



CONNECTIVITY & CLIMATE CHANGE TOOLKIT

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ASSOCIATION of FISH & WILDLIFE AGENCIES

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EXECUTIVE SUMMARY

Landscape connectivity is a critical component of ensuring healthy ecosystems, and in recent decades has become a popular conservation tool. In light of climate change, connectivity is recognized for its potential to provide additional benefits for resiliency and adaptation strategies for fish and wildlife. However, to maximize these benefits necessitates managers consider climate change impacts and adaptation strategies fully.

This toolkit was developed for the Association of Fish and Wildlife Agencies' Climate Adaptation Committee at their request. The purpose is to provide state fish and wildlife agency planners and managers with the information necessary to ensure climate considerations are being accounted for and incorporated in the planning and implementation of terrestrial and aquatic connectivity initiatives. The toolkit is structured as a gateway to provide users with information, tools, and resources critical to understanding and deploying such climate adaptation strategies related to landscape connectivity. Unfortunately, no one-size-fits-all approach works for these kinds of initiatives, and so the goal of the toolkit is to provide users with a variety of considerations and resources to identify their needs.

Throughout the sections, users will find Key Resources which provide links and brief annotations that will direct to websites, tools, journal publications, and other resources for more information. Sections may also contain Case Studies which will take the user to websites or reports that provide a deeper dive into on-the-ground examples. In addition, many sections also contain Key Strategies which identify broad management strategies that can be implemented to more fully incorporate climate change considerations into connectivity initiatives. All the sections begin with general background information and the subsequent lists are designed to help managers quickly find detailed information as they need it.

The toolkit provides information on landscape connectivity and its connection with climate change. It details how climate related changes may impact connectivity which are important considerations when planning a project or initiative. There is a section on project planning and how to ensure that a conservation action is a climate-smart conservation action. Finally, the toolkit provides strategies that can employed for actions related to protection, restoration and management, outreach and education, and monitoring and evaluation. Additionally, it provides some high-level considerations and strategies for various ecosystems.

TABLE OF CONTENTS

INTRODUCTION

MAGGIE ERNEST JOHNSON, ASSOCIATION OF FISH AND WILDLIFE AGENCIES

PURPOSE OF TOOLKIT

The Association of Fish and Wildlife Agencies' Climate Adaptation Committee charged a small working group in September of 2019 to develop a toolkit focused on climate-informed landscape connectivity. The purpose is to provide state fish and wildlife agency planners and managers with the information necessary to ensure climate considerations are being accounted for and incorporated in the planning and implementation of terrestrial and aquatic connectivity initiatives.

HOW TO USE THIS TOOLKIT

This toolkit is structured as a gateway to provide users with information, tools, and resources critical to understanding and deploying such climate adaptation strategies related to landscape connectivity. Unfortunately, no one-size-fits-all approach works for these kinds of initiatives, and so the goal of the toolkit is to provide users with a variety of considerations and resources to identify their needs. Users are encouraged to use the table of contents to help identify the sections most relevant to their conservation goals. However, users can also read through the entire toolkit as each section builds upon the next for a more comprehensive overview of climate change and landscape connectivity considerations.

Throughout the sections, users will find **KEY RESOURCES** which provide links and brief annotations that will direct to websites, tools, journal publications, and other resources for more information. Sections may also contain CASE STUDIES which will take the user to websites or reports that provide a deeper dive into on-the-ground examples. In addition, many sections also contain **Key Strategies** which identify broad management strategies that can be implemented to more fully incorporate climate change considerations into connectivity initiatives. All the sections begin with general background information and the subsequent lists are designed to help managers quickly find detailed information as they need it.

WHAT IS CONNECTIVITY

KIMBERLY TENGGARDJAJA, CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE

Biodiversity is critical for human health, economies, and livelihoods. Not only is loss of biodiversity one of the most likely environmental risks for the next decade, but it also is considered one of the most impactful in terms of severity (World Economic Forum 2020). Among the top threats to biodiversity are habitat loss, fragmentation, and degradation. Connectivity, "the degree to which the landscape facilitates or impedes movement among resource patches" (Taylor et al. 1993), is key to addressing these major threats to biodiversity. Connectivity involves both structural and functional components. Structural connectivity is the physical relationship between patches of habitat, while functional connectivity is the degree to which landscapes facilitate or impede the movement of organisms and processes (Ament et al. 2014). Though sometimes used synonymously with connectivity, a corridor refers to a distinct component of the landscape that provides connectivity (Ament et al. 2014). Typically, efforts to increase connectivity are referring to functional connectivity. For instance, conservation of corridors links areas of crucial habitat and facilitates wildlife movement. Increasing connectivity is one of the most frequently recommended climate adaptation strategies for biodiversity management (Heller and Zavaleta 2009). Without connectivity, ecological processes, such as nutrient flow, pollination, gene flow, and predator-prey relationships, cannot occur. In acting as the primary stewards for fish and wildlife and their habitats, state fish and wildlife agencies face the task of determining how to manage natural resources for connectivity.

DEFINING LANDSCAPE CONNECTIVITY

Note that we use the term **'landscape connectivity'** to encompass both land- and water-scapes. As defined, landscape connectivity is "the degree to which the landscape facilitates or impedes movement among resource patches" (Taylor et al. 1993), to which resource patches, both terrestrial and aquatic may be considered. This allows us to take a broader view of the heterogenous matrix and employ strategies that serve terrestrial, aquatic, or both systems, along with the species that inhabit or traverse them. Related, we also use the term **'habitat connectivity'** to further narrow the discussion to the functional degree to which the landscape facilitates or impedes movement of a species or suite of species associated with a particular habitat matrix. Again, we use the term 'landscape' in the broadest sense, encompassing both terrestrial and aquatic systems.

There are some general considerations that come into play when managing for connectivity. Typically, efforts to increase connectivity will include conserving areas that are known to facilitate movement, removing features that prevent movement (i.e., barriers), or a combination of the two. Additionally, it is important for managers to consider the spatial scale at which they would like to address connectivity issues. At smaller spatial scales, projects may be species-specific, focusing only on a movement function as it relates to a species' particular needs, whereas projects at larger spatial scales may focus on the integrity and continuity of features across a landscape (Ament et al. 2014). Finally, because connectivity issues frequently cross jurisdictions and sectors, collaboration is key in securing connectivity across a landscape.

Climate change represents another major consideration that managers must account for in connectivity initiatives. Climate change may impact both the quality and distribution of habitat. As such, it may not be sufficient to design a connectivity initiative based on current land cover patterns and habitat conditions. To account for wildlife being able to adapt and adjust and to move in response to environmental change, it may be necessary to predict areas that would support wildlife movement under future conditions and how those may facilitate movement to refugia habitats. A number of models exist that can simulate climate conditions and guide managers in designing connectivity initiatives, but it is worth noting that species with limited dispersal ability may not be able to move in response to climate change and consequently would need to adapt in place. Climate change already has started and will continue to drive changes in species assemblages, as species leave and move into new habitats.

KEY RESOURCES

Wildlife Connectivity: Fundamentals for Conservation Action. Center for Large Landscape Conservation. Ament et al. 2014.

Great resource with case studies and comparison of modeling techniques.

The Role of Landscape Connectivity in Planning and Implementing Conservation and Restoration Priorities. Rudnick et. al. 2012.

This article provides an overview of the basic concepts of landscape connectivity, the effects of fragmentation, practices on how to measure, analyze, and design landscape connectivity, modeling approaches, and recognizing and addressing uncertainties. Multiple case studies are included.

Habitat Corridors and Landscape Connectivity: Clarifying the Terminology. Center for Large Landscape Conservation.

Resource for terminology with references.

Conservation Corridor.

Provides up-to-date findings from science that will inform applied conservation. It highlights new innovations in applied conservation, with the goal of guiding the direction of applied science toward management needs. The mission is "… to bridge the science and practice of conservation corridors and connectivity."

Corridor FAQ: https://conservationcorridor.org/the-science-of-corridors/

Connectivity Toolbox: https://conservationcorridor.org/corridor-toolbox/programs-and-tools/

Wildlife Corridor fast facts. National Wildlife Federation.

Brief overview of wildlife corridors with multiple examples of species and locations.

Flowing Forward: Freshwater ecosystem adaptation to climate change in water resources management and biodiversity conservation. Publication by Water Partnership Program and WWF.

This report provides an overview of climate change impacts to freshwater systems, a framework for managing adaptation in freshwater systems, and recommendations for operational integration.

Climate change, aquatic ecosystems, and fishes in the Rocky Mountain West: implications and alternatives for management. Forest Service publication.

Great table of management options, including connectivity, on page 19.

Planning for connectivity. Ament et al. 2015.

This guide focuses on requirements established under the National Forest System land management planning rule to manage for ecological connectivity on national forest lands and facilitate connectivity on planning across land ownerships. Good overview of aquatic connectivity starts on page 16.

Best management practices for wildlife corridors. Beier et al. 2008.

Brief providing best management practices for wildlife corridors, with attention to roads, canals, railroads crossing corridors. It also includes best management practices for streams in corridors and practices for urban development in corridors.

CASE STUDIES

Florida Wildlife Corridor.

Good state corridors example. “The Florida Wildlife Corridor organization champions the public and partner support needed to permanently connect, protect and restore the Florida Wildlife Corridor – a statewide network of lands and waters that supports wildlife and people.”

CLIMATE CHANGE AND CONNECTIVITY

BETH STYS, FLORIDA FISH AND WILDLIFE CONSERVATIO COMMISSION AND TODD JONES-FARRAND, US FISH AND WILDLIFE SERVICE

Many terrestrial, freshwater, and marine species have already begun to shift their geographic ranges, seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change. These shifts will continue as species, habitat, and socio-ecological systems are impacted by the increasing effects of a changing climate. A large percentage of both terrestrial and freshwater species face increased extinction risk under projected climate change during and beyond the 21st century, especially as climate change interacts with other stressors, such as habitat modification, over-exploitation, pollution, invasive species, and barriers to migration or other impediments to life cycles. Due to the extent of sea level rise projected throughout the 21st century and beyond, coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion. Within this century, the magnitudes and rates of climate change associated with greenhouse gas emissions under medium-emission to high-emission scenarios pose high risk of abrupt and irreversible regional-scale change in the composition, structure, and function of terrestrial and freshwater ecosystems.

The spatial and temporal scales that climate change operates on present an unprecedented challenge for fish and wildlife agencies. Typically, these agencies operate within defined political boundaries and on 1 to 15-year planning cycles. Addressing climate impacts requires us to work in concert with organizations outside our boundaries, jurisdictions, and disciplines, and plan actions with an eye on long-term implications. Maintaining or re-establishing connectivity is frequently discussed as a reasonable approach for addressing climate impacts on species sustainability because it can allow animal and plant species to respond to changes when they need to and at their own pace (recognizing that some species may need help more immediately through assisted migration or other approaches). This approach also can be useful in dealing with the uncertainties surrounding species response to climate stressors. Given the complexity of ecological systems and species, we may never know what gradient (temperature, moisture, food availability, competition, predation) each species will respond to first. Providing quality habitats and connections between them offers a potentially efficient approach to conserving a maximum amount of biodiversity and is consistent with the words of Antoine de Saint Exupéry (paraphrased) – *our task is not so much to foresee the future as to make it possible*. On the flip side, however, climate impacts may compromise connectivity. In this section, we examine how climate impacts may negatively affect the ability to maintain a connected network of lands and waters.

CHALLENGES OF ADAPTING TO CLIMATE CHANGE IN FRAGMENTED LANDSCAPES

Habitat loss, fragmentation, and degradation are the most pervasive threats to biodiversity with human caused habitat fragmentation the greatest of these threats. Fragmented habitats and human land uses hinder movement of species, further reducing their ability to shift their distributions in response to climate change. The ability of plant and animal species to retreat in response to rising waters (both sea level rise and flood events) will be affected by barriers preventing their retreat, including human-made structures, such as buildings, bulkheads, roadways, dams, and other obstructions. Additionally, human-made ecosystem alterations, either those already existing or those put in place in response to effects from climate change, may lead to increased habitat loss, degradation, and fragmentation. For example, the use of hardened shoreline stabilization measures coupled with more intense storms could lead barrier islands (and their habitats) to fragment and disappear. The effects of roads as barriers altering natural hydrology will be exacerbated by changes in the amount of precipitation and large storm events. If precipitation patterns shift to fewer rainfall events but with larger amounts of rainfall, existing transportation infrastructure, such as bridges and culverts, and water infrastructure such as dams may not be sufficient to accommodate the increased flow.

