available counsel from these resources but offer some brief suggestions on how to integrate connectivity science into conservation planning following these guidance frameworks. We present these suggestions because we believe it is difficult to clearly separate connectivity assessment from conservation planning and recommend close integration of these two processes.

Marxan: A Reserve System Selection Tool. University of Queensland.
http://www.ecology.uq.edu.au/marxn.htm also Marxan with Zones (Watt et al. 2009)
Marxan incorporates best scientific information and makes the costs and benefits of alternative decisions clear, leading to more informed decision making. In addition, having multiple solutions to choose from helps in stakeholder driven decision making processes. Marxan has been used to support the design of marine and terrestrial reserves worldwide. Marxan can assist with the evaluation of existing reserve systems to identify gaps in biodiversity protection, identify areas to include in new reserve systems, and provide decision support by producing a number of different options that meet both socio-economic and conservation objectives. Marxan has also been used to support multiple-use zoning plans that balance the varied interests of stakeholders.

TNC IN-Vest: Integrating Ecosystem Services and Tradeoffs into Planning
http://www.naturalcapitalproject.org/InVEST.html
Government officials, conservation professionals, farmers, and other land owners make decisions about how to use their land all the time. Yet never before have any of these groups had a systematic way to deomonstrate the future costs and benefits of their decisions for people and the environment. The Natural Capital Project developed a tool to meet that need called InVEST, which can model and map the delivery, distribution, and economic value of ecosystem services. The tool helps visualize the impact of potential decisions, identify tradeoffs and compatibilities between environmental, economic and social benefits.

Zonation: Conservation Planning Tool http://www.helsinki.fi/bioscience/consplan/index.htm
Zonation produces a hierarchical prioritization of the landscape based on the conservation value of sites (cells), iteratively removing the least valuable cell (accounting for complementary) from the landscape until no cells remain. In this way, landscapes can be zoned according to their value for conservation. The program produces, among other things, basic raster files from each run, which can be imported to GIS software for further analysis and visualization. The data requirements for the program are realistic and it can be run with large datasets containing up to 4 000 species or 16 million element landscapes on an ordinary desktop PC.

Miradi: Conceptual Modeling Tool https://miradi.org/files/miradi_overview.pdf
Miradi is a user-friendly program that allows nature conservation practitioners to design, manage, monitor, and learn from their projects to more effectively meet their conservation goals. The program guides users through a series of step-by-step interview wizards, based on the Open Standards for the Practice of Conservation. As practitioners go through these steps, Miradi helps them to define their project scope, and design conceptual models and spatial maps of their project site. The software helps teams to prioritize threats, develop objectives and actions, and select monitoring indicators to assess the effectiveness of their strategies. Miradi also supports the development of workplans, budgets, and other tools to help practitioners implement and manage their project. Users can export Miradi project data to donor reports or, in the future, to a central database to share their information with other practitioners.

NatureServe Vista. http://www.natureserve.org/prodServices/vista/overview.jsp
NatureServe Vista is a powerful, flexible and free decision support system that helps users integrate conservation with land use and resource planning of all types. Vista supports quantitative and defensible planning approaches that incorporate science, expert opinion, community values, and GIS. It works with a number of other useful software tools to incorporate land use, economics, ecological, and geophysical modeling. The flexibility of this tool is suitable for planning and GIS experts as well as non experts can use it with minimal training and support.

Biovision. John Gallo, University of Santa Cruz, Department of Geography. gallo.ja@gmail.com
A hierarchy of nested modelbuilder models was built to create a prototype decision-support system for open space conservation and management. The prototype is termed BioVision and is designed to meet site valuation and scenario evaluation goals of NatureServe Vista while also meeting the goals of Marxan with Zones, i.e. conservation planning that addresses and allocates a variety of land management options in a near optimal solution. BioVision is linked to data pre-processing steps also in modelbuilder, facilitating a "living tool" to provide updated decision-support as conditions change on the biophysical landscape or within the socio-political culturescape. It uses a hierarchical, multi-criteria framework with a return on investment approach embedded. It also incorporates issues of regional context, such as reserve adjacency, target achievement, and habitat connectivity.

Figure 9. Planning and Decision Support Tools for Connectivity Conservation

(1) Identify stakeholders for the planning region:

- Stakeholders include: (a) those who have decision-making powers; (b) those who will be affected by conservation plans for the region; (c) those with expertise about the region and (d) those who may commit resources for conservation plans;
- Include both local and global stakeholders;
- Ensure transparency in the involvement of all stakeholders from the beginning.

(2) Compile, assess, and refine biodiversity and socio-economic data for the region:

- Compile available geographical distribution data on as many biotic and environmental parameters as possible at every level of organization;
- Compile available socio-economic data, including values for alternate uses, resource ownership and infrastructure;
- Collect relevant new data to the extent feasible within available time; remote-sensing data should be easily accessible; systematic surveys at the level of species (or lower levels) will rarely be possible;
- Assess conservation status for biotic entities, for instance, their rarity, endemism and endangerment;
- Assess the reliability of the data, formally and informally; in particular, critically analyze the process of data selection;
- When data do not reflect representative samples of the landscape, correct for bias and model distributions.

(3) Identify biodiversity surrogates for the region:

- Choose true surrogate sets for biodiversity for part of the region; be explicit about criteria used for this choice;
- Choose alternate estimator surrogate sets; Prioritize sites using true surrogate sets; prioritize sites using as many combinations of estimator surrogate sets as feasible and compare them;
- Potentially also use other methods of surrogacy analysis to assess estimator surrogate sets, including measures of spatial congruence between plans formulated using the true and estimator surrogate sets;
- Assess which estimator surrogate set is best on the basis of (a) economy and (b) representation.

(4) Establish conservation targets and goals:

- Set quantitative targets for surrogate coverage;
- Set quantitative targets for total network area;
- Set quantitative targets for minimum size for population, unit area, etc.;
- Set design criteria such as shape, size, dispersion, connectivity, alignment and replication;
- Set precise goals for criteria other than biodiversity, including socio-political criteria.

(5) Review the existing conservation-area network (CAN):

- Estimate the extent to which conservation targets and goals are met by the existing set of conservation areas;
- Determine the prognosis for the existing CAN;
- Refine the first estimate.

(6) Prioritize new areas for potential conservation action:

- Using principles such as complementarity, rarity and endemism, prioritize areas for their biodiversity content to create a set of potential conservation-area networks;
- Starting with the existing CAN, repeat the process of prioritization to compare results;
- Incorporate socio-political criteria, such as various costs, if desired, using a trade-off analysis;
- Incorporate design criteria such as shape, size, dispersion, connectivity, alignment and replication, if desired, using a trade-off analysis.
- Alternatively, carry out the last three steps using optimal algorithms.

(7) Assess prognosis for biodiversity within each newly selected area:

- Assess the likelihood of persistence of all biodiversity surrogates in all selected areas. This may include population viability analysis for as many species using as many models as feasible;
- Perform the best feasible habitat-based viability analysis to obtain a general assessment of the prognosis for all species in a potential conservation area;
- Assess vulnerability of a potential conservation area from external threats, using techniques such as risk analysis.

(8) Refine networks of areas selected for conservation action:

- Delete the presence of surrogates from potential conservation areas if the viability of that surrogate is not sufficiently high;
- Run the prioritization protocol again to prioritize potential conservation areas by biodiversity value;
- Incorporate design criteria such as shape, size, dispersion, connectivity, alignment and replication.

(9) Examine feasibility using multi-criteria analysis:

- Order each set of potential conservation areas by each of the criteria other than those used in Stage 6;
- Find all best solutions; discard all other solutions;
- Select one of the best solutions.

(10) Implement a conservation plan:

- Decide on most appropriate legal mode of protection for each targeted place;
- Decide on most appropriate mode of management for persistence of each targeted surrogate;
- If implementation is impossible return to Stage 5;
- Decide on a timeframe for implementation, depending on available resources.

(11) Periodically reassess the network:

- Set management goals in an appropriate timeframe for each protected area;
- Decide on indicators that will show whether goals are met;
- Periodically measure these indicators;
- Return to Stage 1.

Figure 10. Systematic conservation planning modified from Margules and Pressey (2000) and Sarkar (2004), describes this overall approach in eleven more-detailed stages

Evaluating Institutional Capacities

Practicing conservationists around the globe have identified that institutional capacity is important to the successful conservation of biodiversity and connectivity (Worboys et al. 2010). Conservation planning requires several important capacities which are outlined in Hough (2006). These are:

- Capacity to conceptualize
- Capacity to develop strategies and programs
- Ability to formulate policies and regulate
- Capacity to implement policies, regulation, strategies and programs
- Capacity to engage and build consensus among stakeholders
- Capacity to mobilize information and knowledge
- Capacity to monitor, evaluate, report and learn

We recommend that conservationists engaged in connectivity assessment evaluate their institutions capacity in each of these areas. Through this evaluation we anticipate that institutuional weaknesses, necessary partnerships and important stakeholders can be identified at early stages of assessment and planning.

Apply Systematic Planning

The most important challenges faced in land use management are 1) harmonizing and integrating different datasets, 2) selecting appropriate indicators, 3) fitting suitable models to adequate scales, and 4) integrating data indicators and models into systems that allow participation and flexibility in decision making (Furst et al. 2010). An integrated and systematic planning process can help us cope with these muti-faceted challenges. According to Furst and others (2010) an integrated and systematic planning system should be able to:

- Deal with discontinuity of information.
- Create a standardized list of indicators.
- Support a conceptual modeling approach.
- Support stakeholder participation in decisions.
- Help to develop, compare and evaluate alternative options.
- Help to assess the efficiency and trade-offs of strategies.
- Assist Stakeholders in balancing and estimating preferences.

Systematic conservation planning requires that clear choices are made about how biodiversity is to be measured and mapped and setting conservation targets and goals. These are two key aspects of planning that must be integrated closely with a robust project to assess connectivity in a conservation area. Systematic conservation planning also provides an outstanding framework for identifying conservation priorities including important connectivity areas. Through systematic conservation planning goals and constraints of conservation and socio-economic challenges are explicitly stated, allowing identification of trade-offs and conflicts, and assisting to find a resolution (Margules and Pressey 2000).

Application of Planning Tools

A variety of technological tools are available to planners, some are generic while others are purpose-built, but many provide great opportunities for incorporating connectivity assessment into the planning process. Many of these tools are excellent platforms to integrate connectivity assessments and can be linked to connectivity modeling tools and processes. Important concepts to consider when applying these modern tools for connectivity assessment and planning are transparency, accountability, scenario planning, optimization techniques, and institutional capacity and expertise. Many of the planning tools applied today are difficult for all stakeholders to understand and managers need to be transparent and accountable when using them. The capability to explore planning alternatives through scenarios and to optimize the alternatives is important. Finally it is not always possible for institutions to host the capacity and expertise to use these new tools. Outsourcing to experts or internal training to use these new technologies is an important consideration in the planning process.

One important feature of these new technologies is the ability to produce interactive maps to visualize management alternatives and explore data (Andrenko and Andrenko 1999). Cartographers have long adhered to the view that maps were primarily a medium for communication (MacEachren 1995). However, influenced by the ideas of scientific visualization and exploratory data analysis, we can now produce maps that can be used for visual thinking and decision making (MacEachren and Kraak 1997). To play this role effectively, a map needs two principal capabilities: interaction and dynamics. We believe it is essential that conservation scientists and managers conducting connectivity assessment and planning apply the latest technologies to produce interactive and dynamic maps that support visual thinking and allow comparison of alternative management options.

It is helpful for planners, ecologists and land managers to convene prior to development of a connectivity conservation initiative to develop a conceptual model of systematic conservation planning that integrates the conservation of ecological connectivity. Part of conceptualizing an initiative should include an evaluation of the best modeling tools and technologies that can be used to support the connectivity initiative.

Setting Conservation Targets and Goals for Connectivity

Conservation targets are features or elements of biodiversity that planners seek to conserve (Groves 2003). Groves (2003) offers a framework for thinking about conservation targets for biodiversity. His 4-R framework proposes that targets should be representative, resilient, redundant and restorative. In his discussion of 7 habits of effective conservation planning the identification of conservation targets is the first step. Margules and Pressey (2000) reinforce the notion that conservation targets should be representative and persistent. Connectivity is certainly an important landscape feature that helps to conserve biodiversity. Today's comprehensive conservation plans should have explicit language regarding this landscape feature and seek to protect, maintain or restore connectivity through conservation strategies and actions.

The idea of using coarse filter and fine filter for biodiversity conservation originated with the Natural Heritage Program (Noss 1987). The original idea behind this approach was to find conservation targets that would represent broad elements of a ecological system (coarse) to conserve most species and then use the fine filter approach to conserve those not represented by the coarse filter conservation targets. This idea has evolved considerably over the past two decades and has led to expansion in the classification of targets (focal, imperiled, umbrella species etc.). The emerging principle is that there is a continuum of conservation targets across spatial scales and biological levels of organization (Poiani et al. 2000). Setting conservation targets for connectivity is no simple task and will involve development of a clear selection framework that includes both coarse and fine filter targets.

Systematic conservation planning has been slow to develop tools to address dynamic threats, such as the threat posed by ongoing climate change (Pressey et al. 2007). Conserving land facets as surrogates for biodiversity and ecological processes is an emerging alternative for prioritizing conservation areas in the face of climate change (Beier and Brost 2010). Compared with climate-modeling approaches, an approach based on land facets does not depend on uncertain data from emission scenarios or climate predictions. Compared with approaches based on mapped species occurrences, land-facet maps are not biased toward data-rich areas. This approach, based on Digital Elevation Models, can be used even in areas lacking maps of current land cover and species distributions. We believe designs based on land facets should conserve ecological and evolutionary processes. The land facet approach emphasizes conserving the stage for ecological and evolutionary processes and should be used to complement rather than replace fine filter approaches (Beier and Brost 2010). A limitation of this approach is that it does not explicitly protect the actors (species) or the play itself - the ecological interactions among species.

Once a clear assessment is completed that informs a conservation plan and conservation targets are clear it is important to set both qualitative and quantitative goal(s) for connectivity conservation to measure implementation progress. Conservation goals are often scale-dependent in nature and arrange along an extended planning and implementation timeline. Although most connectivity projects will have more than one measurable goal, individual products or steps in the assessment process may emphasize only one. Goals surrounding each of the connectivity assessment and planning steps should be specific, measurable, attainable, reportable, and timely (SMART).

A significant challenge for developing smart conservation goals is refining the values of stakeholder from a broad vision to specific goals (Worboys et al. 2010). The capacity for institutions to be inclusive is important to meeting this challenge. The ability of conservation leaders to communicate the value of biodiversity and ecosystem services is essential. We suggest planners develop an inclusive participatory process and communication strategy that inspires stakeholder participation in all steps of the planning process especially goal setting for biodiversity conservation.

Strategies for Conserving Connectivity

Four significant scientific advances in the last decade of the 20th century have shaped the development of a contemporary conservation planning framework (Groves et al. 2003). First, the growing list of endangered species highlighted the need for approaches to conservation that are proactive and complement the reactive measures of most endangered species programs. Second, scientists increasingly recognized the importance of conserving the underlying ecological processes that support the patterns of biological diversity (e.g., Balmford et al. 1998). Third, we began to realize that biodiversity occurs at multiple spatial scales and levels of biological organization (Schwartz 1999) and that a greater emphasis to conserve this diversity must be placed at all appropriate levels and scales (Poiani et al. 2000). Finally, we have learned that systematic conservation planning approaches are more effective at conserving biological diversity than are the ad hoc approaches of the past (Margules and Pressey 2000). These scientific advances are clearly shaping the strategic approaches being applied to connectivity conservation.

There are many strategies applied to protect or maintain connectivity and each has specific data requirements, present distinct challenges and demands different analysis approaches (Appendix Table 3). Many of the current strategies are based on and incorporated within the broader mission and management framework of institutions responsible for managing a landscape. Most of these conservation strategies are designed to achieve species conservation outcomes or support a broader management framework. Unfortunately few of these strategies are specifically designed to target connectivity as a landscape property and most bring connectivity under the umbrella of other management frameworks or conservation missions (e.g. conservation of an endangered species, transportation and land use planning). We recommend integrating clear and specific strategies for conserving connectivity into every comprehensive conservation plan.

Strategies for conserving connectivity will differ with targets and scale (Noss and Daly 2006). Some strategies can be successfully applied at broad scales while very different approaches will be necessary to influence conservation at smaller scales. We recommend developing specific and appropriate conservation strategies that influence ecological connectivity at various biological, spatial or temporal scales.

Prioritizing Corridors for Connectivity

Once connectivity assessment is completed and planning is underway there may be a need to prioritize connectivity areas and conservation actions prescribed through the planning process. From a practical standpoint it is unlikely that all identified corridors can receive equal management emphasis and resources available through a managing entity. In most landscapes, especially larger ones, it will be important to develop a process for prioritizing corridors and conservation actions. Several possible approaches have been developed to determine priorities for connectivity and biodiversity conservation. These include:

- **"No Regrets" Analysis:** Has been applied to the Two countries-One Forest region. This assessment was based on expert opinion where consensus on priority connecting landscapes was achieved and agreement that there would be no regret for directing conservation at these areas. Local connectivity planning is now underway in these connecting landscapes.
- **Irreplacability and Vulnerability:** Margules and Pressey (2000) presented a matrix approach using two important characteristics-irreplacability and vulnerability.
- **Threats and Opportunities:** Yellowstone to Yukon used a priority species approach looking at grizzly bear as the keystone species to identify priority corridors. Then conducted an assessment of threats opportunities and conservation capacity for each priority area.
- **Stratified Classification Approach:** Based on width and intactness corridors in Bhutan were classified as intact, with bottlenecks, and critical with high biological significance (Worboys et al. 2010)
- **Modeling Approach:** The Florida Ecological Network used an intensive modeling approach prioritizing based on the interactions between ecological significance and development pressure (Hoctor et al. 2004).
- **Resilience to Climate Change:** Setting priorities around resilience to climate change (Hannah et al. 2002). This has led some to consider dynamic conservation strategies around temporary or moveable conservation areas (Hannah and Hansen 2005).

Managing the Matrix

Conservation biologists warned in 1985 that habitat fragmentation is the most serious threat to biological diversity and is the primary cause of the present extinction crisis (Wilcox and Murphy 1985). As a result a significant movement arose to increase the amount of land in protected status around the world. However, it soon became evident that protected areas around the world were insufficient to protect the world's biodiversity (Rodriguez et al. 2004). Focusing exclusively on establishing protected areas to protect biodiversity will leave predictable gaps in overall conservation (Hilty et al. 2006). The uncertainty of future landscape structures and functions in the face of climate change will also challenge the integrity of existing protected areas around the world.

Resource management practices that maintain or improve the suitability of land used by humans are fundamental to the conservation of biodiversity (Franklin and Lendenmayer 2009). Some scientists argue that we need to emphasize conservation in production landscapes over protected areas (Knight et al. 2006, Lombard et al. 2010). Recent work by Prugh and others (2008) demonstrates that the quality of matrix habitat was a better predictor of occupancy than was patch size. No matter where on the globe, sustainability will depend on the management of matrix habitat and successful mediation between what nature needs and man wants.

Two important concepts to consider when planning for connectivity in matrix habitat are permeability and fracture zones. Singleton and company (2002) define landscape permeability as "the quality of a heterogeneous land area [a landscape] to provide for passage of animals." The evaluation of landscape permeability should provide a broader measure of resistance to animal movement and give a consistent estimate of the relative potential for animal passage across entire landscapes. They explain that “permeability provides for the identification of potential barriers to animal movement.

Areas of reduced landscape permeability between habitat patches are called fracture zones. Singleton and others (2002) write fracture zones are typically blocks of habitat, where human population centers are usually located and where linear features such as roads, railroad and power line densities are often high. Fracture zones can be relatively small such as an interstate highway or very large such as with urban centers or energy developments between intact habitat patches or vast tracts of agribusiness-dominated lands. The impact of human activities in a fracture zone can vary but all generally decrease permeability.

Managing Uncertainty

Conservation decisions about how, when and where to act are typically based on some expectation for the future (Peterson et al 2002). However, the world is unpredictable and we are working from a limited range of experience and knowledge. Uncertainty in conservation planning and implementation is the only certainty. It can come from many sources both external and internal to the planning process. The very nature of ecosystems is that they are dynamic and unpredictable creating a tension between understanding ecosystems (the science) and managing ecosystems (the plan). Although uncertainty often creates a barrier between planners and scientists there is growing convergence in the interest to conserve biodiversity and public interest in quality of life (Stein 2007). There is great opportunity to exploit these common interests through the conservation of connectivity.