CLIMATE RELATED CHANGES THAT MAY IMPACT CONNECTIVITY

TEMPERATURE

MAUREEN MILLMANN, WISCONSIN DEPARTMENT OF NATURAL RESOURCES

Current climate studies indicate an increase in air temperature over time. Increases in air temperature may result in changes to seasonal timing, such as an earlier start of spring and summer, as well as a later start to fall and winter. These seasonal changes will impact when and where species will be able to find food or the location of their breeding grounds. Seasonal migrations will be disrupted. For many species, connectivity is vital to breeding habitat and available food. Hotter summers may shift habitat and species north in the northern hemisphere, or to higher elevations in mountainous areas. More frequent freeze-thaw cycles will result in icy conditions making it difficult for many species to forage for food.

Increase in air temperature, as well as frequent droughts may lead to an increase in water temperature in cold water and warm water streams. Changes will result in species seeking cooler areas, if they are available. For example, roads with culverts and bridges that do not allow for a natural stream bottom may become more of a barrier to movement for aquatic species. Unnatural, non-erodible stream bottoms inhibit cool water refugia from forming and impede aquatic organism passage by causing culverts to become perched during low flow periods. Dams and other fish passage barriers also prohibit aquatic species from reaching cooler waters. Reservoir releases for maintaining downstream water temperatures become more challenging or impossible as the climate warms and reservoir operations cannot adapt.

KEY RESOURCES

US Global Change Research Program Climate Science Special Report (CSSR). Chapter 6: Temperature Changes in the United States. June 2017.

Chapter within the Fourth National Climate Assessment Vol. 1 covering key findings on temperature changes in the United States due to climate change.

Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road Stream Crossings. August 2008.

Provides information on road-stream crossing issues and how to better plan for changing systems.

PRECIPITATION

MAUREEN MILLMANN, WISCONSIN DEPARTMENT OF NATURAL RESOURCES

Precipitation is a significant outcome of increasing global temperatures. Not only the quantity of precipitation, but the timing of it during the seasons. Winters and springs that are excessively wet or dry could impact the flora of an area, which may impact fauna movement, breeding, and mortality. The following subsections provide greater detail in potential precipitation changes and how those may impact landscape connectivity: Drought, Flood, and Snowpack.

KEY RESOURCES

US Global Change Research Program Climate Science Special Report (CSSR). Chapter 7: Precipitation Change in the United States. June 2017.

Chapter within the Fourth National Climate Assessment Vol. 1 covering key findings on precipitation changes in the United States due to climate change.

DROUGHT (DECREASED, OR LESS FREQUENT PRECIPITATION)

Drought may be the result of decreased or less frequent than normal precipitation. Ecological responses to drought will vary depending on the frequency, duration, severity or intensity, and recurrence intervals of drought events. Drought can lead to degradation or loss of connectivity through a reduced matrix of suitable habitat as areas become drier. The ability of some species to navigate dry areas will be reduced, especially in already arid regions where water sources are already scarce. This can lead to individuals, groups, or populations of species to become isolated. Altered physical conditions of habitats may create barriers to species movement.

Drought can lead to dried up stream/riverbeds, removing or altering critical habitat components such as food sources or increasing water temperatures in smaller pools where some species may not be able to survive. It may also result in decreased water quality, due to the decrease in quantity of water. Drought followed by a precipitation event may cause increased erosion, sedimentation, turbidity, and siltation in aquatic systems, creating barriers to movement, including physical barriers.

Drought may decrease the size and quality of wetland habitat needed for migrating birds. Certain areas in the United States may see wetlands of increased salinity, which is poor habitat for migrating birds. The impacts of drought may be mitigated by planning for connectivity between habitats that may handle the changes in precipitation through time.

Drought may decrease the ability of resource managers to perform needed maintenance on protected lands and streams. The risk to property and personnel due to decreased ability to conduct prescribed burns may contribute to alterations to community structure or permeability to movement. Uncontrolled wildfires and changing fire-return intervals, as we have seen in recent years, may destroy habitat and force species that are able to escape into areas that may not be appropriate for their life cycle.

KEY RESOURCES

Climate poised to threaten hydrologic connectivity and endemic fishes in dryland streams. Jaeger et al. 2014.

Study demonstrating projected changes in southwest regional climate regimes and how these may input streamflow responses and the persistence of endemic fish.

Climate-Altered Wetlands Challenge Waterbird Use and Migratory Connectivity in Arid Landscapes. Haeg et al. 2019.

Examines multi-scale changes in arid landscapes that provide critical habitat for migratory waterbirds. Reduced hydroperiod and lower water quality likely will reduce chick survivorship.

FLOOD (INCREASED, OR MORE FREQUENT PRECIPITATION)

Flooding may be the result of increased precipitation, more frequent than normal precipitation, rise in sea level or a rise in groundwater elevations. Flooding can lead to degradation or loss of connectivity through a reduced matrix of suitable habitat as areas become saturated and/or flooded. The ability of some species to navigate wet or flooded areas will be reduced. This can lead to individuals, groups, or populations of species to become isolated. Altered physical conditions of habitats or increased infrastructure to handle flooding may create barriers to species movement.

Flooding and an increase in more frequent or destructive storms may result in scouring of stream/riverbeds, removing or altering critical habitat components (e.g., substrate type, woody debris, food source) that may serve as “stepping stones” for movement along the stream/river. Scouring and downcutting of perennial or ephemeral streambeds can result in deeper water tables and desertification of riparian and grassland areas along waterways. It may also result in decreased water quality, creating a barrier of inhospitable conditions, due to increased runoff from farm fields and paved areas carrying pollutants into the aquatic system. Increased erosion, sedimentation, turbidity, and siltation in aquatic systems, creating barriers to movement, including physical barriers.

Flooding may cause an introduction of predators into isolated wetlands, impacting amphibians and native fish where flooding or significant inundation can transport fish (predators/consumers of amphibians/eggs/young) into isolated wetlands. An increased dispersal or spread of invasive species may create physical barriers to movement and/or ecological barriers (e.g. presence of competitors or predators). There may be an increase in harmful algal blooms, creating inhospitable conditions for movement.

Flooding may decrease the ability of resource managers to perform needed maintenance on protected lands and streams, such as prescribed burns because of higher humidity and/or higher soil moisture. This decrease in maintenance may cause alterations to community structure and permeability to movement.

KEY RESOURCES

US Global Change Research Program Climate Change Special Report (CSSR). Chapter 8: Droughts, Floods, and Wildfire. June 2017.

Chapter in the Fourth National Climate Assessment Vol. 1 looking at anticipated projections in droughts, floods, and wildlife in the United States.

SNOWPACK

Decreased snowpack may have impacts similar to drought conditions. In undammed streams, spring flows will be reduced or absent. Decrease in soil moisture will impact flora, which impacts the fauna that rely on vegetation for food and cover. Stream depth may be decreased, which can change water temperatures and impact movement of fish and aquatic invertebrates, impacting reproduction. If snowpack is reduced, movement of species that can adapt and move may move to locations where habitat is more abundant or higher quality.

Increased snowpack, or heavy, wet, more frequent snowfalls may impact the movement of species who may not be able to traverse areas of deep snow or access forage. Increased snowpack may also lead to early spring floods, which will impact aquatic and terrestrial species in the form of flooding. Early spring green up following a receding snowline may result in shifts to migration patterns.

KEY RESOURCES

Northern forest winters have lost cold, snowy conditions that are important for ecosystems and human communities. Contosta et al. 2019.

Study looks at 100 years of data from Canada and the United States to assess how winter temperatures and snow cover have been changing and how these shifts may impact ecosystems and surrounding human communities.

SEA LEVEL RISE

BETH STYS, FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION

One of the most direct and pronounced changes due to climate change is sea level rise (SLR). Easily modeled and quantified at multiple scales, SLR is commonly used as a landscape level example of the consequences of climate change. SLR occurs as a result of thermal expansion of the oceans and melting of the polar ice caps and glaciers due to increasing global temperatures, which are especially pronounced in the higher latitudes. While SLR is not technically a climatic change itself (rather a result of major climatic changes), it is associated with specific measurable shifts that result in ecological impacts in much the same way as the other climatic changes. It is too simplistic to treat SLR as purely a habitat loss or inundation, as some land cover types may expand or shift up inland in the face of SLR. Some habitat and community shifts are likely to occur, especially with a more modest rise in sea levels. However, as the rate of SLR increases, open water will become more prominent as other habitats diminish.

Sea level rise (SLR) will have varying degrees of impact to the coastal areas of the United States, based on local conditions and contributing factors. Variables that will influence the type of changes and impacts include location, coastline complexity, elevation, habitat type, rate of subsidence and/or accretion, and the presence of barriers to inland migration. Barriers to inland migration of wildlife and the habitats they rely on include anthropogenic structures such as seawalls, dikes, and coastal development including transportation infrastructure, as well as natural biophysical factors such as soil type or available groundwater. These barriers may make it difficult or impossible for species and habitats to migrate inland with increasing sea levels.

Inundation by increasing sea levels will have variable impacts on ecosystems, depending on various factors including elevation, species' salt tolerance, inland migration pathways, and extent. Connectivity will be impacted as systems become more fragmented due to inundation or changes in vegetative communities. Sea level rise has the potential to eliminate critical resting grounds/stopover sites for migratory birds, and impact beach nesting habitats for birds and other species such as sea turtles, whose hatchlings are a food source for many coastal wildlife species. The decline of important intertidal habitat along critical flyways, reducing or eliminating key stopover sites, could greatly exacerbate wildlife population declines.

Other factors within ecosystems will be impacted due to SLR, such as salinity (both water and soil) and turbidity, altering the suitability of areas to serve as core habitat and corridors for some species. As sea level rises, coupled with increased storm intensity, the area impacted by storm surge will increase, further reducing, degrading, and fragmenting key coastal and coastal to inland corridors. Additionally, connectivity may be further impacted as people move further inland as they are displaced from coastal areas due to SLR, potentially causing more habitat loss and fragmentation.

KEY RESOURCES

Landscape connectivity losses due to sea level rise and land use change. Leonard et al. 2016. Animal Conservation.

Research on forecasting changing connectivity patterns based on predicted urbanization and sea level rise.

ALTERED DISTURBANCE REGIME

TODD JONES-FARRAND, US FISH AND WILDLIFE SERVICE

As with sea level rise, climate change can be expected to have direct and indirect impacts on connectivity through changes to natural disturbance regimes. Disturbance is a key ecological process for sustaining ecosystems and species. The historic frequency and extent of natural processes such as fire, insects, wind, and flooding have shaped the landscapes and ecosystems we have today. Changes in these regimes can push ecosystem states out of the historic range of variability and thus make them less suitable for native species and/or more suitable for invaders. These changes also can create barriers to connectivity by changing the course of rivers (via extreme flooding) or the composition of the landscape (via extreme fire or lack of fire) in ways that impose barriers to dispersal for some species.

Human activities to make landscapes more suitable for ourselves, such as fire suppression, flood control, and development, have already altered disturbance regimes. These changes have impacted connectivity by altering landscape permeability through changes in habitat condition and composition. Climatic pressures could exacerbate these changes by reducing the likelihood of the needed disturbance. On the other hand, climatic pressures may counter human activities and make them more costly for humans and biodiversity through changes in frequency, intensity, and extent. For example, increasing wildfire extent, severity, and frequency in the western U.S. and other parts of the globe are having massive ecological consequences. The combination of human and climate drivers creates feedback loops involving burn frequency and post-fire recovery rates. These feedback loops may produce tipping points that result in long-term shifts in some ecological systems (Tepley et al. 2018). Such ecological and structural shifts affect functional connectivity for many species.

Climate-driven changes in the frequency, intensity, and extent of natural processes will also impact our ability to manage landscapes for biodiversity. Although there may be instances where climatic pressures may actually assist restoration efforts, such as in the Missouri Ozarks where a hotter, drier climate will help open up forests to more historic woodland conditions, most changes are expected to hinder our ability to manage species. For example, suitability of weather for conducting prescribed burns is based in large part on temperature, relative humidity, wind speed, and fuel moisture (Kupfer et al. 2020 and references therein). As these elements undergo long-term shifts and increases in the number of extreme events due to climate change (Harris et al. 2018), managers may have reduced opportunities to conduct prescribed fires (i.e. reduced burn windows) in specific seasons as well as annually. In their work on collared lizards in Missouri, Brisson et al. (2003) provide an excellent example of how prescribed fire can increase habitat connectivity by documenting increased glade-to-glade dispersal after fire was returned to the forest matrix. As conditions for prescribed fires are reduced or shift into shoulder seasons not traditionally staffed to effectively conduct prescribed fires, the ability to keep habitat conditions in desired states becomes impaired and connectivity can be lost, as well as increasing the risk of wildfires in areas that are not prone to them now.