The ultimate goal of the planning process should be the establishment of a robust learning institution (Turner and Berkes 2006) that practices adaptive governance (Folke 2007), and is able to implement conservation in its region of governance. Mindful of this goal from the outset it is important to consider uncertainty during the planning process and discuss strategies to reduce its impact on conservation decisions. Knowing that there is uncertainty associated with connectivity assessment and it influences outcomes is important information in itself. Rather than accepting that connectivity assessment is fixed in time and space, decision makers should look for options and design plans that can be readily modified with new knowledge. However, decisions can still be made as long as uncertainty can be qualitatively and quantitatively articulated and accepted by stakeholders in the decision process.

Scenario planning offers one framework for developing resilient conservation plans and policies when faced with uncertainty (Peterson et al. 2002). Scenario planning consists of using a few contrasting scenarios to explore the uncertainty surrounding future consequences of a management decision. Several tools are emerging that allow rapid evaluation of effects of changes in land use patterns enabling better analsyis of scenarios (Furst et al. 2010, Mathies et al. 2007).

One of the most prominent sources of uncertainty in biodiversity conservation is the effects of climate change. Systematic conservation has been slow to develop tools to address dynamic threats due to climate change (Pressey et al. 2007). There remains a mismatch between the static maps and assessment processes used for conservation planning and the dynamic ecological and evolutionary processes we seek to conserve. Ecologists are rapidly advancing the the idea of using land facets to save the arenas not the actors as a solution for this mismatch (Beier and Brost 2010). Others suggest the concept of moveable conservation areas (Hannah and Hansen 2005, Pressey et al. 2007). Systematic planning must consider the impacts of a changing climate and dynamics of natural systems when considering future management scenarios.

Climate adaptation strategies should aim to increase the flexibility in management of vulnerable ecosystems, enhance the inherent adaptability of the species and ecosystem processes within vulnerable natural systems, and reduce trends in environmental and social pressures that increase vulnerability to climate variability (Hulme 2005). Hulme (2005) points out that establishing effective climate adaptation strategies requires that scientists, managers and policymakers work together to:

- identify climate-sensitive system components;
- assess the likelihood and consequences of impacts;
- identify and select options for adaptation.

Feasibility of Implementation

Connectivity is high-stakes conservation that requires innovation and risk-taking by science based modeling and monitoring (Morrison and Reynolds 2006). Groves (2000) defined feasibility as the probability that a conservation entity will achieve some degree of conservation success at an area in the conservation portfolio. He writes that it is related to institutional capacity, effectiveness of institutions, technical soundness, financial costs and political support. To understand the feasibility for implementing conservation measures for connectivity several key questions are raised in the literature and are important to consider.

- Who supports this conservation plan or actions?
- Can we implement conservation measures and abate threats?
- Can we display and understand the real costs associated with protecting connectivity?
- What are the opportunity costs and tradeoffs for this conservation action against others?
- What are risks associated with implementing connectivity conservation measures?
- How much connectivity is enough? (Morrison and Reynolds 2006)
- Can we adequately compare the trade offs between data requirements and information content? (Calabrese and Fagan 2004)

Monitoring and Evaluation

In most instances uncertainty can be mitigated through effective monitoring and evaluation processes (Suring et al 2011). Evaluation and Monitoring are two separate concepts and require separate definition and process. Monitoring infers to watch, keep track of, or check, usually for a special purpose. Monitoring is an investment and the return on this investment is information for making better management decisions and improving conservation practice (TNC-SEM). Evaluation indicates an analysis through careful study and appraisal to determine the significance, worth, or condition of a process or conservation measure. A well designed connectivity conservation initiative will include several evaluations at various steps of project development and describes specific monitoring protocols depending upon conservation design features of an adaptive management plan. We recommend several key evaluations during the process of connectivity assessment including:

- Evaluate critical components of the proposed connectivity project including the:
  - Information management system
  - Institutional capacity
  - Collaboration and partnership engagement
  - Projects feasibility
  - Connectivity assessment methodology
- Conduct a peer review of the project plan before implementation of the project
- Conduct a peer review of connectivity assessment products
- Evaluate integration between connectivity assessment and conservation planning.

Most land use plans still have a fairly static view of the landscape, assuming that in the absence of direct human intervention, what currently exists on the land will remain (Stein 2007). However, because connectivity as a landscape feature is dynamic it is necessary to identify and monitor a few strategic indicators relevant to corridor integrity as a basis for making future adjustments in design (Anderson and Jenkins 2006). Monitoring key indicators for connectivity conservation will provide important feedback about abrupt and gradual shifts in ecosystem dynamics and human use of landscapes. Monitoring should also be designed to capture the effects of climate change on connectivity in the conservation area. Some indicators to monitor for connectivity include:

- Species targets able to move between patches across the connectivity area
- Demographic indicators for species targets are sustainable
- Genes flow across the landscape via managed corridors
- Permeability is increasing at bottlenecks and fracture zones
- Threats to connectivity are abated
- Stakeholder acceptance for conservation measures are increasing
- Public awareness of connectivity needs of wildlife are increasing

Occassionally monitoring and evaluation activities can hinder rather than improve conservation (Salzar and Salafsky 2006). This primarily results from inappropriate indications of problems or when resources spent on monitoring and evaluation divert scarce resources from critical management priorities. Salzar and Salafsky (2006) offer a methodology for balancing investment in action versus monitoring and evaluation. Great care should be taken to invest appropriately in effective monitoring and evaluation activities to measure the success of any connectivity conservation initiative.

A Method for Evaluating Connectivity Projects:

We modified a standard SWOT analysis, a commonly used business management tool, for connectivity assessment and planning. SWOT analysis is usually applied prior to planning and project development. An analysis of project strengths, weaknesses, opportunities and threats can guide the design process for an assessment project or support planning. We suggest that this tool be used in a dynamic fashion so that project managers can determine if they are making appropriate adjustments to transform project weaknesses to strength, transform threats into opportunities and match the internal strengths and opportunities for best improvement (Figure 11).

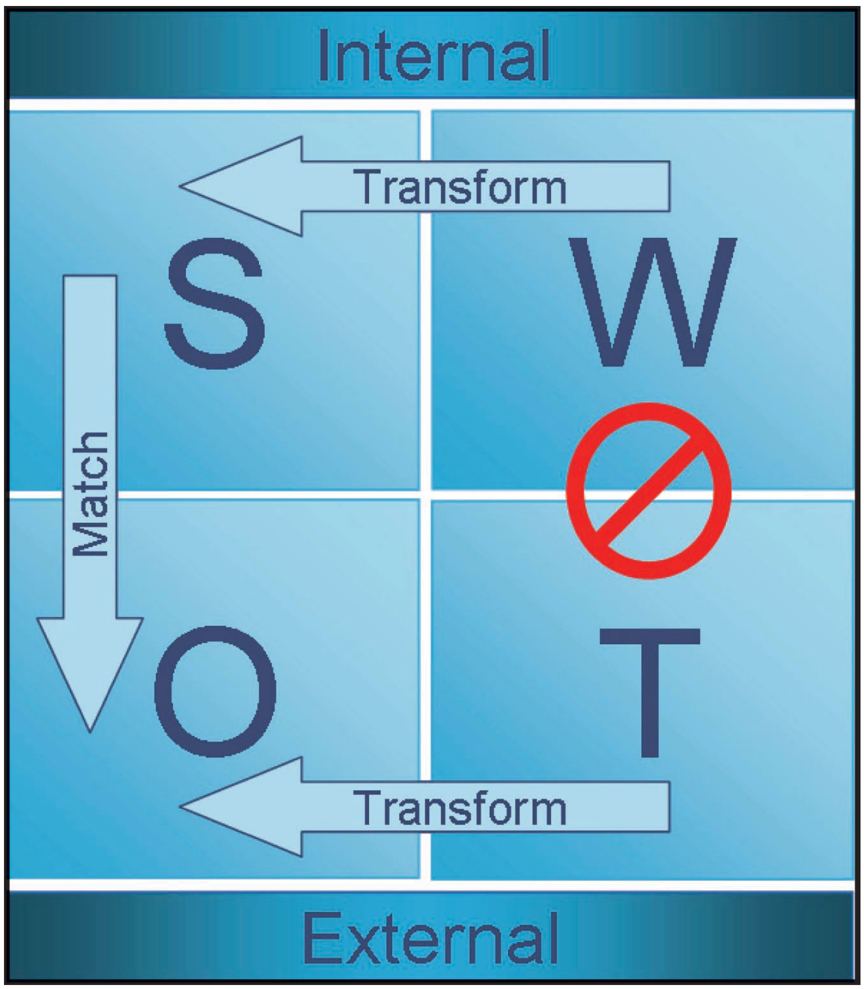


Figure 11. Managing strengths, weaknesses, opportunities and threats using SWOT analysis.

Appendix A offers guidance on how to conduct the analysis and provides a list of some of the internal and external factors we derived from our review of best science for connectivity assessment and planning. We encourage expansion of the factor analysis for the SWOT and find that there may be unique factors appropriate to various geographies and institutions practicing connectivity conservation.

Translating Connectivity Science to Conservation Policy:

Social and Cultural Integration

Protected landscapes and seascapes would not exist without the deeply rooted cultural and spiritual values held by the people that once inhabited these places and who very often continue to care for them. In fact, protected landscapes and seascapes could be seen as one of the most striking outward manifestations of the intangible values inherent in cultural heritage (Mallarach 2008).

Biodiversity must incorporate human cultural diversity, which can be affected by the same drivers as biodiversity, and which has impacts on the diversity of genes, other species and ecosystems (UNEP 2008). Since there is this intimate relationship between these two kinds of diversity, it should come as no surprise that of all the new terms and concepts that have emerged in recent years, the concept of 'biocultural diversity' is the one gaining wide acceptance, revealing clearly the complex linkages of culture and nature (Maffi, ed. 2002).

The laws governing natural systems are somewhat fixed therefore opportunities to improve resource management outcomes will increasingly rely on our ability to modify social systems to serve interests of the natural world (Brunckhorst et al. 2006).

Existing Policy Opportunities

Wildlife Conservation Society (WCS) and Freedom to Roam (FTR) hosted a workshop in June 2010 to discuss integration of science into U.S. policy. This workshop did not address policy opportunities in Canada. The participants in the WCS Science to Policy workshop identified 23 potential existing policy opportunities to address connectivity conservation. For all 23, at least one organization present in this workshop is already working to influence that policy. The group then prioritized the list in order of importance. The numeral behind each item represents its weighted score.