Other natural disturbance processes such as extreme weather events are expected to increase in frequency, intensity (or severity), or both. These trends are being observed now and are expected to continue (Harris et al. 2018). Extreme weather events such as windthrow, tornados, hurricane, ice storms and floods can degrade habitat to the point that it becomes temporarily or permanently unsuitable and/or impermeable for various species. If trends continue towards more frequent and/or more intense events, our ability to sustain habitat condition and connectivity, as well as societal benefits such as food and fiber production, will likely be compromised.

KEY RESOURCES

Influences of fire-vegetation feedbacks and post-fire recovery rates on forest landscape vulnerability to altered fire regimes. Tepley et al. 2018.

Peer-reviewed article discussing fire-vegetation feedbacks in forested landscapes.

Climate change projected to reduce prescribed burning opportunities in the south-eastern United States. Kupfer et al. 2019.

Peer-reviewed article which reviews how climate change impacts may shorten or otherwise reduce opportunities for management activities such as prescribed burning.

Biological responses to the press and pulse of climate trends and extreme events. Harris et al. 2018.

Peer-reviewed article which illustrates the biological responses to the climate press-pulse framework. It highlights the importance of adaptive management and possible consequences of non-intervention.

CASE STUDIES

Impact of fire management on the ecology of collared lizard (Crotaphytus collaris) populations living on the Ozark Plateau. Brisson et al. 2006.

PROJECT PLANNING

ADDRESSING UNCERTAINTY

Awareness that change is likely to happen is critical to planning. However, there is a high degree of uncertainty as to the extent and speed of climate change, as well as the ability of species, habitats, and ecosystems to adapt. Vulnerability assessments and scenario planning can both help reduce some of the uncertainties.

VULNERABILITY ASSESSMENTS

BETH STYS, FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION

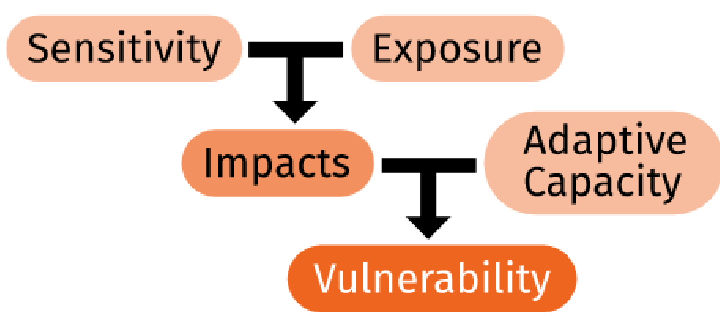
A critical step in analyzing the potential impacts of current and future climate change is the assessment of the vulnerabilities of species and natural communities. Although not designed to specifically assess connectivity, vulnerability assessments could be used to determine which areas of connectivity may be more vulnerable than others. Vulnerability assessments could be used to identify where existing corridors, as well as future corridors and key connections may be vulnerable to fragmentation, shifts in species composition, structural changes, and seasonal alterations that may impact their function. Through a vulnerability assessment, critical “pinch-points”/”bottlenecks” could be identified. Additionally, vulnerability assessments could reveal which areas critical for migratory species may be most likely to be impacted.

Determining the relative vulnerabilities of habitats, species, and systems can lead to the development of more effective management actions and adaptation strategies to enhance resiliency. Additionally, assessing vulnerability to climate change provides insight into which aspects of climate change may have the most impact on habitats, species, or systems.

Uncertainty of various types is an important factor to consider when implementing the results of a vulnerability assessment. For example, a high vulnerability to a particular threat, such as altered precipitation patterns, should be modulated by the relatively high uncertainty in precipitation projections relative to the more predictable change in temperature and sea level rise.

Vulnerability can be separated into three elements:

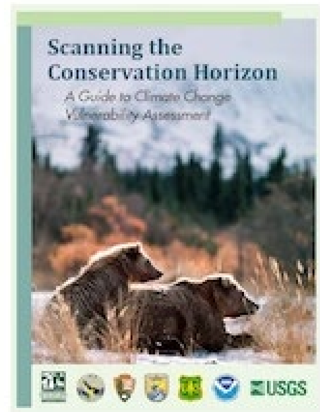
- **Exposure**: the degree to which a species or habitat is likely to experience climate change factors.
- **Sensitivity**: the degree to which a species or habitat is likely to be affected by climate change.
- **Adaptive capacity**: the degree to which a species or habitat can adapt to a changing environment.



Reducing vulnerability will involve decreasing exposure or sensitivity or enabling increased adaptive capacity.

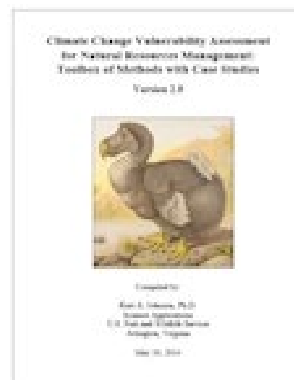
There are various tools designed to determine the relative and cumulative vulnerability of populations, species, or groups of species comprising a natural community, to stressors. Each tool focuses on different aspects of vulnerability, often leading to varied results for the same species. For some species it may be critical to assess vulnerability for various life stages.

KEY RESOURCES



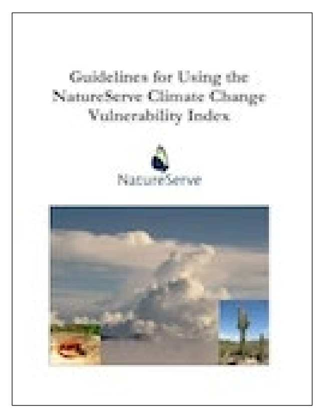
Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. Glick P, Stein BA, Edelson NA, editors. 2011. National Wildlife Foundation.

This is a broad document put together by the National Wildlife Federation and is intended to help fish and wildlife researchers and managers as well as other conservation practitioners recognize how vulnerability assessments can help them manage natural resources in an era of rapid climate change. The document offers guidance on developing and conducting vulnerability assessments in support of conservation and management missions and is a helpful tool when developing climate change adaptation strategies.



Climate change vulnerability assessment for natural resource management: Toolbox of methods with case studies. Johnson KA. 2014. Version 2.0. U.S. Fish and Wildlife Service.

This serves as a compilation of climate change vulnerability assessment methodologies and case studies. The methodologies include those for species, habitats, places, ecosystems, ecosystem services, watersheds, and water resources. This document was developed with intent to be a living document and updated with new vulnerability assessment methodologies.



NatureServe climate change vulnerability index (CCVI). NatureServe. Arlington, VA.

CCVI is a spreadsheet assessment method for estimating a plant or animal species' relative vulnerability to climate change. It combines readily accessible information on the natural history, distribution, and management with downscaled climate predictions from tools. After completion the results can be added to a national database to enable results to be accessible to the public.

Climate Adaptation Knowledge Exchange. EcoAdapt.

Provides over 100 case studies, documents, and tools on vulnerability assessments conducted worldwide. A keyword search on "vulnerability assessments" on the Resources page will return all resources type. More directed searches can be conducted by first selecting the resource type (document, case study, or tool). Also associated with the Cakex site is the Climate Registry for the Assessment of Vulnerability (CRAVe) (http://crave.cakex.org/).

Integrated Assessment of Healthy Watersheds. EPA.

Provides an overview of EPA's Conceptual framework, including guidance on developing a Healthy Watershed Index, attributes of watershed health, and attributes of vulnerability – with a link to Developing a Watershed Vulnerability Index.

CASE STUDIES

A climate change vulnerability assessment of California's terrestrial vegetation. Report prepared for the California Department of Fish and Wildlife. Thorne et al. 2016.

Climate change vulnerability reports for California species. California Department of Fish and Wildlife.

SCENARIO PLANNING

KATE MALPELI, USGS/NATIONAL CLIMATE ADAPTATION SCIENCE CENTER

While we know that the climate is changing, the exact nature, timing, and location of these changes and their impacts is uncertain. Our understanding of Earth's climate is incomplete, and as a result, the various climate models that are used to project future climate conditions are imprecise. These model projections are useful in that they produce plausible climate futures but knowing exactly which of these futures will unfold with 100% certainty in 5, 20, or 50 years is not possible.

Scenario planning is a structured yet flexible approach that can help managers make informed planning decisions, despite these uncertainties. Climate change scenarios are essentially plausible storylines about future climate conditions, developed using data on climate projections, and the potential impacts on ecosystems, infrastructure, and other resources. For example, two plausible scenarios for the same site may include "warmer temperatures with increased precipitation" and "warmer temperatures with decreased precipitation". Rather than focusing all planning efforts on preparing for what may be deemed the most likely scenario, scenario planning considers the full range of what is plausible, relevant, and highly consequential and helps managers prepare for each situation. Managers can also identify "no regrets" actions, or strategies that will be beneficial under all the plausible scenarios.

During a scenario planning exercise, managers work with experts to identify which resources are most vulnerable or sensitive to climate change and examine a range of plausible future climate scenarios for the area they manage. This information can then be used by managers to determine the best course of action for protecting key resources under each alternative scenario. While scenarios are not predictions, they do provide managers with a structured way to plan for a range of possible futures. In a connectivity context, a scenario planning exercise could involve (1) identifying priority linkages that are critical for maintaining connectivity; (2) incorporating information on plausible future climate scenarios into linkage modeling to assess how these linkages may change over time; (3) developing feasible management strategies for maintaining or increasing connectivity under multiple climate futures; and (4) highlighting the potential challenges and costs associated with protecting priority linkage sunder each scenario.

KEY RESOURCES

National Park Service Climate Change Scenario Showcase. National Park Service.

This website lists reports and publications related to NPS's climate change scenario planning efforts. While focused on scenario planning in national parks, the examples and guidance provided can be modified and implemented in other management units.

Scenario planning for climate change adaptation: A guidebook for resource managers. Moore et al. 2013.

This document provides a step-by-step guide to using scenarios to plan for climate change adaptation, including how to plan and carry out a scenario planning workshop. The guide is geared towards natural resource managers, planners, scientists, and other stakeholders working at a local or regional scale to develop resource management approaches that take future possible climate change impacts and other important uncertainties into account.

Considering multiple futures: Scenario planning to address uncertainty in natural resource conservation. US Fish and Wildlife Service. 2013.

This guide synthesizes scenario planning concepts and approaches for natural resource managers. It includes case studies demonstrating how natural resource professionals are using scenario planning to cope with uncertainty in the face of climate change.

Supporting adaptation decisions through scenario planning: Enabling the effective use of multiple methods. Star et al. 2016.

This paper draws on case studies from across the country to demonstrate how different methods for scenario planning have been implemented to support adaptation planning.

Planning for dynamic connectivity: Operationalizing robust decision-making and prioritization across landscapes experiencing climate and land-use change. Jennings et al. 2020.

This paper presents a framework that uses a scenario-based approach to consider how ecosystems, habitats, and species may need to adapt to future conditions.

Adaptation for Conservation (ACT) framework. Wildlife Conservation Society.

This framework for climate adaptation planning incorporates principles of scenario planning and other elements of natural resource planning into a process tailored for addressing climate change.

NatureServe Vista. NatureServe.

NatureServe Vista® is an extension to ArcGIS that supports complex assessment and planning and allows users to test different "what-if" scenarios. The tool helps managers and planners assess impacts on a variety of natural, cultural, and development objectives, and create options for sites, and entire landscapes and seascapes. The tool has been used to generate climate change mitigation and adaptation plans, among other uses.

PARTNERSHIPS

NATE MUENKS, MISSOURI DEPARTMENT OF CONSERVATION

Modern resource conservation is complex, presenting practitioners with a diversity of challenges, including conflicting interests and priorities, dissected networks of landholdings and jurisdictions, regulatory considerations, funding and resource limitations, varying degrees of societal acceptance and support, and a level of uncertainty in expected outcomes. Resulting from this complexity, especially when addressing landscape-level challenges such as climate adaptation, is the realization that success likely cannot be achieved by the actions of one individual or organization. Rather, identifying the opportunities to adequately address these challenges long-term typically requires collaboration through the formation of diverse partnerships.

When partnership building for a connectivity initiative, it is important to focus on a diversity of stakeholders since cross-boundary and cross-jurisdictional issues are inherent to landscape-scale conservation. Moreover, it will also be important to consider the longevity of the partnership over time. While many partnerships will disband after project completion, initiatives that integrate climate considerations will often need to sustain these partnerships long after the project is 'completed.' This is because adaptive management will be a principle tool in ensuring durable conservation outcomes even in the face of uncertainty.