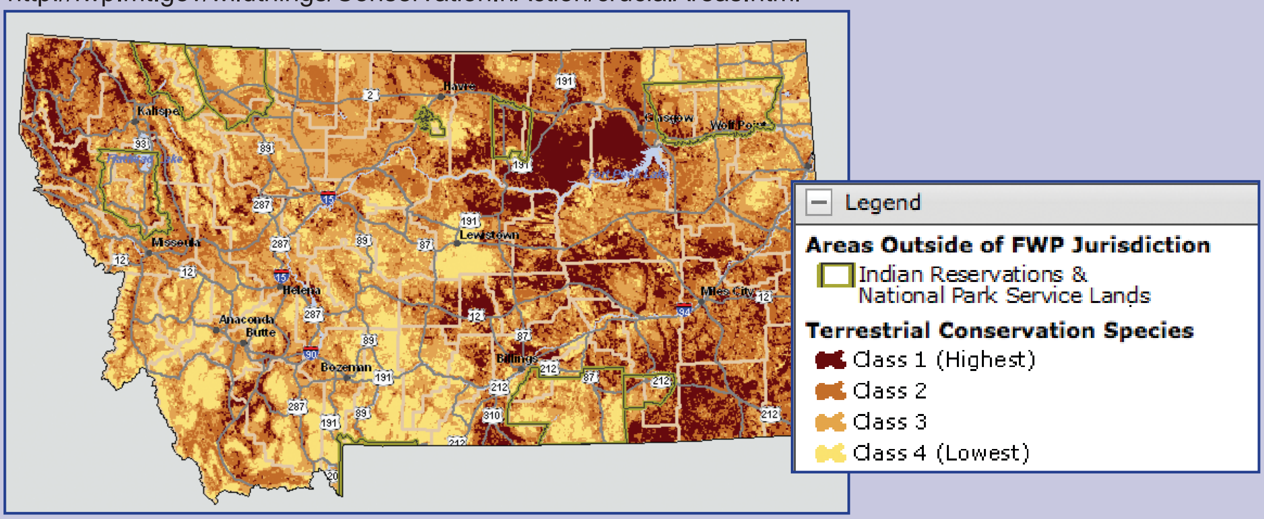
1. Transportation Bill 33
2. State Wildlife Action Plan revisions 19
3. Renewable energy landscape west-wide 12
4. Land and Water Conservation Fund (LWCF) 11
5. USFWS Landscape Conservation Cooperatives 11
6. Private landowner incentives 11
7. Climate Change Legislation 11
8. Western Governors Associaton (Figure 12) 10
9. BLM Ecoregional Assessments 9
10. Corporate Social Responsibility 9
11. Energy Legislation 8
12. BLM sage grouse strategy 6
13. Climate Change Bills 6
14. Colorado-New Mexico MOU 4
15. NEPA guidance from CEQ on climate change 3
16. Land Trust Approach 1
17. State transportation agencies
18. NFMA forest planning rules
19. Statewide resource assessments
20. America's Great Outdoors Initiative
21. National Park Service Second Century Commission
22. Endangered Species Act
23. Department of Defense

In 2007, Western Governors asked the Western Governors' Association to convene a collaborative process that would "identify key wildlife migration corridors and crucial wildlife habitats in the West and make recommendations on needed policy options and tools for preserving those landscapes." WGA launched the WGA Wildlife Corridors Initiative, a state-driven collaborative effort that included six separate working groups each of which was charged with developing findings and recommendations. The WGA Wildlife Corridors Initiative Report was approved by the Governors in June 2008.

In 2008, the Governors established the Western Governors' Wildlife Council (the "Council") under WGA's auspices that was charged with implementing the report. Its initial priorities included establishing state-based and regionally compatible decision support systems (DSS) for crucial wildlife habitat and corridors and seeking policies that ensure that information from these DSSs is used early in the planning process across all jurisdictions. Wildlife DSSs are intended to be a consistent source of landscape-scale mapped biological information that decision makers and the public can use to identify and better understand crucial habitat and corridors.

Linked sites to explore:

Montana Crucial Habitat map
http://fwp.mt.gov/wildthings/ConservationInAction/crucialAreas.html



Washington Connectivity Map
http://waconnected.org

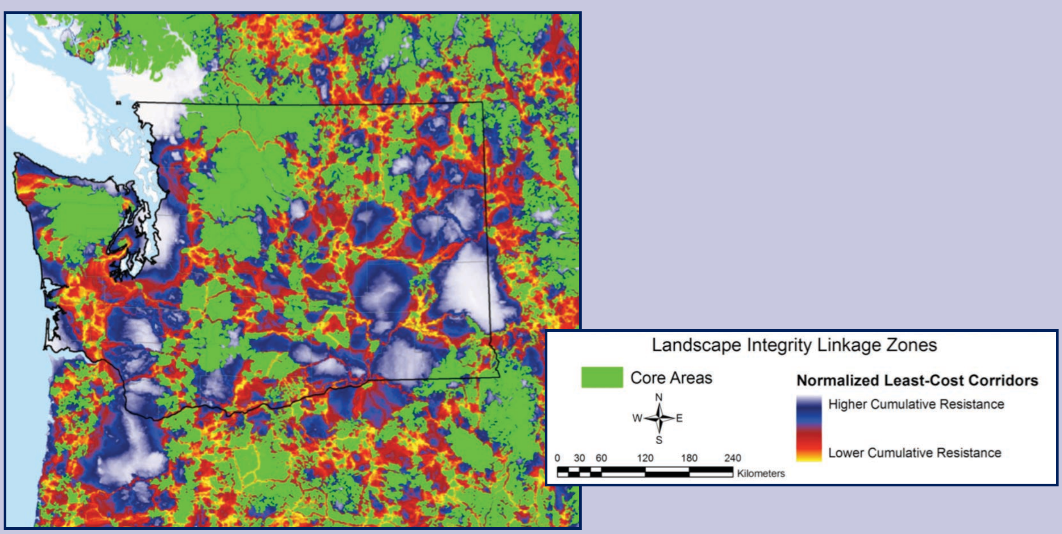


Figure 12. Western Governors Association: Crucial Habitat and Corridors Initiative.

The group decided the top two priorities for policy engagement include the Transportation Bill and the State Wildlife Action Plan revision process. However, the group agreed that it is important to embed connectivity into all 23 opportunities.

The Washington Wildlife Habitat Connectivity Working Group also compiled a recent report on various implementation vehicles for their habitat connectivity analysis. Sara Marinello of Blue Heron Strategies LLC completed a very informative policy vehicles analysis for that working group with a geographic focus on the State of Washington (unpublished report, Blue Heron Strategies at sara@blueheronstrategies.com). This group used a stakeholder interview process to identify implementation vehicles that can be classified into 5 policy buckets. Bucket categories included 1) working lands 2) transportation, energy and defense 3) wildlife and climate change 4) counties and 5) tribal lands. The report describes several important policy vehicles at the state and federal level including Americas Great outdoors, Landscape Conservation Cooperatives, Federal and state climate legislations, state and federal land use plans, intergovernmental consultation with tribes, transportation and energy policy, and USDA agriculture policy. Inventories at the local, statewide and regional level of important policy vehicles is a helpful instrument for agencies or organizations attempting to integrate connectivity into planning and identifying key places where science can be inserted into policy development.

Description of Future Success

As part of that broad discussion at the WCS and FTR Science to Policy workshop the participants explored the question of what conservation success would look like. The participants detailed attributes of a connected world decades and centuries into the future, in order to understand the eventual aims for policy initiatives. These are the attributes defined by that workgroup.

Landscapes Attributes

- Landscapes, both natural and developed must be conducive to movement.
- Landscapes should host an abundance and full array of natural habitats.
- Landscapes should support robust populations of biota.
- Organisms must be able to move across environmental gradients.
- Populations must retain the ability to be resilient and flexible.
- Some protected areas with no human occupancy are needed.
- Conservation must consider all trophic levels.
- Leveraged aquatic connectivity for broader needs.

Governance

- That recognizes the connectivity that nature needs.
- That removes the stovepipes across jurisdictions to help agency coordination.
- That integrates connectivity into planning rather than adding it into decisions late in the process.

Society

- Values nature and livelihoods together and dependent
- Connectivity and wildlife become an American value.
- Connectivity is a way of thinking.
- True costs of fragmentation are reflected in development costs.
- Reinvigorated societal ethic for connectivity and migration, from kids to cab drivers
- More widespread individual responsibility for actions that affect connectivity.
- Improved human engagement-more access to wild places and wildlife.

Land and Water Conservation Community

- Strengthen links to people.
- Focuses on what nature needs.
- Enhanced effectiveness.

Climate Change

- Redesigned cities and towns in appropriate places.
- Wild places remain wild.
- Reduce the human footprint.

The workshop participants felt that we needed to create a social movement to really advance the conservation of biodiversity and connectivity. The participants often noted that corridors and connectivity have yet to become a priority for American society. Many of the desired outcomes will be difficult to achieve without a more widespread urgency within segments of the population calling for them. To gain this popularity, participants offer these suggestions:

- Frame the issue to tap into American values.
- We need specific legislation drafted and passed that would support connectivity across ensuing administrations and jurisdictions.
- We must avoid substantial opposition but meet it as necessary.
- Landowners need to take individual action on private lands.
- The concept must become popular enough to be cool.

A New Policy Framework

Although the science of connectivity conservation is developing rapidly, a policy framework to support this promising approach for conserving biodiversity has not kept pace. The current policy response to a new connectivity conservation movement has been fragmented, limited, and moderately successful in providing the necessary policy framework and proper governance to transform conservation practice in North America.

The participants at the WCS Science to Policy workshop also explored developing a new policy framework for connectivity conservation. A new policy framework will need to embrace the dual threats to biodiversity from human activities and climate change. It will need to reconsider the status and condition of an existing policy framework and identify gaps in current policy and legislation. In addition, it will be important to explore new and innovative policies and law that will meet the needs of nature while exploring new ways for sustaining human activities on landscapes. It will be critical to evaluate the impact of new policies on many sectors of public that impact connectivity especially transportation, energy, agriculture, and housing development. A comprehensive policy framework will include features that affect all levels of government and society. Policy support from community, county, state and federal levels of government are going to be essential to the conservation of connectivity and biodiversity conservation. Best practices from the business community will also be important as they are key stakeholders in many government decisions and can dramatically influence conservation practice at many levels. The group identified several key policy initiatives that could start building a new policy framework including:

1. Create new federal legislation with possible names such as Ribbons of Life/ Freedom to Roam/ Biodiversity/ National Wildlife Corridors Act to designate conservation corridors.
   a. The legislation would coordinate planning & action across jurisdictions.
2. Secretarial orders (could need more than one) or an executive order could be crafted to include connectivity in all applicable vehicles and processes of government.
3. Establish a "Wildlife Heritage Area" designation in the National Park Service's Heritage Area Program.
4. Permit and enable resource agencies to take connectivity into account in decision processes.
5. Establish administrative policy to educate elected officials, including training for agency and tribal employees
6. Expand conservation cooperation to address connectivity across U.S. borders with Canada and Mexico.

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Appendix

Appendix Table 1. Common Issues and Challenges Associated with Connectivity Assessment.

Important Issues and Challenges Associated with Connectivity Conservation	Relationship to Connectivity Conservation	Recommended Spatial Layers and Data	Referenced Tools, Techniques and Useful Concepts
Evaluating the Social-Cultural-Political Landscape	Building social capital and community support for connectivity conservation Integration of cultural values into connectivity	1) Social attitudes toward wildlife and conservation measures 2) Cultural values mapping and assessment 3) Forms of governance in the conservation area. 4) Social and demographic characteristics and trends	1) Social Surveys and Public attitude assessments (Chapter 3 and 10 in Worboys et al. 2010) 2) Including indigenous peoples involvement and traditional knowledge (Borrini-Feyerabend et al. 2004, Redford and Painter 2006, Chapter 15 in Westley & Miller 2003) 3) Population and Habitat Viability Analysis (Westley and Miller 2003 - Chapter 14) 4) Integrating Cultural Values (Bennett and Witt 2001, Wilkie et al. 2008, Mallarach 2008) 5) Valuation of Wildlife/Biodiversity (MEA 2005 6) Megaconservancy Network (Knight et al. 2006, Rouget et al. 2006)
Defining the Economic Landscape	Understanding the social and economic framework that influences connectivity	1) Economic data from the conservation area and regions 2) Poverty Issues 3) Economic and cultural drivers 4) Conservation trade-offs against various land uses 5) Social and demographic trends 6) Ecosystem services from the conservation area	1) Biodiversity offsets using Marxan (Kiessecker et al. 2009) 2) Model and Map Ecosystem services with InVEST - http://www.naturalcapitalproject.org/InVEST.html 3) Economic surveys of landscapes and Protected Areas (Ashley & Evans 2000) 4) Atlas of Demography and Economies (ecoregional to county levels) (Rasker et al. 2009) 5) Cost-assessments of connected networks (Shilling and Girvetz, 2007)
Uncertainty of the Science	What is known? What is not known? What is unknowable? What are the assumptions of the modeling or assessment processes being applied? What are the benefits of connectivity to species?	1) Species monitoring protocols 2) Monitoring and evaluating outcomes from conservation actions (success and failures) 3) Knowledge Map	1) Uncertainty Analysis (Beier et al. 2008, Harwood & Stoke 2003) 2) Knowledge mapping (Centre for Evidence Based Conservation 2010) 3) Species or population viability assessment (Gilpin 1989) 4) Risk of Extinction (NRC 1995)
Climate Change	Connectivity that is resilient to climate change.	1) Climate change models 2) Velocity of Climate Change 3) Predicted biome or range shift 4) Vulnerability analysis-Species response to climate change 5) Focal or indicator species data 6) Landscape attributes (habitat and human use)	Ecological connectivity for a changing climate (Krosby et al. 2010, Hansen & Hoffman 2010)Species Distribution Modeling 1) Species-climate response surfaces (Hole et al. 2009) 2) Generalized additive models (Hole et al. 2009) 3) Maxent and Zonation (Carroll et al. 2009) 4) Climate Envelope Models (Pearson and Dawson 2003) 5) Model ensemble approach (Elith et al. 2006) 6) Pace and pattern of range shifts (Davis and Shaw 2001) 7) Velocity of climate change (Loarie et al. 2009) Other Concepts and Tools 1) Multiple species or guilds (Moritz et al. 2008, Carroll 2007) 2) Species Vulnerability Assessment (Hansen & Hoffman 2010, MEA 2005, Carroll 2007, Carroll 2003, Thomas et al. 2004) 3) Vulnerability indicators (Hansen & Hoffman 2010) 4) Climate Wizard (TNC website, by Zganjar, Girvetz & Raber) 5) Assisted migration (Hansen & Hoffman 2010, Ricciardi & Simberloff 2009)
Data Availability, Quality, and Limitations	Existing limitations of information and information tools	1) Metadata 2) Established data standards for various formats 3) Data management systems and storage capacity	1) Adaptive Management Monitoring Principles (Ringold et al. 1996, Lee 1999, Nichols 2006) 2) Integration of GIS data formats - Chris Friel ESRI 3) Data Standards…..Agree on targets and where it is and how is it doing. 4) Conservation Information Value Chain (Schwolow & Jungfalk 2009, NatureServe) 5) EBM tools (http://www.ebmtools.org/about_ebm_tools.html) 6) Data exploration and visualization tools (Zuur et al 2010, Ferreira deOliveira and Levkowitz 2003) 7) Visualization of spatially referenced data (Andrienko & Andrienko 1999: http://www.ercim.eu/publication/ Ercim_News/enw40/andrienko1.html)

Appendix Table 1. (cont.) Common Issues and Challenges Associated with Connectivity Assessment.

Scale (Time and Space)	What is the appropriate scale for assessment and analysis of connectivity	1) Current scale of conservation plans 2) Species life history 3) Focal species dispersal ability and perceptual range 4) Temporal aspects of the management framework	1) Connectivity is a multi-scale phenomena – fine scale processes occur in the context of coarser scale patterns (Noss 1991). 2) Both spatial and temporal scales are important (Hilty et al. 2006) 3) Spatial and temporal scales can vary with species and life cycle (Bennett 1999) 4) Coarse and fine scales distinguish difference in grain (Hilty et al. 2006) 5) Functional grain is important to animal movement (Baguette & Van Dyck 2007) 6) Finest scale is the perceptual range of animals which influences movement and use of matrix habitats (Olden et al. 2004) 7) Ecological resilience, biodiversity and scale (Peterson et al 1998)
Defining Structural Versus Functional Connectivity	Distinguish and identify characteristics of structural and functional connectivity	1) Spatially explicit characteristics of landscapes and species 2) Description (Spatial or non-spatial) of the functional components driving connectivity 3) Species occurrence, abundance, demography. 4) Species and landscape interactions 5) Species movement and dispersal ability 6) Landscape attributes (habitat and human use)	Assessment (See Kindlmann & Burel 2008, Baguette & Van Dyck 2007) 1) Graph Theoritic based models - Landscape Networks (Theobold et al. 2006) 2) Ecological Function and Species (Verboon & Pouwels 2004) 3) Circuit Theory (McRae et al. 2008) 4) Optimizing Climate Change Resilience (Carroll et al. 2009) 5) Functional grain (Baguette & Van Dyck 2007)
Species as Biological Targets	Focal, Umbrella, Indicator, Interactive, Endangered or at-risk	1) Species occurrence, abundance, demography. 2) Habitat needs and resource selection assessment 3) Understanding of its interaction with other species and landscape 4) Vulnerability to Climate and Land use change 5) Landscape attributes (habitat and human use) 6) Species sensitivity to loss of connectivity – vulnerability to threats	1) Categories of target species and definitions (Martino et al. 2005) 2) Keystone Species Concept (Mills and Soule 1993) 3) Conservation Status Assessment: Risk of Extinction (Master et al. 2009, NatureServe website, USFWS Recovery Program) 4) Crucial or Critical Habitat Designations for species (USFWS Recovery Plans, Schreiner 1976,WGA corridors and crucial habitat initiative 2007) 5) Population Viability Assessment (Groves 2003, Morris et al. 1999, Westley and Miller 2003) 6) Landscape-Species Approach (Coppolillo et al. 2004) 7) Focal Species as umbrella's (Lambeck 1997, Soule & Noss 1998) 8) Climate Vulnerability Assessment (USEPA 2009, Martin et al. 2001) 9) Highly Interactive Species (Soule et al. 2003) 10) TNC Coarse/fine filter approach (TNC 2000 11) Land use planning to maintain populations of terrestrial wildlife (Suring et al 2011)
Managing the Matrix	Preserving some level of permeability in matrix landscapes. Buffering protected areas.	1) Species occurrence, abundance, demography. 2) Habitat needs and resource selection assessment 3) Landscape attributes (habitat and human use) 4) Sensitivity to human activities, vulnerability to threats and loss of connectivity	1) Core reserves are important (Dominick et al. 1996) 2) An emphasis use approach (Everett & Lehmkuhl 1996) 3) Importance of matrix in biodiversity (Franklin & Lindenmayer 2009) 4) Properties of matrix are more important than habitat patch size (Prugh et al. 2008) 5) Simap D - a model to assess permeability (Finke & Sonnenschein 2007) 6) Restoring habitat permeability (Bisonette & Adair 2008, Singleton et al. 2002)
Detrimental Effects of Connectivity	Minimizing the negative effects of connectivity on conservation of biodiversity	1) Disease prevalence and epidemiologic factors 2) Presence of and potential impact from Invasive species 3) Mortality sinks 4) Deleterious genes in animal populations	1) There are possible detrimental effects to increased connectivity. (Bennett 1999, Crooks & Sanjayan 2006, Hilty et al. 2006). 2) Consider all alternative ideas for protecting biodiversity (Bennett 1999, Hodgson et al. 2009) 3) Invasive species may become a problem (Crooks and Suarez 2006, Haddad et al. 2010) 4) Disease transmission and connectivity (Hess 1994, Condeso & Meentemeyer 2007) 5) Hyperconnectivity-Anthropogenic effects on invaders (Crooks & Suarez 2006) 6) Source sink dynamics (Simberloff et al. 1992)
Prioritizing Corridors for Ecological Connectivity	Directing conservation action toward priority areas to ensure connectivity	1) Connectivity Assessment 2) Threat Assessments 3) Climate Change models that predict habitat change for species targets	1) No Regrets Analysis (Unpublished 2 Countries 1 Forest) 2) Priority Linkage Assessment(American Wildlands 2009) 3) Prioritizing Transportation Corridors (Williamson et al. 2009, Beckmann et al. 2010) 4) Land Use Change Models (Habitat Triage) (Hobbs & Kritstjanson 2003) 5) Irreplacability and Threat (Noss et al., Spring et al 2010) 6) Current versus future threats & delay costs (Spring et al. 2010) 7) Expanding and contracting threats (Pressey et al. 2007)s

Appendix
Table 2. Important issues and challenges related to integrating connectivity into conservation plans.