Partnerships can also be a good tool for leveraging funding for connectivity initiatives given that most corridors will cross boundaries and jurisdictions. Grants, for example, can be a tool to shape regional connectivity efforts through the development and use of directed grant questions leading to projects that support regional priorities. Partnerships can also provide creative ways of leveraging one issue with another. For instance, the nexus with Greenhouse Gas (GHG)/Carbon Sequestration credits and climate action and resiliency strategies is one such important avenue. Research on local carbon sequestration can help recognize the need for and push forth development of local carbon credit programs instead of off-site, hard to monitor, monetary systems. These collaborations also hold the power to expand into new regulatory terrain and adapt into multijurisdictional climate challenge realms. Such collaborations also bring new audiences and useful tools including genetic research, frozen zoos/seed banks, and technological advances/expertise (such as remote sensing and drone use, etc.).

Partnerships have long been recognized as important to advance common objectives. Increasingly, the conservation community is recognizing the need for improved partnership, finding common ground, and pooling resources toward shared interests. The term "shared interests" does not imply uniformity among representation – a common flaw in networking and partnership building is the assumption that contributing members or partners should be like-minded and share similar values. In practice, this assumption may lead to overlooking critical pitfalls or opportunities, limit project vision, create distrust, hinder progress, and ultimately may kill the project. Alternatively, heterogeneity among partners involved, especially those with conflicting viewpoints, is recognized as an asset, enriching diversity in thought and approach and drawing strength from variation in beliefs and resources.

The following resources can be referenced to aid the formation of effective partnerships. Draw upon these resources to begin partnership building through recognition of mutual interests and development of shared vision, clear communication, trust, accountability, and the necessary tools to focus finite resources effectively and efficiently toward collective priorities.

KEY RESOURCES

Conservation Gateway. The Nature Conservancy.

The Nature Conservancy (TNC) worked with an extensive network of partners to create the *Conservation Gateway* to aid the conservation practitioner, scientist, and decision-maker in project planning, design, and implementation. Within the *Conservation Planning* section, they describe a ten-step process for creating effective partnerships.

Seven Principles for Effective Conservation Partnerships. Clematis-Hart and Marz. 2011.

Understanding the increased need for improved collaboration and partnerships, Hanna Clematis-Hart and Leigh Marz developed *Seven Principles for Effective Conservation Partnerships.* Within the document the authors describe seven core principles for successful conservation partnerships.

Connected Conservation webinar series. National Park Service.

Within this online resource, The National Park Service (NPS) introduces "Connected Conservation" through a series of webinars, which describe tools and case studies focused on the importance of creating connections with an extensive network of diverse partners and stakeholders.

Resource Library. Center for Large Landscape Conservation.

The Center for Large Landscape Conservation supports a variety of regional and international collaborations and professional networks, including the Network for Landscape Conservation, described below. The Center also offers a vast library with a variety of resources to advance landscape conservation through collaborative partnerships, including publications like *Facilitating Local Stakeholder Participation in Collaborative Landscape Conservation Planning*, by Catherine Doyle-Capitman and Daniel Decker.

Resource Library. Network for Landscape Conservation.

The Network for Landscape Conservation (NLC) offers a variety of resources, including a webinar series, case studies, and other informative and guidance resources focused on advancing landscape conservation and building partnerships through collaboration.

REGULATORY CONSIDERATIONS

ROB AMENT, CENTER FOR LARGE LANDSCAPE CONSERVATION AND RENEE CALLAHAN, ARC SOLUTIONS

Policies are being developed across the U.S. at the federal, tribal, state, and local levels to provide state agencies and bureaus the tools they need to protect wildlife movement and corridor habitat in the face of a changing climate.

The first significant policy statement on this issue was developed by the governors of 19 western states that in 2007 unanimously approved Policy Resolution 07-01, *Protecting Wildlife Corridors and Crucial Wildlife Habitat in the West*, under the umbrella of the Western Governors Association (WGA). The WGA resolution took a collaborative approach, seeking to work with federal agencies, industry, conservationists, and the Association of Fish and Wildlife Agencies. To implement the resolution, the WGA launched the *WGA Wildlife Corridors Initiative*. The *Initiative* included six working groups, including the Climate Change Working Group, which was charged with developing findings and recommendations on how climate change in the West would "increasingly . . . alter the functions and values of crucial habitats and wildlife corridors" (p.5).

This multi-state policy initiative was echoed in 2016 by the New England Governors and Eastern Canadian Premiers when they passed *Resolution 40-3: Resolution on Ecological Connectivity, Adaptation to Climate Change, and Biodiversity Conservation*. Among other things, the resolution "recognize[s] the importance of ecological connectivity for the adaptability and resilience of our region's ecosystems, biodiversity, and human communities in the face of climate change" (at 2), and identifies land protection, land planning transportation enhancement, and the sustainable management of land and aquatic systems "in order to maintain and improve connectivity" as areas for agency cooperation.

Since the passage of the WGA's Corridors initiative in 2007, federal, state, tribal, and local policies regarding the importance of improving or maintaining ecological connectivity as a way to ensure fish and wildlife are able to move to meet their daily needs as our climate changes have been evolving and expanding across the nation. The tools to create such policy include legislation; official memoranda by executives, legislators, or agencies; executive orders promulgated by federal agencies, tribal councils, governors, or other governmental leaders; and via interagency or intergovernmental cooperative agreements. Just a few examples of the use of these policy tools are:

- California Assembly Bill No. 498, *Wildlife Conservation*, encourages connectivity conservation on private lands by amending section 1930.5(c)(1) of the Fish and Game Code to state as follows: "It is the policy of the state to promote the voluntary protection of wildlife corridors and habitat strongholds in order to enhance the resiliency of wildlife and their habitats to climate change, protect biodiversity, and allow for the migration and movement of species by providing connectivity between habitat lands."
- Enacted in 2016, New Hampshire Senate Bill 376, *An Act Relative to Wildlife Corridors* made it the policy of the state of New Hampshire to encourage, wherever feasible and practical, voluntary steps to protect the functioning of wildlife corridors through various means. Among other things, the act recognizes the importance of creating "habitat strongholds," defined as "high-quality habitat that supports wildlife in being more resilient to increasing pressures on species due to climate change and land development."
- Oregon's House Bill 2834, *An Act Relating to Wildlife Corridors* was signed by the Governor in 2019. It states that "formally designating and protecting wildlife corridors is a crucial strategy for bolstering Oregon's ecosystem resiliency and for ensuring the long-term viability of wildlife population[s] and communities." The centerpiece of the act requires the Oregon Department of Fish and Wildlife to prepare a Wildlife Corridor Action Plan. In addition to identifying species of concern, known migration corridors, known and potential barriers to wildlife movement, the plan must also include a "description of the potential effects of climate change on the movement of species."
- In April 2018, the Blackfeet Tribe, located in Browning, Montana, published a *Climate Change Adaptation Plan*. The plan includes a goal to "maintain wildlife populations and habitat and limit disturbance in the face of changing climatic conditions" by "identifying and mapping key corridors and connectivity areas on and across the Blackfeet Nation." While tribes often have their own wildlife and natural resource agencies, as in the case of the Blackfeet, they also work frequently with state agencies. With readily available wildlife movement area information, states could actively and effectively engage with tribes to enhance their land management plans.
- Prepared in 2008 at the direction of U.S. Forest Service Chief Gail Kimball, the *U.S. Forest Service Strategic Framework for Responding to Climate Change* describes the "development of wildlife corridors to facilitate wildlife migration" as one of several "anticipatory actions intended to prevent serious disruptions due to changing climate." The Framework states "[e]cosystem health and resilience, productivity, biological diversity, and carbon storage are likely to decrease over large areas without direct intervention and management," such that the Forest Service should "assist private landowners and communities to voluntarily implement adaptation techniques on their lands, and…work collaboratively with other federal agencies and international partners." Further, the Framework emphasizes that "[m]aintaining ecosystem services while contributing to mitigation will require integrated, landscape-level and regional approaches to management across ownerships."
- In 2018, Secretary of the Interior Ryan Zinke signed Secretarial Order 3362 (SO 3362): *Improving Habitat Quality in Western Big-Game Winter Range and Migration Corridors*. Focused on the 11 Western states (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming), SO 3362 directs relevant federal bureaus to work with State, tribal, and territorial agencies to enhance and restore migration corridors and winter range habitat for big-game species such as elk, mule deer, and pronghorn antelope on federal lands. Among other things, the order directs the BLM, FWS, and NPS to "[e]valuate and appropriately apply site-specific management activities, as identified in State land use plans, site-specific plans, or the Action Plan . . . that conserve or restore habitat necessary to sustain local and regional big-game populations through measures that may include . . . utilizing other proven

actions necessary to conserve and/or restore the vital big-game winter range and migration corridors across the West." While these and other directives within SO 3362 do not expressly mention climate change, its focus on "proven actions necessary to conserve and/or restore the vital big-game winter range and migration corridors" could include climate-related projects aimed at conserving or restoring big-game terrestrial connectivity.

The preceding examples are just a small sample of the many legislative, executive and agency policies that aim to improve terrestrial and aquatic connectivity as species seek to adapt to a changing climate.

KEY RESOURCES

US Policies to conserve ecological connectivity since 2007. Center for Large Landscape Conservation.

Report summarizing state and federal wildlife corridor policy development.

Resource guide to Federal climate adaptation programs for state fish and wildlife agencies. Association of Fish and Wildlife Agencies. 2014.

Provides an overview of the various Federal climate adaptation programs.

Case Studies

Blackfeet Climate Change Adaptation Plan. Blackfeet Nation. 2018.

Wildlife Conservation: Wildlife Corridors. CA Assembly Bill 498. 2015.

Secretarial Order No. 3362: Improving Habitat Quality in Western Big-Game Winter Range and Migration Corridors. US Department of Interior. 2018.

Forest Service Strategic Framework for Responding to Climate Change, Version 1.0 US Forest Service. 2008.

Wildlife Corridors Initiative. Western Governors' Association. 2008.

FUNDING

ROB AMENT, CENTER FOR LARGE LANDSCAPE CONSERVATION AND RENEE CALLAHAN, ARC SOLUTIONS

A variety of public and private funding is potentially available to support climate-related considerations for projects aimed at maintaining or improving terrestrial or aquatic habitat connectivity.

At the federal level, states have long relied on a portion of federally-collected taxes from the *Federal Aid in Wildlife Restoration Act* (also known as the Pittman-Robertson Act) of 1937 and the *Federal Aid in Sport Fish Restoration Act* (commonly called the Dingell-Johnson Act) of 1950 to fund state wildlife agencies. Among other activities, these two acts authorize states to use these funds to support research, habitat acquisition, and fish, wildlife, and habitat restoration projects. Although not required, such projects may include climate-related considerations, where appropriate.

Other potential funding sources include long-standing federal initiatives, such as the *Land and Water Conservation Fund*, which supports conservation of federal lands and waters as well as voluntary conservation on private lands, and select *Farm Bill* programs, including the *Conservation Reserve Program*, *Wetlands Reserve Program*, and *Wildlife Habitat Incentive Program*, as well as funding available under the *Endangered Species Act* and *Clean Water Act*. Newer laws enacted in 2020, including the *Great American Outdoors Act* and *America's Conservation Enhancement Act*, also provide funding for an array of eligible projects that may include climate-related elements. Funding under the *Fixing America's Surface Transportation Act*, Public Law No. 114-94, 23 USC § 101 *et seq*. (2015), may also be used to fund highway infrastructure and mitigation measures related to maintaining or improving fish and wildlife habitat connectivity across roadways, while also potentially improving the resiliency of our nation's transportation infrastructure.

Annual federal budget appropriations are another potential source of funding. Among other things, annual appropriations support conservation activities and grant programs on federal and, in some cases, private lands. Recipients include federal agencies that manage land, such as the Department of Defense, Department of the Interior, and USDA Forest Service as well as regulatory agencies, such as the Environmental Protection Agency.

Two other well-known funding sources include State and Tribal Wildlife Grant programs administered by the U.S. Fish and Wildlife Service. The *State Wildlife Grant* program provides federal funds to State fish and wildlife agencies to develop and implement programs that benefit wildlife and their habitats, including species that are not hunted or fished. Funds may be used for conservation needs identified in the state's State Wildlife Action Plan (SWAP), including habitat loss and fragmentation and stress due to changing climatic conditions. The *Tribal Wildlife Grant* program has provided over $60 million to tribal conservation initiatives spearheaded by more than 300 tribes (USFWS 2015). Open to federally-recognized tribes, the goal of the program is "to provide a funding opportunity for tribal governments to develop and implement programs that benefit native species and their habitats, including those of cultural importance to Native Americans and those that are not hunted or fished" (USFWS 2015). Proposals should highlight where the proposed project will address one or more of the following FWS priorities, including Adaptation to Climate Change (USFWS 2015).

In addition to public funding, private philanthropic initiatives, such as the *National Fish and Wildlife Foundation* and the *Wildlife Conservation Society's Climate Adaptation Fund*, provide private funding to protect and conserve fish, wildlife, and their habitats, including climate-adaptive projects. Private funding sources can be significant: in 2019, Americans donated ~$450 billion to charitable endeavors (NPT 2019). Private funds have the added benefit of potentially qualifying as non-federal monies that can be used to "match" federal funds, a requirement of some federal programs.

KEY RESOURCES

Adaptation Clearinghouse. Georgetown Climate Center.

An online database and networking site that serves policymakers and others who are working to help communities adapt to climate change.

Fixing America's Surface Transportation (FAST) Act & Moving Ahead for Progress in the 21st Century (MAP-21), Synopsis of Wildlife Provisions. Ament R, Callahan R. 2015. Center for Large Landscape Conservation.

Provides a synopsis of the wildlife-related provisions in the FAST Act and MAP-21.

Wildlife Connectivity: Opportunities for State Legislation. Ament R, Callahan R, Maxwell L, Stonecipher G, Fairbank E, Breuer A. 2019. Center for Large Landscape Conservation.

This report covers connectivity more broadly, centering on how states may consider integrating connectivity into state-level legislation.

BIA Tribal Resilience Program. Bureau of Indian Affairs.

Provides resources spanning across Indian Country, to federally recognized Tribal Nations and Alaska Native Villages to build resilience through leadership engagement, delivery of data and tools, training, and tribal capacity building.

EPA Funding that Supports Climate Adaptation. Environmental Protection Agency.

EPA has modernized the financial assistance programs below to encourage climate-resilient investments. Each of these programs now incorporate specific criteria, allow for adaptation planning, or otherwise encourage communities to anticipate, plan for, and adapt to the changing climate.

"Federal Aid in Wildlife Restoration Act," 16 U.S.C § 669-669i & 50 CFR § 80.50.

"Federal Aid in Sport Fish Restoration Act," 16 U.S.C. 777, *et seq*. & 50 CFR § 80.51.

Investing in Wildlife: State Wildlife Funding Campaigns Summary of Findings. McKinney et al. 2005.

Report describing several innovative approaches that states have taken to secure funding for wildlife conservation programs and highlights key attributes of successful funding mechanisms.

National Fish and Wildlife Foundation.

Awards competitive grants through our programs to protect and conserve our nation's fish, wildlife, plants, and habitats. The Foundation works with public and private partners in all 50 states and U.S. territories to solve the most challenging conservation problems.

National Philanthropic Trust. 2019.

National Philanthropic Trust curates statistics from recent studies and reports on charitable giving in the U.S.

The State and Tribal Wildlife Grant Programs: 20 Years of Conservation Success. US Fish and Wildlife Service. 2020.

Compilation of case studies highlighting successful state and tribal wildlife grant program initiatives.

Summary of Projects Supported by the U.S. Fish and Wildlife Service Tribal Wildlife Grants Program (2007-2012). US Fish and Wildlife Service. 2015.

Summary report on a variety of projects funded through the Tribal Wildlife Grants Program.

Where Does Conservation Funding Come From? National Wildlife Federation.

Website hosted through the National Wildlife Federation that provides a concise summary of the variety of sources for conservation funding.

Climate Adaptation Fund. Wildlife Conservation Society.

Provides a total of $2.5 million in grant awards between $50,000 and $250,000 to conservation non-profit organizations each year in support of projects that implement science-driven, on-the-ground actions aimed at assisting wildlife and ecosystems in adapting to climate change at a landscape scale.

UNINTENDED CONSEQUENCES

MAGGIE ERNEST JOHNSON, ASSOCIATION OF FISH AND WILDLIFE AGENCIES

As with any conservation action, managers must weigh the potential risks or benefits of any connectivity initiative. While there are many benefits to facilitating movement of species, especially in light of climate change, there is also the risk of unwanted species dispersal or other deleterious factors. Invasive species, predators, human-wildlife conflict, or disease spread via corridors could present unintended consequences that undermine conservation goals.

The potential for novel species assemblages warrants attention. For example, native species may utilize corridors to enter previously unused habitat due to shifting climate and habitat envelopes, causing potential unknown consequences for that ecosystem. Careful consideration of these risks are required to prevent or mitigate any potential issues. For instance, ecosystem transformation, driven by increased wildfires is opening more moose-friendly habitat in Canada. As moose, and subsequently predators, move north into these expanded ranges, they threaten the survival of native caribou (Frenette et al. 2020). Managers will need to consider these possible new interactions and choose a course of action, whether that is to accept the novel species assemblages or not, and understand how a connectivity initiative may drive those changes. Some strategies for dealing with invasive species (native and non-native) can be found in many of the provided Key Strategies for Systems.

While it is important to note that the current literature suggests not every manager or researcher will run into such issues (Haddad et al. 2014), it nonetheless does not mean these possibilities should not be expected. Managers will need to consider possible consequences on a project-by-project basis to determine if the benefits of a corridor would indeed outweigh potential risks.

KEY RESOURCES

Corridor Concerns. Conservation Corridor.

Conservation Corridor provides up-to-date information, tools, and resources related to landscape connectivity. They have additional resources on corridor concerns, such as invasive species, predators, or disease spread from connectivity projects. There is also a table of articles related to these issues, identifying positive and negative conclusions.

Northeast Regional Invasive Species and Climate Change (RISCC) Management. Northeast Climate Adaptation Science Center.

The Northeast Regional Invasive Species and Climate Change (RISCC) Management team has a variety of original research and tools available to help managers consider invasive species movement and range shifts under climate change scenarios.

MODELING CONNECTIVITY

KATE MALPELI, USGS/NATIONAL CLIMATE ADAPTATION SCIENCE CENTER

The ability to model the connectedness of a landscape is important to understanding its resilience to climate change. A more connected landscape will be better able to maintain ecological functions and sustain diverse species. The ability to model how connectivity may be affected by changes in climate and land use, and the implications for the wildlife that utilize those connections, is an important element of informed habitat planning. A large suite of methods for modeling connectivity exist, each of which comes with its own set of assumptions, best practices, and outputs. The two main approaches to modeling connectivity are functional connectivity (i.e. species-specific connectivity) and structural connectivity (i.e. non-species-specific connectivity). Functional connectivity is focused on the ease with which a specific species can move across the landscape, whereas structural connectivity is a measure of the intactness of particular habitat types (e.g. open canopy forests, grassland, ephemeral wetlands, etc.) within the landscape as a whole. The most common approach for developing estimates of landscape connectivity is to create resistance surface. This type of approach models the degree to which landscape features impede or facilitate movement across a grid and is a relatively accessible method that does not require excessive data or computational power (Wade et al. 2015).

Traditionally, conservation strategies to promote habitat connectivity have focused on connecting patches of suitable habitat so that individuals can move within their current range. However, as the earth's climate warms, the need for climate-wise connectivity has been recognized, the aim of which is to connect areas of currently suitable habitat to areas of habitat that will be suitable in the future (Keeley et al., 2018). Incorporating climate information into connectivity modeling is particularly important for species whose habitat requirements are closely tied to certain climatic conditions (Costanza and Terando 2019). Several approaches for doing so have been developed in recent years. Having a clearly defined conservation goal can help managers select which method can best address their needs (Wade et al. 2015). Some approaches for considering climate change in connectivity planning involve linking climate model projections with habitat models for a species or group of species to assess potential future changes in functional connectivity at a fine scale, or to assess changes in structural connectivity at regional or national scales. Other approaches harness traditional connectivity design methods and consider, but aren't explicitly tied to, climate change objectives (Costanza and Terando 2019). Littlefield et al. (2019) divide these approaches into four categories: (1) those that use projected species range shifts; (2) those that use projections of future climate conditions and climate analogs to identify how and where climatic conditions will move across the landscape; (3) those that leverage existing environmental and climate gradients to map routes along which species might move; and (4) those that focus on linkages between similar geophysical features within a landscape.

It's important to recognize that incorporating climate information into connectivity modeling will typically require the availability of climate projection information at a higher resolution than what is available from the current generation of global climate models. Downscaling methods can provide such information, but it is imperative that practitioners have a clear understanding of the limitations of these data (Wade et al. 2015). The inherent uncertainties associated with projecting future changes in climate and land cover can lead to false precision regarding model outputs and overconfident decision making (Costanza and Terando 2019). Connectivity modelers often also lack the type of detailed data needed to understand the specific climatic factors that limit species' distributions (Littlefield et al. 2019). Another important consideration is the need to account for not only *where* habitats will change, but over what *timescale* these changes will occur. Explicitly accounting for the temporal impacts of climate change across a landscape can lead to more robust connectivity conservation strategies whose success are less sensitive to future outcomes (Costanza and Terando 2019).

KEY RESOURCES

Numerous tools, software programs, and resources exist to educate users on the basics of connectivity modeling, how to select a modeling approach, and best practices for carrying out a connectivity modeling project. A list of potentially useful guidance documents, primary literature, and tools and software are outlined below.

Pulling the Levers: A Guide to Modelling and Mapping Ecological Connectivity. Chernoff 2016.

This guide is a basic primer on connectivity modeling, geared towards those with little or no experience in connectivity modeling. The guide covers project scoping, identifying data inputs, running the model, refining model outputs, and how to use model results.

Resistance-surface-based wildlife conservation connectivity modeling: Summary of efforts in the United States and guide for practitioners. Wade et al. 2015.

This guide provides an overview of resistance-surface-based connectivity modeling for terrestrial wildlife conservation through a review of the literature on connectivity modeling efforts in the U.S. The guide also provides practitioners with guiding questions for constructing a robust, ecologically-sound, resistance-surface-based connectivity model.

New concepts, models, and assessments of climate-wise connectivity. Keeley et al. 2018.

Identifies and assesses 13 climate-wise connectivity approaches that seek to connect current habitat to habitat that will become suitable in the future. Guidance is provided on selecting the best methods for connectivity design depending on the objectives, available data, and landscape context. Table 2 in the paper lists the advantages and disadvantages of the 13 approaches, including riparian corridors, carbon corridors, and environmental gradients.

Landscape Connectivity Planning for Adaptation to Future Climate and Land-Use Change. Costanza and Terando. 2019.

Examined recent advances in the literature on approaches for modeling, maintaining, and enhancing connectivity under future climate and land-use change. A framework is also provided that can help users select an appropriate approach for modeling corridor networks under climate and land-use change.

Connectivity for species on the move: supporting climate-driven range shifts. Littlefield et al. 2019.

Reviewed a suite of connectivity modeling approaches that address the challenges posed by climate change, to identify how these approaches incorporate species' responses, identify movement routes, and address uncertainties.

Connectivity planning to address climate change. Nunez et al. 2013.

Delineated corridors based on species' movement in response to changing temperatures in the Pacific Northwest. The modeling approach connects areas with currently suitable temperatures for focal species, to areas that may have suitable temperatures for those species in the future.

TOOLS (TERRESTRIAL)

Circuitscape.

Circuitscape is a widely used, free, and open-source software package that uses electronic circuit theory to predict ecological connectivity. The software, which can be run from a stand-alone interface or from ArcGIS, allows users to analyze ecological flow by assessing landscape permeability. It includes the ability to connect climate analogs and climate gradients. The site is home to Omniscape, which uses a moving-window approach to predict connectivity.

ResistanceGA R Package.

This package provides a framework for optimizing resistance surfaces without requiring a priori assumptions, which can be particularly useful in systems where the underlying ecological processes are poorly understood.

Linkage Mapper.

A set of ArcGIS tools that use least-cost corridor analysis, circuit theory, and barrier analysis to map and prioritize wildlife habitat corridors. It includes a "Climate Linkage Mapper" tool which optimizes the route of linkages to minimize the climate gradient traversed, and the "Linkage Priority" tool which estimates the priority of each linkage based on a set of weighted considerations, including climate change.

Conefor.

An open-source software package that enables the importance of habitat areas and links for connectivity to be quantified and can be used to evaluate the impacts of landscape changes to connectivity.

TNC Resilient Land Mapping Tool.

This tool defines resilient and connected lands across the continental U.S. by providing scores for climate change resilience, landscape connectedness, and landscape diversity for points and areas at a town-parcel scale. Users can upload a polygon of interest to get resilience scores for that area. As part of this effort, a metric was developed to measure local connectedness based on the presence of structures that impair connections between natural ecosystems within a landscape. The metric measures permeability based on the level of similarity between adjacent cells and is a resistance-surface approach for understanding the level of access a species has to the microclimates within its neighborhood. This metric was integrated with information on landscape diversity to develop resiliency scores. Details on how the local connectedness metric was calculated can be found in Anderson et al. 2016.