Important Issues & Challenges Associated with Connectivity Conservation Planning	Relationship to Connectivity Conservation	Recommended Spatial Layers and data	Referenced Tools, Techniques and Useful Concepts
Public Participation/Community Support	Building social capital and community support for connectivity conservation Integrating cultural values into connectivity	1) Available social-economic data (e.g. planning unit, county wide or regional) 2) Recreational activities in the planning unit 3) A cultural values assessment 4) Existing forms of governance in the planning unit 5) People groups associated with the landscape	1) Adaptive management principles (Holling 1978, Walters 1986) 2) Conservation Action Planning (Groves 2003, Groves et al 2002, TNC 2007, DeLacy et al 2006)) 3) Designs for Nature (Bottrill and Pressey 2009) 4) Integrating regional stakeholder needs into land use planning (Furst et al 2010) 5) Communication Planning (Delacy et al 2006) 6) Integrating Cultural and Social Values in Planning (Lockwood in Worboys et al 2010, Jongman and Pungetti 2004) 7) Eight Principles of Good Governance (Lockwood in Worboys et al 2010) 8) Governance principles for natural resource management (Lockwood et al 2010) 9) Array of Instruments for organizations doing connectivity conservation (regulation, economic, voluntary agreements, communication based) (Lockwood in Worboys et al 2010) 10) Nature Serve VISTA (Nature Serve 2009) Community Viz (integrated into Vista) 11) The MegaConservancy Network-integrating biophysical assessment and economics (Lombard et al 2010) 12) Evaluating Collaborative Natural Resource Management (Conley and Moote 2003)
Economics of the Landscape	Understanding the social -economic framework that influences connectivity planning	1) Economic data from conservation area or region defining economic drivers 2) Demographic characteristics and trends in conservation area or region 3) Local poverty issues 4) Ecosystem Services and trade offs	1) Business and Economic Planning for Conservation Areas (Lockwood and Quintela 2006, Hanemann 1986 and Norton 1986 (in EO Wilson) 2) Economic Valuation Techniques (Farber 2005) 3) MEA assessments in 2005 (MEA 2005 a and b) 4) Selecting offset sites with Marxan (Kiesecker et al 2009) 5) Modeling future development (Copeland et al 2009) 6) Predicting ex-urban development-FunConn-D. Theobold 7) Model and map ecosystem services with InVEST- http://www.naturalcapitalproject.org/InVEST.html (Nelson et al 2009, Tallis et al 2009) 8) Assessing benefit transfer of ecosystem services (Plummer 2009)
Uncertainty of the Science	What is unknown about the landscape or species? What is unknowable? What are assumptions behind modeling and assessment processes being applied?	1) Climate change models 2) Long tern species monitoring protocols 3) Methods to measure and report outcomes from proposed conservation actions (success and failures)	1) Management monitoring-adaptive strategies (Holling 1978, Walters and Holling 1990). 2) Adaptive Management in habitat conservation (Wilhere 2002) 3) Scenario Planning (Peterson et al 2003, Hansen and Hoffman 2010) 4) Intractable Problems in Environment (Elliot et al , 2003) 5) Uncertainty Connectivity and Climate Change (Hodgson et al 2009) 6) Learning and optimization in planning (Williams 2001) 7) Knowledge mapping (Centre for Evidence Based Conservation 2010)
Integrating Connectivity in a Climate Change Context	Increased Connectivity as an adaptation strategy Implementing climate robust conservation	1) Climate uncertainty 2) Velocity and Pace of climate change in this planning unit. 3) Species Vulnerability 4) Mitigation strategies 5) Climate stressors	Planning (for broad and general guidance see Hansen and Hoffman, MEA 2005, Halpin 1997) 1) Resistance versus resilience (Hansen and Hoffman 2010) 2) Adaptation Strategies (Carroll 2007 , Araujo et al 2004 , Hansen and Hoffman 2010) 3) Increased Connectivity (Krosby et al 2010, Hole et al 2009, Heller and Zavaleta 2009, Halpin 1997) 4) Mitigation Strategies ( ) 5) Assisted Migration (Hoegh-Guldberg et al 2008, Richardson et al 2009,Ricciardi and Simberloff 2009). 6) Managing Climate Stressors-Reducing Vulnerability (Hansen and Hoffman 2010)
Monitoring and Evaluation	How do you determine if you are achieving connectivity conservation goals	1) Clearly defined conservation targets 2) Assessment of conservation actions to determine successes and failures 3) Goals need to be linked to targets that can be monitored	1) Adaptive Management Principles-Learning from management outcomes (Holling 1978, Nichols and Williams 2006). Kay et al 1999 addresses active versus passive adaptive management. 2) Status measures-state of the system (Groves et al 2003, Biodiversity index and values see above) 3) Strategy effectiveness measures (Groves et al in press, CMT paper, Salafsky et al 2002) 4) Evidence based conservation-inference from multiple projects or programs (Groves et al in press) 5) Linking Measurements across scales (Defries et al 2009) 6) Are we saving what we say we are saving….(Parrish et al 2003) 7) Miradi-Adaptive Management Software (https://miradi.org/files/miradi_overview.pdf) 8) Open Standards for Conservation Practice (Conservation Measures Partnership 2007) 9) CEE Systematic Review (Center for Evidence Based Conservation 2010) 10) Structured decision making and adaptive management (Lyons et al 2008) 11) Allocating Resources between action and evaluation (Salzer and Salafsky 2006)

Appendix Table 2. *cont.* Important issues and challenges related to integrating connectivity into conservation plans.

Planning Scale (Space and Time)	Planning at the right scale (temporal and spatial) for the right species or suite of species Planning for the right timescale	1) Jurisdictional and land ownership boundaries 2) Planning Unit scaled to biology of species 3) Distribution and habitat patches for species or specie group being conserved or managed. 4) Connectivity map for targeted species or species groups 5) Spatial and temporal aspects of extractive use and human activity on the planning unit.	1) Conservation of species or processes associated with fine-scale habitat characteristics will require site specific evaluations (Keitt et al 1997) 2) Systematic Planning Tools (Margules and Pressey 2000) 3) The need for broad scale analysis to optimize climate resilience (Carroll et al 2009) 4) Regionally focused adaptive management approaches (Hole et al 2009, Trombulak and Baldwins book???, Bird Conservation Areas. Joint Ventures, Minor and Urban 2008,). 5) Continental Scale approaches (Wildlands Project-Spine of the Continent and Wild LifeLines, Forman et al 2000, Leu et al 2008, Woolmer et al 2008) 6) Intercontinental approach (e.g.Partners in Flight-Bird Conservation) 7) Eco-civic optimization: A nested framework for planning and managing landscapes (Brunckhorst et al 2006)
Species as targets for planning	Focal, Umbrella, Indicator, Interactive, endangered or at-risk	1) Species occurrence, current status, and demography. 2) Habitat needs and resource selection models 3) Landscape attributes (habitat and human use) 4) Sensitivity of species to loss of connectivity and vulnerability to threats 5) Species relationships and community dynamics	1) Biodiversity assessments- Benchmarking Biodiversity Conservation toolbox (Dept. Env-Australia 2008) 2) State/Province species conservation plans (Species Planning, State Wildlife Action Plans, Species at-Risk plans) 3) IUCN Red List and conservation strategies (IUCN) 4) National Endangered Species Classification and Planning (e.g. ESA and COSEWIC) 5) Ecoregional Planning (TNC, WWF) 6) Categories of target species and definitions (Martino et al 2005, Groves 2003) 7) Highly interactive species (Soule et al 2003)
Managing the Matrix	Preserving some level of permeability in matrix landscapes. Buffering protected areas.	1) Species behavioral response to human activities 2) Species sensitivity to loss of connectivity – vulnerability to threats 3) Important Landscape attributes (habitat and human use) 4)	Importance of Matrix….protected areas are small portion of the globe (Lindenmayer and Franklin 2002, Franklin and Lindenmayer 2009) 1) Critical Core reserves (Dominick et al 1996) 2) Critical Role of the Matrix (Lendmayer and Franklin 2002) 3) Buffering protected areas (Janzen 1983 Kelly and Rotenberry 1993,, Lindenmayer and Franklin 2002) 4) Emphasis Use approach (Everett and Lehmkuhl 1996) 5) Linkages in Land Use Planning (Bennett 1999) 6) Predictive impact modeling (Copeland et al 2009) 7) Natural corridors are better than manipulated corridors (Gilbert-Norton et al 2010) 8) Landscape permeability (Singleton et al 2002, Finke and Sonnenschein. 2007, Bissonette and Adair 2008)
Funding and Resources for Connectivity Conservation	Establish the appropriate financial support and human resources to implement connectivity conservation	1) Amount of land needing protect in cores and connecting landscapes 2) Human resources needed to perform conservation tasks 3) Carbon Stocks	1) Financial Considerations (Lockwood in Worboys et al 2010) 2) Legislation and Law (U.S. Climate Change Act-Information Program Section Whitelaw and Eagles 2007) 3) Carbon Trade (U.S. Climate Change Act, Nelson et al 2009) 4) Farm Bill Funding (Safe Journeys-EDF) 5) Washington DSS links to workplans (Pierce) 6) Taxing resource extraction industries (CARA, Nelson et al 2009) 7) Conservation Foundations (DDCF, Hewlett) 8) Redirected Government Funding
Setting Conservation Priorities	Set the appropriate priorities to achieve extensive connectivity in landscapes	1) Connectivity Assessment of the Landscape 2) Where species and habitat resources are within core areas and connecting landscapes 3) Land use/Land Cover 4) Target Resource values 5) Threats to conservation targets	1) Biodiversity hot spots (Myers et al 2000) 2) Ecoregional Priorities (TNC, WWF, Groves et al 2003 , Olson and Dinerstein 1998) 3) Vulnerability versus Irreplacability (Noss et al 2002) 4) InVest (Tallis et al 2008) 5) Threat Assessment (Salafsky et al 2002, IUCN-CMP 2006) 6) Habitat Triage (Hobbs and Kristjanson 2003) 7) Forward-looking reserve linking and delay costs (Spring et al 2010) 8) Nature Serve VISTA Software (Nature Serve 2009) 9) Optimizing reserve system resilience to climate change (Carroll et al 2009)
Feasibility of Connectivity Conservation	The connectivity conservation measures and plan activities are realistic and implementable	1) Conservation targets and goals 2) Real costs of conservation measures 3) Institutional capacity 4) Opportunity costs and trade offs 5) Implementation risks	1) Integrating feasibility (Morrison and Reynolds 2006) 2) A checklist for network designs (Noss 2003)