TOOLS (AQUATIC)

Barrier Analysis Tool (BAT).

An ArcGIS plug-in that calculates functional river networks, counts the upstream and downstream barriers, the total length of all upstream networks, and the distance to river mouth.

Dendritic Connectivity Index.

Quantifies longitudinal connectivity (the connections between upstream and downstream sections of a river network), based on the probability of an organism being able to move freely between two random points of the network. This approach can help managers characterize watersheds, determine priorities for restoration, and optimize resource allocation and infrastructure plans.

Additional programs and tools that support connectivity modeling can be found at conservationcorridor.org.

WHAT MAKES A STRATEGY/ACTION 'CLIMATE SMART'?

WHITNEY ALBRIGHT, CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE

Conservation practices are focused on protecting and preserving biodiversity and ecological function, protecting species, and maintaining the habitats upon which they depend, and enhancing ecosystem services. To successfully conserve biodiversity, resource managers must account for a myriad of anthropogenic and natural threats that may affect the efficacy of their actions and the appropriateness of their goals and strategies. As such, many existing or traditional conservation activities already aim to increase resilience of the landscape over time to a multitude of risks. So how is planning for climate change any different? And how do climate-related risks affect conservation planning and action?

Climate-smart conservation is defined in Stein et al. 2014 as "the intentional and deliberate consideration of climate change in natural resource management, realized through adopting forward-looking goals and explicitly linking strategies to key climate impacts and vulnerabilities." At its core, climate-smart conservation requires a holistic approach to conservation, thinking beyond jurisdictional boundaries and considering the broader landscape context, while actively managing for change, not just persistence (Stein et al. 2014).

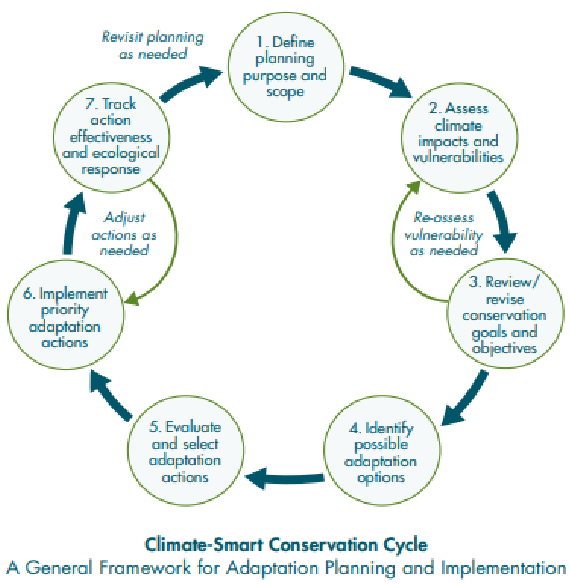


Figure 1. The Climate-Smart Conservation Cycle (Stein et al. 2014)

Climate change projections and observed or expected impacts should be considered at multiple points within the conservation planning process, as reflected in Figure 1 from Stein et al. 2014. A good first step is to identify the climatic variables (e.g. temperature, precipitation, sea-level rise, streamflow, etc.) that strongly affect your site or resource and then locate climate model projections of how this suite of variables may change compared to local historical trends over time under a range of future climate scenarios (see section on Addressing Uncertainty – Scenario Planning). Once you have identified pertinent climatic and hydrologic changes that are projected to occur, it will be necessary to determine how those changes will affect your resources (see section on Addressing Uncertainty – Vulnerability Assessment) and their management. Armed with this information, conservation practitioners and natural resource managers can craft appropriate strategies and actions that are designed to address climate impacts, robust to uncertainty, and have the greatest likelihood of enhancing resilience and supporting successful adaptation. "Most adaptation actions will draw from existing conservation techniques, but may differ in when, where, and why they are applied" (Stein et al. 2014), and in some cases, the "what" will need to be modified as well (Cross et al. 2018).

In the climate-smart conservation cycle, climate considerations are not only used to identify strategies and on-the-ground actions but should inform long-term project and conservation goal setting. Managers should embrace forward-looking goals wherever possible and avoid basing decisions solely on historical conditions; this concept can be applied to new goals and existing goals that may need to be re-evaluated in light of ongoing climatic and environmental change. Due to the dynamic nature of climate change, and the heterogeneous manifestation of climate impacts on the landscape, adaptive management must also be employed. Monitoring plays a more important role than ever before, by providing the opportunity to detect climate impacts to the effectiveness of adaptation actions and signaling when activities or goals must be adjusted accordingly (see 'Track action effectiveness and ecological response' in the conservation cycle).

WHAT DOES CLIMATE-SMART CONSERVATION LOOK LIKE IN THE CONTEXT OF CONNECTIVITY PLANNING?

Business-as-usual connectivity planning might include identifying and protecting known wildlife corridors between existing or historical habitat. Climate-smart connectivity planning will inject climate change-related considerations throughout the planning process to help evaluate whether existing linkages will continue to be effective, and if not, where connectivity should be enhanced to support species migrations and movement across the landscape in response to climate change and other landscape stressors. Projected species range shifts, potential habitat degradation under future climate scenarios, and potential habitat transitions are all climate-driven factors that will need to be taken into consideration in connectivity planning exercises, as new connections may be needed to link existing habitat to future habitat and areas of refugia (Carroll et al. 2018; Krosby et al. 2018; see Modeling Connectivity). In a nutshell, "Climate-wise connectivity focuses on maintaining and restoring resilient landscapes to facilitate species movement required for future range shifts…" (Keeley et al. 2018).

As noted above, climate-smart conservation also includes reevaluating past and existing goals to determine if they can realistically be met or whether new goals should be created. In many instances, creating new linkages and enhancing connectivity may not be feasible. Managers will have to determine how best to adjust existing conservation goals based on what can be achieved by current levels of landscape and habitat connectivity and considering projected impacts to species distributions and assemblages. The next section provides additional examples of how we can modify existing practices and determine new actions that may be needed to achieve climate-smart conservation.

A NOTE ON RESILIENCE & ECOLOGICAL TRANSFORMATION

The term 'resilience' has become a buzzword in recent years, but it does have a specific meaning in ecology. Resilience refers to a system's ability to bounce back to a long-standing historical condition (Hollings 1973). However, returning to previous conditions may be impossible when climate change and related ecological responses may cause a system to transition to something different than seen historically. Managers should consider a full range of options, from resisting the change, to accepting the change, or even directing the change towards a desired outcome (Millar et al. 2007; Lawler 2009; Schuurman et al. 2020). These are important concepts to consider for landscape connectivity because under a changing climate, managers may need to decide what habitats/species assemblages or future habitats/potential species assemblages they are trying to connect.

KEY RESOURCES

Climate Smart Conservation: Putting Adaptation into Practice. Stein BA, Glick P, Edelson N, Staudt A, editors. 2014. National Wildlife Federation.

The goal of this guide is to aid policy makers and practitioners in recognizing, designing, and employing good climate-smart conservation strategies and goals. It offers strategies for carrying out conservation in a rapidly changing climate.

Embracing Change: Adapting Conservation Approaches to Address a Changing Climate**.** Cross M, Rowland E, Tully E, Oakes L, Long D. 2018. Wildlife Conservation Society.

Address a Changing Climate. Wildlife Conservation Society. New York, NY. The goal of this report is to help conservationists learn how to move beyond business-as-usual conservation approaches and make their work climate informed. Twelve real-world examples of how conservation practitioners around the United States are modifying their approaches to support the capacity of wildlife and ecosystems to adapt to a changing climate.

ADAPTATION STRATEGIES

MAGGIE ERNEST JOHNSON, ASSOCIATION OF FISH AND WILDLIFE AGENCIES

There are a variety of strategies that may be employed to help ensure any landscape connectivity initiatives taken incorporate climate change considerations. With any action, there are advantages and disadvantages (see Table 1 from Keely et al. 2018) so managers should carefully contemplate what their goals for target species or habitats may be and how these strategies can more effectively provide resilience or adaptation into the system. In this section we review relevant adaptation strategies for landscape connectivity initiatives as they might relate to goals of protection, restoration and management, outreach and education, or evaluation and monitoring.

Strategy	Advantages	Disadvantages
Increasing the amount of habitat throughout the landscape	Increases speed of range shifts in fragmented landscapes; benefits most species	
Concentrating habitat in few, large areas	Increases species persistence for some species	Slows speed of range shifts
Adding corridors between natural or protected areas	Increases speed of range shifts in fragmented landscapes	Trade-off with increasing protected area system; most effective for species with medium dispersal capabilities in moderately fragmented landscapes with lower climate velocity
Creating small stepping stones embedded in the matrix	Increases speed of range shifts in fragmented landscapes	Benefits few species
Increasing the size of existing protected areas	Increases species persistence; improves temporal connectivity for some species	
Improving the permeability of the matrix	Increases speed of range shifts in fragmented landscapes; benefits many species	Unlikely to serve specialist species unless significant habitat restoration is undertaken
Maintaining naturally isolated habitats at a density that permits exchange between habitats	Enables dispersal; ensures species persistence; creates genetic refugia	

Table 1. Advantages and disadvantages of strategies to improve climate-wise connectivity. (Keeley et al. 2018)

PROTECTION

Protecting aquatic and terrestrial corridors has become a major tool in the conservation toolbox. Through the lens of climate change, however, corridor protection takes on additional importance as a means of providing opportunities for range shifts or navigation to climate refugia. Climate-smart corridors, therefore, consider not only where species are moving in the landscape now, but where they may shift their movements to in the future. Considering corridor protection strategies in a changing climate requires managers to consider where, why, and how they pursue protection for future conditions. For example, a coastal corridor may facilitate current species movement, but given sea level rise and storm surge predictions, a network of corridors from the coast to inland habitats may be a better use of time and money in safeguarding future species populations and movement.

Key Strategies

- Use GIS and other tools to identify important and potentially resilient areas that represent multiple habitat types to ensure that a variety of these habitats are included in land protection planning
- Identify and protect areas that are naturally positioned to be more resistant/resilient to climate change to serve as refugia and provide opportunities for range shifts.
- Include ecologically significant areas such as breeding/nesting sites, wintering sites, and areas of high species diversity that will continue to serve these functions under climate change, including changes in hydrology.
- Riparian corridors should be included in most connectivity plans because of their importance as natural movement corridors, climate gradients, and refugia.
- Develop wide corridors (> 1 km) as they are more functional than narrow corridors because they tend to offer more diverse microclimates and provide live-in habitat for slow dispersers.
- Establish protections for transitional habitats that will provide for range shifts and serve as potential climate refugia, allowing shift in community composition where appropriate.
- Protect buffer zones to allow for future system shifts/migration through easements, acquisition, or purchase of development rights.
- Identify and prioritize protection of corridors between forested wetland areas and associated upland habitats to enhance species movement and migration.
- Identify and prioritize barriers to species movement and migration (such as roads, fences, dams, or energy infrastructure) for removal or remediation.
- Provide landowners and stakeholder groups with incentives for conservation and restoration of key corridors that will provide connectivity under current and future conditions.

KEY RESOURCES

Habitat Priority Planner (HPP). Land Trust Alliance.

The Habitat Priority Planner (HPP) is a geographic information system (GIS) tool for identifying and prioritizing areas for conservation, restoration, and land use planning. The tool can be used in conjunction with climate change data to assess potential impacts on fragmentation/connectivity and prioritize areas for conservation based on those impacts.

U.S. Climate Resilience Toolkit.

Provides a catalog of more than 200 digital tools that can help you take steps to build resilience, from engaging a community to developing a climate action plan.

Identifying riparian climate corridors to inform climate adaptation planning. Krosby et al. 2018.

Published journal article describing a project that completed a novel analysis across the Pacific Northwest, USA, that identifies potential riparian corridors featuring characteristics expected to enhance their ability to facilitate range shifts and provide refugia.

Preserving connectivity under climate and land-use change: No one-size-fits-all approach for focal species in similar habitats. Costanza et al. 2020.

RESTORATION AND MANAGEMENT

In addition to protection, restoration, and management offer managers the ability to maintain and/or increase connectivity to facilitate species adaptations to future climate conditions. For instance, replacing undersized culverts restores habitat quality and aquatic connectivity. This may enable cold water species to find deeper, cooler refugia as many streams are becoming too warm or are too shallow to support these species. In addition, larger culverts or bridges will accommodate future flow conditions, critical to areas where increased precipitation and storm events have significantly altered historical flows and may provide bonus connectivity opportunities such as terrestrial species passage when not inundated. Other restoration activities may include actions such as migration barrier removals (i.e. dams), assisted migration, or translocations, as appropriate. Management actions often align with current conservation best practices, with the difference being an emphasis on proactive management (i.e. planning for future conditions rather than current or historical baselines).