Appendix Table 3. Common strategies applied to the conservation of connectivity

Conservation Strategy	Conservation Target	Spatial Layer/Data and Information Needs	Weaknesses of Approach	Referenced Tools, Methods and Useful Concepts
Protecting a movement corridor for a single species	Saving the last Unique long distance migrations Protecting movement corridors for a single species Species persistence	1) Specific long range migration and individual animal movement data. 2) Movement data over multiple years to capture the appropriate temporal scale of this movement and variation in path selection. 3) Species Distribution (seasonal and yearlong) 4) Landscape attributes (habitat and human use)	Not all migrations are known and those that are may not be well studied / documented Planning for the existing conditions does not consider future scenarios. Long distance migration is influenced by multiple jurisdictions and may extend across multiple planning areas.	1) Animal movement approaches: a. Redistribution Analysis (mark – recapture studies) b. Detailed animal studies using GPS technology (Berger 2004, Berger et al. 2006, Waller 2005) c. Landscape genetics approach (Schwartz et al. 2009, Cushman et al 2006, Manel et al. 2003) 2) Modeling approaches a. Resource Selection Functions (Manly et al. 2002, Boyce & McDonald 1999) b. Patch Dynamics (Schumaker 1996, Fahrig & Merriam 1994, Girvetz et al. 2007, Moilanen & Hanski 2006-IFM Model) c. Least Cost Path Models (Walker & Craighead 1997, Singleton & Lehmkuhl 2000) d. Dynamic optimization models (Martin et al 2007) e. Virtual Migration (Hanski et al. 2000) f. Migratory Connectivity (Marra et al. 2006)
Ecological networks design	Maintaining networks of protected landscapes Conserving ecological processes and flows.	1) Protected Areas with broad connectivity zones 2) Data from focal species at various trophic levels. 3) Gene flow data 4) Landscape Attributes (Habitat and human use attributes)	How much connectivity is enough? Representative or Focal species may not represent all species needs. When do we have strong enough empirical data to predict connectivity? Estimates of resistance or permeability are not always known or empirically derived	Connectivity assessment of an ecological networks (Bier et al. 2008, Graham Bennett 2004, Bennet & Wit 2001, Jongman & Pungetti 2004) A Checklist for Wildlands Network (Noss 2003) Ecological networks as conceptual frameworks for operational tools.(Boitani et al. 2007) 1) Individual animal movement and species distribution (Berger et al. 2006, Hebblewhite et al. 2006, Waller & Servheen 2005, Gibeau et al. 2001) 2) Maxent modeling (Phillips et al. 2006, Carroll et al. 2009) 3) Graph theoretic approach (Keitt et al. 1997; Bunn et al. 2000; Urban & Keitt 2001, Minor & Urban 2008, Jantz & Goetz 2008, Theobold 2006) 4) Circuit Theory (McRae et al. 2008, Shah & McRae 2008) 5) Least Cost Path Models (Singleton et al. 2002, Cushman et al. 2006) 6) Habitat Contours as a landscape model (Fischer et al. 2004, Shilling et al. 2002) 7) Expert Opinion (Dinerstein et al. 2000) 8) Internet modeling tools (see Figure 3)
Protect representative plant community or ecotypes	Saving plant communities that provide habitat (Can serve as a surrogate for animal conservation). Biodiversity of plants and plant communities Conservation of various ecotypes across a larger ecosystem	1) Major ecotype maps 2) Crucial representative areas map 3) Detailed Vegetation mapping 4) Landscape attributes (habitat and human use)	Plant community classification schemes may not capture all species represented on a landscape. Protecting a community may not prevent loss of a species. Rare or uncommon species may be vulnerable to loss. What is a natural landscape? Community dynamics are often not well understood.	1) Assessment and inventory methods (Parkes et al 2003) 2) Habitat-Hectares (Parkes et al. 2003) 3) Remote sensing (Jones et al. 2009) 4) Spatial analysis (Baldwin 2006, Baldwin et al. 2007) 5) Naturalness Index (Grivetz *in press*) 6) Coarse Filter approach with species assessment (Haufler et al. 1996, Noss 1987) 7) Predictive Modeling of plant distribution or habitats (Haufler Grassland model. Roloff 1994). 8) Habitat Contours in Landscape modeling (Fischer et al. 2004)
Protect ecosystem services	Conserve connectivity on the basis of the economic value of ecosystem services Protecting specific services ecosystems provide to humans (such as recreational values, water) of one ecosystem service	1) Atlas of local and regional economies 2) Demography of Human Populations 3) Human values map 4) Water and hydrology 5) Geologic and soils maps 6) Other Landscape attributes especially land use.	Placing values on services is an imperfect science yet. There is no market history for most ecosystem services. The future market for services is unknown and unpredictable. Economic values and societal values are linked but the relationships are not always clear. Can we influence and predict shifting societal values? The influence of various and dynamic cultural frameworks on ecosystems and value of services is not always known or predictable.	Assessment General Review of 103 projects in Tallis et al. (2009) 1) Value of Biodiversity-Natural Capital Project. (MEA 2005, CBD Tech Series 36, Daily et al. 2009, Plummer 2009) 2) Modeling ecosystem services, biodiversity conservation, commodity production and tradeoffs---InVest Modeling tool (Nelson et al. 2009) 3) Markets for Ecosystem Services-Payment for Environmental Services (MEA 2005, Bohlen et al. 2009, Tallis 2008) 4) Importance of connectivity to ecosystem services (e.g. pollinators) (Ricketts et al. 2006) 5) Megaconservancy network concept connectivity in production landscapes (Knight et al. 2006,Rouget et al. 2006) 6) Nectar Corridors to preserve migratory pollinators (Nabhan 2004)

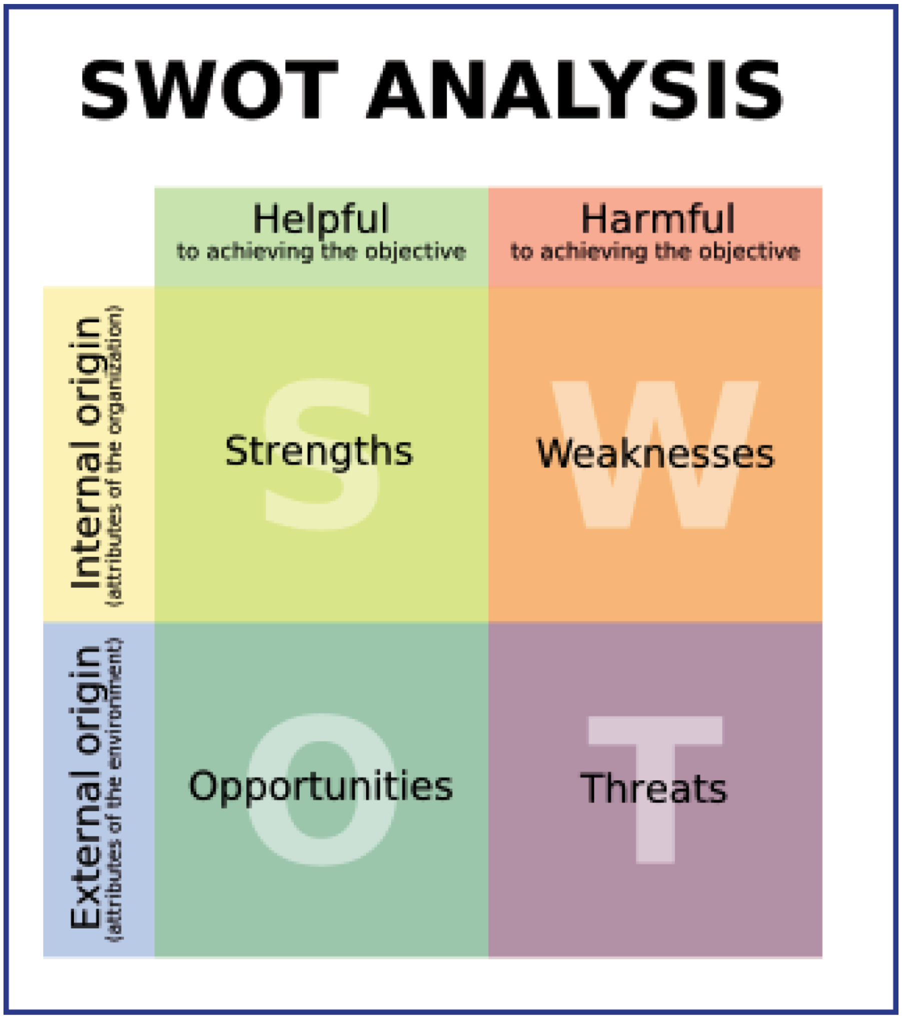
Appendix
Table 3. ***cont.***
Common strategies applied to the conservation of connectivity