Key Strategies

- Select native plant species for restoration efforts that are expected to be better adapted to future climate conditions.
- Consider assisted migration or translocations for species, where appropriate, along corridors.
- Restore hydrologic connections, implementing designs that will accommodate both increased and decreased flow.
- Replace culverts with those designed to accommodate future flow conditions and allow for fish and wildlife passage.
- Remove or remediate migration barriers such as dams or fences to accommodate future flow conditions or migration corridors to allow for fish and wildlife passage.
- Review and revise techniques to maintain or mimic natural disturbance regimes (e.g., what techniques should be used when prescribed fire is no longer feasible).
- Remove existing non-native species, where appropriate. Plan for anticipated native species range shifts into new habitats. This may mean preparing for novel species assemblages, trying to remove the species, or to manage the ecosystem to either encourage/discourage the anticipated arrival.
- Plan wetland or other mitigation banking, reforestation, or other carbon sequestration techniques deliberately to favor connectivity

KEY RESOURCES

Eco-Logical. Federal Highways Administration.

Eco-Logical is a program developed by the Federal Highways Administration. It organizes current methods for addressing natural resource identification, avoidance, minimization and mitigation into a systematic, step-wise process that starts at the beginning of the transportation planning process and concludes with establishing programmatic approaches to recurring natural resource issues that are implemented at the project level. It is useful for developing advance mitigation strategies for ecosystem priorities where offsetting unavoidable impacts of infrastructure projects is necessary.

Climate-Friendly Stream Crossings toolkit. North Atlantic Aquatic Connectivity Collaborative.

You will find in this toolkit a compilation of resources and tools spanning a range of topics, developed by many different organizations working to improve road-stream crossings. These resources are intended to be used at a variety of scales – from small watershed to state or even regional – and by a variety of organizations, including watershed groups, conservation organizations, universities, and natural resource and transportation departments.

The toolkit is organized in a sequential order in terms of key steps for addressing aquatic connectivity through infrastructure redesign.

OpenNSPECT. Nonpoint Source Pollution and Erosion Comparison Tool. NOAA.

This open-source version of the Nonpoint Source Pollution and Erosion Comparison Tool is used to investigate potential water quality impacts from climate change and development to other land uses. The downloadable tool is designed to be broadly applicable for coastal and non-coastal areas alike. Tool functions simulate erosion, pollution, and the accumulation from overland flow.

FishXing.

This software is intended to assist engineers, hydrologists, and fish biologists in the evaluation and design of culverts for fish passage. It is free and available for download. FishXing 3 is a unique software tool for the assessment and design of culverts for fish passage. FishXing models the complexities of culvert hydraulics and fish performance for a variety of species and crossing configurations. The model has proven useful in identifying culverts that impede fish passage, leading to the removal of numerous barriers. As a design tool, FishXing accommodates the iterative process of designing a new culvert to provide passage for fish and other aquatic species.

Riparian areas and restoration in a time of climate change. Evans. 2017.

Overview of basic principles of corridors in riparian systems in Washington state and creating resilient areas as a climate adaptation strategy.

Tips for Reducing Pesticide Impacts on Wildlife. Environmental Protection Agency.

This Web page provides tips for pesticide users in residential and agricultural settings, as well as tips for certified pesticide applicators for ways to protect wildlife from potentially harmful effects of pesticides. You will also find links to some additional sources of information on wildlife and habitat protection.

National Invasive Species Council. US Department of Interior.

Website that provides information (and links) to various invasive species related content, including NISC Guidance Documents, Early Detection and Rapid Response, Technology Innovation, Wildland Fire and Invasives, Stories of Success and Stakeholder Engagement.

OUTREACH/EDUCATION

Successful connectivity efforts, like all successful conservation efforts, require public support and buy-in which cannot happen without dedicated outreach, engagement, and education efforts. Without such, connectivity initiatives can be misinterpreted by the public, leading to opposition. Early outreach, education, and engagement of local communities is imperative to ensure initiatives can move forward. This requires that local stakeholders understand the benefits of a connectivity initiative for native fish, wildlife, and habitats, but also for the communities themselves. Communities may benefit from ecosystem services such as improved water quality, more recreational opportunities via trails or parks, or by natural buffers to extreme weather events. Ensuring public support and cross-agency collaboration requires managers to prioritize outreach and education strategies to ensure initiative success.

Key Strategies

- Develop educational materials on the purpose of using existing and emerging tools for managing systems under climate change (e.g., landscape connectivity initiatives).
- Provide education and incentives for communities to reduce invasive plants and to choose native vegetation in favor of non-native vegetation. Promoting native vegetation on the landscape benefits connectivity and climate change goals by improving the quality of habitat (via enhanced water, air, or soil quality), by creating habitat, or by creating natural barriers or buffers to other climate-related impacts such as extreme weather.
- Promote and/or work with communities to integrate green infrastructure, such as stormwater runoff management, by making clear links to habitat, water, or air quality enhancements which are critical for landscape connectivity and climate change management goals.
- Actively engage with communities to minimize urban encroachment or edge effects along habitats. These might include noise and light pollution, domestic animal interactions with wildlife, recreational trails, or pesticide use, among others. It will be important to link these topics to corridor function, especially as some of these may shift in light of climate change impacts and responses.
- Develop focused outreach efforts and materials aimed at local communities that explain the benefits of management actions such as prescribed fire, invasive plant removal, and water body restoration activities (focusing on activities that may be highly visible and not always "acceptable"). Connect how these activities are important for climate adaptation for fish and wildlife, as well as how it benefits the broader landscape matrix.
- Develop focused outreach efforts and materials on the need to retain sensitive native plant populations or animal nursery and bedding sites near corridors that may elicit planned or unplanned recreational use. This is especially critical for populations being impacted by climate changes and/or using these sites as climate refugia.

KEY RESOURCES

CDFW Recreation Journal (Summer 2020). California Department of Fish and Wildlife.

Special issue of California's quarterly newsletter. This issue focuses on issues related to non-consumptive recreation on wildlife.

Certified Wildlife Habitat Program. National Wildlife Federation.

Information on how to/requirements toa develop NWF Certified Wildlife Habitat for homeowners, schools, and communities.

Prevent Stormwater Runoff Pollution. University of Arkansas, Cooperative Extension Service.

Provides a list of ten things everyone can do to prevent stormwater runoff pollution.

Corridor FAQ infographics. Conservation Corridor.

Provides accessible infographics around commonly asked or misunderstood aspects of habitat connectivity.

Fish and Wildlife Relevancy Roadmap. Association of Fish and Wildlife Agencies and Wildlife Management Institute.

This resource provides a high-level strategy on engaging with diverse constituents. It does not provide climate-specific outreach but may provide ideas on how your agency can do better outreach and education to local communities.

MONITORING & EVALUATION

Given the inherent uncertainties surrounding climate projections, future species movement patterns, and species adaptive capacity, monitoring and evaluation is imperative to successful climate-smart connectivity initiatives. Tracking how the target species are (or are not) utilizing corridors provides managers the opportunity to better understand species needs, their adaptive capacity, and whether similar connectivity initiatives should be replicated in other areas. There are many methods to do this such as GPS collars, VHF collars, remote cameras, track beds or plates, or hair snares, among others. Tracking outcomes over time will assist in future decision-making by employing the principles of adaptive management. As discussed in the 'What makes a strategy/action climate-smart?', adaptive management should be prioritized in any connectivity focused adaptation action. This should be done from the start by identifying clear and quantifiable measures of success. Using these measures of success will help managers more readily identify the best monitoring methods to use. Building monitoring and evaluation into the project process will ensure the best investments in time and money are made for the most durable conservation outcomes.

Key Strategies

- Consider the following as you develop methods for monitoring and evaluation:
    - Whether, where, or how fast species are moving in response to changing climatic conditions
    - Whether and where there may be previously unforeseen barriers (natural or anthropogenic) that could be reduced with management actions
    - Whether newly protected corridors are working to facilitate anticipated species movements (i.e. new observations of change or variability compared to original projections)
        - Monitor corridors for introductions/increases in invasive species, disease spread, or other unintended consequences of facilitating connectivity. Keep in mind that as species respond to climate changes, there may be instances where a native species invades an ecosystem it previously was not found in and may cause novel species interactions. How managers respond will depend on long-term goals for the species and/or ecosystem.
- Ensure the evaluation process is iterative to employ adaptive management fully.

KEY RESOURCES

Best Practices Manual: Wildlife Vehicle Collision Reduction Study. Federal Highways Administration.

Great resource for identifying, prioritizing, and planning road mitigation activities for fish, wildlife, and habitat concerns. Includes information for managing specific Threatened and Endangered species for which road mortality is directly affecting species long-term survival.

Groundwater and Streamflow Information Program. US Geological Survey.

Database that monitors streamflow and groundwater.

CASE STUDIES

Springs inventory, assessment, and management planning in the Sky Islands. Sky Island Alliance.

CONSIDERATIONS BY SYSTEMS

This section briefly highlights general climate change impacts on a number of ecosystems and provides broad-sweeping adaptation strategy suggestions that would benefit landscape connectivity initiatives. The intent is to identify how climate change may affect connectivity from a system perspective rather than a drivers perspective. The systems chosen were meant to cover broad systems found throughout the United States but is not meant to be comprehensive. The key strategies, key resources, and case studies will help managers quickly identify topics and examples to explore as their needs require.

Key Strategies

(These are adaptation strategies that are easily applied across a diversity of systems. More systems-specific adaptation strategies can be found in under each system section.)

- Develop partnerships to increase capacity and adaptation resources to land managers and landowners.
- Select native plant species for restoration efforts that are expected to be better adapted to future climate conditions.
- Consider assisted migration or translocations for species, where appropriate, along corridors.
- Restore hydrologic connections, implementing designs that will accommodate both increased and decreased flow.
- Replace culverts with those designed to accommodate future flow conditions and allow for fish and wildlife passage.
- Remove or remediate migration barriers such as dams or fences to accommodate future flow conditions or migration corridors to allow for fish and wildlife passage.
- Review and revise techniques to maintain or mimic natural disturbance regimes (e.g., what techniques should be used when prescribed fire is no longer feasible).
- Remove existing non-native species, where appropriate. Plan for anticipated native species range shifts into new habitats. This may mean preparing for novel species assemblages, trying to remove the species, or to manage the ecosystem to either encourage/discourage the anticipated arrival.
- Plan wetland or other mitigation banking, reforestation, or other carbon sequestration techniques deliberately to favor connectivity
- Use GIS and other tools to identify important and potentially resilient areas that represent multiple habitat types to ensure that a variety of these habitats are included in land protection planning
- Identify and protect areas that are naturally positioned to be more resistant/resilient to climate change to serve as refugia and provide opportunities for range shifts.
- Include ecologically significant areas such as breeding/nesting sites, wintering sites, and areas of high species diversity that will continue to serve these functions under climate change, including changes in hydrology.
- Riparian corridors should be included in most connectivity plans because of their importance as natural movement corridors, climate gradients, and refugia.
- Develop wide corridors (> 1 km) as they are more functional than narrow corridors because they tend to offer more diverse microclimates and provide live-in habitat for slow dispersers.
- Establish protections for transitional habitats that will provide for range shifts and serve as potential climate refugia, allowing shift in community composition where appropriate.
- Protect buffer zones to allow for future system shifts/migration through easements, acquisition, or purchase of development rights.

- Identify and prioritize protection of corridors between forested wetland areas and associated upland habitats to enhance species movement and migration.
- Identify and prioritize barriers to species movement and migration (such as roads, fences, dams, or energy infrastructure) for removal or remediation.
- Provide landowners and stakeholder groups with incentives for conservation and restoration of key corridors that will provide connectivity under current and future conditions.

AQUATIC & WETLANDS SYSTEMS

REBECCA QUIÑONES, MASSACHUSETTS DIVISION OF FISHERIES AND WILDLIFE

Rivers, streams, lakes, ponds, springs, and wetlands provide important linkages between aquatic and terrestrial ecosystems across landscapes (Capon et al. 2013, Ameli and Creed 2019, Mushet et al. 2019, Smith et al. 2019, Spence et al. 2019). Unimpeded connectivity among these ecosystems facilitates the exchange of sediment, nutrients, plants, animals, and energy (Jones et al. 2019). Consequently, connectivity is an important driver of biodiversity in both aquatic and proximate non-aquatic ecosystems (e.g., Naiman et al. 1993, Nilsson et al. 2013). Aquatic ecosystems themselves provide both habitat and migration corridors to a myriad of species (Krosby et al. 2018, Schmutz and Sendzimir 2018 and references there in), including plants, fishes, amphibians, birds, mammals, and insects (Steel et al. 1999, Naiman et al. 2000, Olson et al. 2007, Besacier-Monbertrand et al. 2014, others). However, the same characteristics that shape aquatic systems make them particularly vulnerable to climate change (Jones et al. 2019).