Land use planning (beyond the transportation planning approach described below)	Maintaining connectivity in the face of human development	1) Human footprint (at local and ecoregional scale) 2) Residential and urban zoning or other development regulations 3) Isolation from human activity- naturalness or wilderness index map	Behavioral response of species to human disturbance is often unknown and unpredictable. Demographic impacts are not always clear. Human use of landscapes is dynamic, not static. Forecasting the future use of land is difficult and uncertain	1) Land use inventory and mapping tools (Sanderson et al. 2002, Woolmer et al. 2008) 2) Cumulative effects (Johnson et al. 2005) 3) Permeability mapping (Singleton et al. 2002) 4) Naturalness index (Cook 2002, Machado 2004, Girvetz *in press*) 5) A Wilderness Index (Lesslie & Maslen 1995) 6) Planning the Future Landscape-Nature and Culture (Pungetti & Romano 2004, Theobold 2004) 7) EBM Tools - A comprehensive toolbox (http://www.ebmtools.org/about_ebm_tools.html 8) Future Exurban development (Theobold 2004, Theobold 2006) 9) Maintaining Wildlife Populations through land use planning (Suring et al 2011) 10) Integrated land use management support tools (Furst et al 2010)
Transportation planning	Protecting critical linkage zones fragmented by transportation infrastructure Transportation safety	1) Highway crossing zones and transportation infrastructure 2) Animal road kill data 3) Species movements and distribution along highway corridors or road network 4) Landscape Attributes along the targeted highway corridor or road network	Animal behaviors vary across species and may not be well known. Species response to traffic volume and barriers. Behavior response of many animals to crossing structures and underpasses is unknown Demographic impacts are often unknown. Transportation infrastructure is shifting and often linked to other human uses of the land	General Reviews (Trombulak et al. 2000, Beckman et al. 2010, Cramer & Leavitt 2009, Gunderson et al. 2005) 1) Animal Movement and Survey methods along highway corridors (invasive and noninvasive tools) (Singleton & Lehmkul 2000, Waller & Servheen 2005, Long et al. 2008, Graves et al. 2006) 2) Landscape Genetics approaches (Cushman et al., Neel & Cummings 2003, Frankham 2006, Schwartz et al. 2009) 3) Roadkill surveys (Jongman & Pungetti 2004, Williamson et al. 2009) 4) Least Cost Path Model (Singleton et al. 2002, Bier et al. 2006, Shilling and Girvetz, 2007) 5) Graph Theoretic Models (Jantz & Goetz 2008, Theobold et al. 2006) 6) Habitat Permeability Models (Singleton et al. 2002, Finke & Sonnenschein 2007, Bissonette & Adair 2008) 7) Expert Opinion (Clevenger et al. 2002, Arizona Wildlife Linkages Assessment) 8) Effective Mesh Size (Girvetz et al. 2007) 9) Mitigation (Curlatti et al. 2009, Ford et al. 2009,TransWild Alliance at http://www.transwildalliance.org/resources, Western Transportation Institute)
Genetic conservation and evolution	Maintain genetic flow across landscapes. Allow evolutionary process to shape ecosystems.	1) Genetic markers for target species or populations 2) Measures of genetic integrity for populations studied 3) Gene flow as a product of individual animal movement 4) Species Demography and Distribution (population wide and rangewide) 5) Evolutionary Significant Units	Estimates of the Resistance to gene flow vary with species and landscape disturbance. Are often not well known. Time frames for understanding the evolutionary significance of human disturbance on species are longer than conservation programs leaving uncertainty about measuring success of conservation actions. Can we even manage an evolutionary pathway? Is it beyond our influence or capability? What are practical thresholds for gene flow and at what level does resistance influence evolutionary process? Are there detrimental effects associated with enhancing gene flow across landscapes?	General Reviews and Tools (Oyler McCance & Lebeg 2005, Long et al. 2008) 1) PathMatrix (Ray 2005) 2) Landscape genetics (Cushman et al., Neel & Cummings 2003, Frankham 2006, Schwartz et al. 2009) 3) Gene Flow (Allendorf 1996, Whitlock & McCauley 1999, Chesser 1991, McRae & Bier 2007, Swartz et al. 2009) 4) Genetic consequence of Reserve Design (Neel & Cummings 2003) 5) Overpasses prevent genetic isolation (Corlatti et al. 2009) 6) Rangewide and population level assessment (Benedict 2003, Gilpin & Soule 1986, Bouzat et al. 1986, Kendall et al. 2009, Schwarz et al. 2009) 7) Other conservation genetics approaches (reproductive technologies, Ballou & Lacy 1995 found in Ballou, Gilpin & Foose 1995- captive breeding, Miller 1995 - Selective breeding as in Przewalskis horse, CA Condor) 8) Evolutionary Significant Units (Waples 1991)
Restoration	Restoring species or repairing damaged landscapes to increase connectivity and ecological integrity	1) Inventory of damaged landscapes 2) Restoration methods for a species 3) Landscape features both natural and disturbed 4) Species inventory and distribution data 5) Economic impact of damaged lands and cost of restoration	Restoration ecology is not yet a very well developed science. Technically sound methods to restore species are needed & for many species are not known. Control of invasive species is an emerging science. Methods to control and consequences of control are often unknown. The cost of restoring weighed against that of maintaining natural characteristics are not easy to estimate.	1) Restoring Large Mammals (Maehr et al. 2001) 2) Rewilding (Soule & Noss 1998) 3) Assisted migration (Hansen & Hoffman 2010, SER 2009) 4) Ecological Restoration (Clewell & Aronson 2007, SER 2008) 5) Restoring habitat permeability (Bisonette & Adair 2008) 6) Restoration to promote resilience and reduce vulnerability to climate change (Hansen & Hoffman 2010) 7) Controlling Invasive species (Lonsdale 1999) 8) Natural corridors afford better connectivity than manipulated corridors (Gilbert-Norton et al. 2009)

APPENDIX A. SWOT Analysis Modified For Connectivity Conservation Projects

SWOT analysis is a strategic planning method used to evaluate the **S**trengths, **W**eaknesses, **O**pportunities, and **T**hreats involved in a project or in a business venture. It involves specifying the objective of the business venture or project and identifying the internal and external factors that are favorable and unfavorable to achieve that objective. The technique is credited to Albert Humphrey, who led a convention at Stanford University in the 1960s and 1970s using data from Fortune 500 companies.

A SWOT analysis must first start with defining a desired end state or objective. A SWOT analysis may be incorporated into the strategic planning model. The aim of any SWOT analysis is to identify the key internal and external factors that are important to achieving the objective. SWOT analysis groups key pieces of information into two main categories:



Internal factors – The *strengths* and *weaknesses* internal to the organization.

External factors – The *opportunities* and *threats* presented by the external environment to the organization. One can use a PEST or PESTLE analysis to help identify factors.

Strengths: characteristics of the Project that give it an advantage.

Weaknesses: are characteristics that place the Project at a disadvantage.

Opportunities: *external* chances to improve the Project.

Threats: *external* elements that could cause trouble for the Project.

SWOT analysis tools are available on the internet at http://www.inghenia.com/gadgets/swot/swot_en.php

Follow the standard SWOT analysis procedures to evaluate your connectivity assessment and/or planning project. Address the recommended factors and considerations in the matrix below to determine whether your projects strengths, weaknesses, opportunities and threats. Identified Weaknesses and Threats will be harmful to the project whereas Strengths and Opportunities are helpful and allow you to meet conservation objectives. We suggest for simplicity you place the assigned Alpha-numeric value assigned to a factor in the appropriate quadrant in the SWOT to ordinate the key elements to guide you as you move the project forward.

Appendix A. continued

Recommended Connectivity SWOT Factors	S	W	O	T
1. Select Conservation Targets and Set Goals A. Are the conservation targets clear? B. Targets should include both biotic and abiotic elements. C. Clearly articulate why connectivity relates to your agency/organizational mission. D. Connectivity goals are established and SMART.				
2. Evaluate Organizational Capacity A. Institutional Capacity B. Financial Capacity C. Technical Capacity - Staffing, multi-disciplinary, experience D. Capacity to form partnerships with other agency/organizations E. Inventory policy vehicles for assessing, managing and planning for connectivity				
3. Develop and Evaluate the Connectivity Assessment Process A. A connectivity assessment process is defined and approved by the agency/organization. B. The project development plan has evaluation checkpoints throughout the process. C. Background review and literature search is completed and informs the project. D. A well defined information management system is developed and implementable. (1) Includes a review and assessment of existing Information Management Systems. (2) Project is capable of using outside data sources and data sharing. (3) Selection criteria for including and excluding information are clear. (4) Project has completed a data gaps analysis. (5) Data integration procedures are reviewed by experts in this field. E. A participatory process to achieve stakeholder investment and “buy in” is developed. F. A peer review process is applied to the project during development. G. Methodology is rigorous and systematic within the framework of purpose and goals. (1) A robust connectivity modeling approach is being applied in the analysis. (2) A robust species habitat modeling approach is being applied to the analysis. (3) The approach considers both structural and functional connectivity (4) The approach integrates methods for designing climate robust connectivity.				
4. Define the Conservation Area A. A science based process was used to define the conservation area. B. The connectivity conservation area is properly matched to conservation targets and goals. C. Connectivity planning units and connectivity assessment areas are properly aligned.				
5. The Assessment Project Meets Critical Challenges A. Social Economic and Cultural Factors (1) Community values are integrated in the assessment process and if possible are spatially explicit. (2) Economic drivers are understood and articulated. (3) Traditional knowledge is incorporated into data sets and considered during the assessment process B. Uncertainty of the Science (1) Uncertainty is clearly articulated and discussed in the assessment plan. (2) Assumptions underlying selection of methods and targets are explicit. (3) Evaluate the pattern and velocity of climate change in target landscapes. (4) Climate vulnerability assessment for target species is completed. C. Limitations in the data available and used are understood and explained in metadata. D. Monitoring and Evaluation (1) A project evaluation process and timelines are clearly defined. (2) Monitoring is integrated into the conservation plan that the connectivity assessment informs. (3) An evaluation process is being used to determine the level of collaboration & participation in the process E. Scale (1) Both the temporal and spatial scale of the project is clear. F. Detrimental effects are considered and mitigated. G. A process to prioritize corridors is defined. H. Conservation targets are representative and persistent. (1) The assessment addresses multiple species. (2) The focal species selection process is clear. (3) Focal species move cross environmental gradients and represent key taxa. (4) Highly Interactive species, wide ranging, or endangered species are included.				
6. Integrating Connectivity Into Conservation Plans A. Systematic conservation planning is being applied in the planning process. B. Planning Units are biologically appropriate and integrate connectivity needs of species and habitats. C. Apply robust planning tools with an ability to evaluate scenarios. D. A decision support system is used in each decision process. E. An ability to forecast and evaluate future scenarios through robust modeling approaches. F. Connectivity is considered in each land use decision in the planning unit. G. Implementation is feasible. H. Planning reveals the real and opportunity costs of conservation measures.				
7. Meeting Challenges Associated with integrating connectivity into conservation plans A. An adaptive management process is clear and defined in the plan. B. Social and cultural factors are considered when defining planning units. C. Economics and ecosystem services are integrated into planning process. D. Areas of Uncertainty are identified and how they will be addressed is clear. I. Dynamics of ecological systems and changing climate are integrated into planning. E. Research proposed and directed to filling important gaps and questions. F. A communication plan is developed that explains your connectivity conservation strategy. G. A system to prioritize Conservation Areas is included in systematic planning process. H. Governance and Policy (1) The current form of governance in the conservation area supports connectivity conservation. (2) A satisfactory policy framework exists to support connectivity conservation. (3) Jurisdictional authority exists to develop and implement connectivity conservation strategies. I. There is some ability to influence future policy for the sake of connectivity conservation.				

Internal	
Strengths	**Weaknesses**
1.	1.
External	
Opportunities	**Threats**
1.	1.

SWOT Analysis Summary

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