Climate change affects the structure and function of aquatic systems both directly and indirectly. Direct effects include increases in water temperatures and changes to hydrology while indirect effects may degrade habitats, alter plant communities, and accelerate invasive species spread (Schmutz and Sendzimir 2018, others). Rivers and streams are particularly susceptible to these changes because habitat conditions (i.e. water temperature and volume) are climate-dependent, species that inhabit them are less able to disperse, and multiple anthropogenic stressors are already adversely impacting them. Some aquatic habitats are considered priority areas for climate-smart conservation because they provide multiple environmental conditions including microclimates that can act as climate change refugia (Krosby et al. 2018, Ebersole et al. 2020). Nevertheless, climate change is altering aquatic systems and the connections they provide. Some systems will be little altered in the future (i.e., climate change refugia; Morelli et al. 2016) while others are expected to shift into new states (e.g., novel ecosystems; Catford et al. 2012) without aggressive climate adaptation.

Key Strategies

- Design stream crossings to accommodate future conditions and incorporating fish and wildlife passage.
- Publicly funded culverts and crossings should be designed, sized, and set at elevations to properly accommodate increased stream flow conditions and fauna passage (encourage the same of privately funded culverts).
- Establish river corridor easements that allow natural river channel migration
- Maintain or restore the integrity of watersheds to reduce the magnitude of scour and flooding events and retain water in the landscape.
- Maintain access to springs and spring runs for all species, remove physical barriers to fish movement.
- Strengthen protection of water bodies that are most vulnerable to climate change.
- Manage connected lake systems as a complex to provide variable habitat staggered among years, throughout the complex.

- Reconnect rivers to floodplains by removing restrictions (e.g., removing dams, modify culverts, berm, and levee removal) or implementing designed ecological flows to mimic natural high-flow events.
- Identify and prioritize protection of corridors between aquatic systems and associated upland habitats to promote species migration corridors.
- Increase the efficiency of water use by farms and cities while maximizing beneficial use of stormwater and reclaimed water.
- Begin nationwide implementation of US Army Corps RGL-2018-01 - "Compensatory mitigation credits for removal of obsolete dams and other structures from rivers and streams." Align with other resource agencies with jurisdictions over waterways.

KEY RESOURCES

Climate Change and River Ecosystems: Protection and Adaptation Options. Palmer et.al. 2009.

Paper looking at the impacts of climate change on river ecosystems and their associated ecosystem benefits. Also provides adaptation options for management.

Flowing Forward: Freshwater ecosystem adaptation to climate change in water resources management and biodiversity conservation. Publication by Water Partnership Program and WWF.

This report provides an overview of climate change impacts to freshwater systems, a framework for managing adaptation in freshwater systems, and recommendations for operational integration.

Human effects on ecological connectivity in aquatic ecosystems: integrating scientific approaches to support management and mitigation. Crook et al. 2015.

Reviews anthropogenic threats to aquatic system connectivity including habitat loss, altered hydrology, invasive species, and climate change. Also provides case studies highlighting multi-disciplinary approaches.

Conserving Freshwater and Coastal Resources in a Changing Climate. The Nature Conservancy. 2009. Broader overview of climate change impacts and adaptation strategies.

Climate change, aquatic ecosystems, and fishes in the Rocky Mountain West: implications and alternatives for management. US Forest Service.

Great table of management options, including connectivity, on page 19.

Planning for connectivity. Ament et al. 2015.

This guide focuses on requirements established under the National Forest System land management planning rule to manage for ecological connectivity on national forest lands and facilitate connectivity on planning across land ownerships. Good overview of aquatic connectivity starts on page 16.

Aquatic Connectivity Scenario Analysis Tool. North Atlantic Aquatic Connectivity Collaborative.

This tool uses road-stream crossing data from the North Atlantic Aquatic Connectivity Collaborative (NAACC) and the UMass Critical Linkages assessment to allow users to create scenarios that involve combinations of crossing replacements and/or dam removals, and evaluate them for gains in aquatic connectivity and ecological restoration potential.

Replacing culverts for flood resiliency and aquatic connectivity (Slide show). New Hampshire Dept of Environmental Services.

Really good source for visualizing the importance of replacing culverts to address flood resiliency and aquatic connectivity can benefit fish and wildlife, habitat, and infrastructure.

USGS ScienceBase Catalog. US Geological Survey.

Provides links to several stream crossings/connectivity projects across the continental US.

Assessing Stream Crossings for Vulnerability. North Atlantic Aquatic Connectivity Collaborative.

Toolkit providing details on how to assess stream crossings for climate change impacts and vulnerability.

Southeast Aquatic Barrier Prioritization Tool. Southeast Aquatic Resources Partnership.

Improve aquatic connectivity by prioritizing aquatic barriers for removal using the best available data.

Northeast Aquatic Connectivity project tool. Freshwater Northeast Region. Freshwater Network.

A tool for exploring in-stream barriers to aquatic connectivity and identifying opportunities for connectivity restoration projects. This tool was developed as part of the North Atlantic Aquatic Connectivity Collaborative and is part of a family of spatial decision support tools supported through the Natural Solutions Toolkit.

Great Lakes Connectivity.

Website providing information related to connectivity in the Great Lakes.

CASE STUDIES

Aquatic Connectivity in the Northeast Region (Strategic Plan 2018). US Fish and Wildlife Service.

California fish passage forum. National Fish Habitat Partnership.

Aquatic Connectivity and Barrier Removal. New York Department of Environmental Conservation.

Urban Water Re-Use for Wetlands in the Mojave Desert. Las Vegas Wash Coordination Committee.

FORESTED SYSTEMS

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Climate change is expected to affect forested systems in a variety of ways including but not limited to drought, frost, flooding, fire, introduced species, and insect/pathogen outbreaks. The alteration, frequency, intensity, and duration of these and other natural events (e.g. hurricane, tornado, wind/ice storm, landslide) will need to be considered for connectivity. These disturbances are likely to be most pronounced in boreal and coniferous forest ecosystems versus broadleaved and mixed forest ecosystems, although climate change effects will vary considerably among forest types. Connectivity as defined by the United States Forest Service (USFS) planning rule are "...ecological conditions that exist at several spatial and temporal scales that provide landscape linkages that permit the exchange of flow, sediments, and nutrients; the daily and seasonal movements of animals within home ranges; the dispersal and genetic interchange between populations; and the long distance range shifts of species, such as in response to climate change" (36 C.F.R. § 219.19). A range of adaptive/coping strategies and approaches will be needed to maintain forested system ecological conditions through sustainable management, conservation, and restoration efforts since forest management will interact with these disturbances differently. While forest patch size and isolation play an important role in connectivity for species dispersal, the structure of the surrounding matrix also must be considered. Additionally, species persistence is not guaranteed without consideration of the underlying amount and quality of the habitat being considered for connectivity in the landscape.

Key Strategies

- Foster management strategies before climate change disturbances occur that reduce vulnerability and enhance recovery such as altering forest/landscape structure or changing/adjusting species composition.
- Fire prescriptions to reduce fuel loads and manage introduced species or maintaining natural fire regimes during optimal windows for burning.
- Increase tree species diversity to improve forest productivity (Liang et al. 2016) and resiliency to disturbance (e.g. Jactel et al. 2017).
- Promote diverse age classes to maintain and enhance species and structural diversity.
- Manage herbivory or overbrowse to promote generation of desired or future-adapted species.
- Healthy connected forests can be planted by matching seedlots of planted sites with future climate change scenarios.
- Revise National Forest and other agency Land Management Plans to be climate-smart (e.g. USFS Planning Rule; Williamson et al. 2020).
- Consider conservation-based land use designations for areas of high connectivity ("key linkage areas") as staging grounds for climate-smart forest management.
- Incorporation of private forested systems into adaptation strategies to maintain connectivity, especially in highly forested landscapes (e.g. Maine, New Hampshire, West Virginia).
- Determine if collective forestry practices are "Climate Smart" by addressing the "Four I's": 1) Innovations 2) Institutions 3) Infrastructures and 4) Investments. See Rockström et al. (2017) and Verkerk et al. (2020) for more details.

KEY RESOURCES

Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers (2nd edition). US Forest Service.

The Forest Adaptation Resources provides a collection of resources designed to help forest managers incorporate climate change considerations into management and devise adaptation tactics.

National Roadmap for Responding to Climate Change. US Forest Service.

Developed in response to the need for US forest Service programs and field units to work together closely in an integrated national response for the sustainability of the Nation's forests and grasslands and to address Goal 2 of their 201-2015 Strategic Plan. Strategic Goal 2 - Ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources.

Seedlot Selection Tool.

Mapping tool to match seedlots with planting sites based on current and projected climate change scenarios.

RIPARIAN SYSTEMS

MACK FRANTZ, WEST VIRGINIA DIVISION OF NATURAL RESOURCES

Riparian systems are the connections or aquatic-terrestrial linkages between land and water. Climate change is expected to make some riparian systems wetter and others drier as the linkages that exist between ecosystems on land and water are altered. Increased frequency, intensity, and duration of flood and stormwater events are anticipated. As such, climate change stressors and consequential connectivity disruptions may affect species migration, interactions, and community composition among other impacts (Häder and Barnes 2019). Land managers will need to consider what impact these may have on water quality and availability for public consumption and wildlife communities that depend on them. Effective climate smart adaptation strategies start at a watershed level to maintain and restore watershed connectivity, health, and resiliency to sustain current and projected ecological service needs and demands. Considering >89% of the global river network are headwater streams (temporary flowing waters, Downing et al. 2012), the traditional focus on perennially flowing waters has the potential to lead to irreversible loss of ecological function if frequency of surface flow is disconnected (e.g. "flow permanence," Ward et al. 2020). As such, adaptation actions must consider both land and water components since it is rare for terrestrial and aquatic areas to possess similar connectivity value (Gray et al. 2020).

Key Strategies

- Restore riparian areas to increase water retention/surface flows and uptake of soils and reduce impacts of flood events, erosion, and sedimentation.
- Improve riparian zone and floodplain connectivity by removing restrictions between rivers and floodplains (e.g., removing dams/roads and culvert modification)
- Plant vegetation along stream banks that provide shade to cool stream temperatures, particularly along important cold-water freshwater fisheries.
- Prevent streambank erosion and channel infilling by use of heavy equipment exclusion zones and restricting yarding operations that drag logs across streams (Olson and Burton 2019)
- Maintain floodplains as undeveloped areas.
- Protect wetlands for floodwater storage (see Aquatic and Wetlands systems).
- Encourage the passage of state regulations supporting local level zoning and planning ordinances to strengthen protection of forested wetlands.
- Increase the efficiency of water use by farms and cities while maximizing beneficial use of stormwater and reclaimed water
- Management, protection, and consideration of headwater streams to maintain "flow permanence" (e.g. Ward et al. 2020) and exchange of sediments and nutrients, not just perennially flowing streams.
- Manage over-ridge wildlife dispersal habitat from areas with perennial surface slow (Olson and Burton 2019)

KEY RESOURCES

Why Climate Change Makes Riparian Restoration More Important Than Ever: Recommendations for Practice and Research. Seavy et.al. 2009.

Provides a review of the potential role for riparian restoration to prepare ecological systems for the threats posed by climate change. The researchers suggest that healthy riparian ecosystems promote ecological resilience both within and beyond riparian zones. They address 1) how and why riparian restoration prepares ecosystems for climate change; 2) how riparian restoration can be enhanced to accommodate climate change; and 3) research needed to ensure that riparian restoration is robust to climate change.

Getting Climate Smart: A Water Preparedness Guide for State Action. NRDC. Joint Collaboration of American Rivers and Natural Resources Defense Council.

A broad, holistic overview of how state planners can develop preparedness plans for climate-related impacts to water resources.

GRASSLAND SYSTEMS

MATTHEW GRABAU, US FISH AND WILDLIFE SERVICE

Grasslands across North America are critical for a wide array of species and provide extensive ecosystem services: livestock and game production, pollinator populations, and healthy lakes, rivers, and streams all depend on the health of grasslands. North American grasslands extend from southern Canada into Northern Mexico, supporting seasonal migrations as well as migration in response to climate change. Unfortunately, native grasslands are considered among the most threatened biomes in North America—they have been extensively converted to agriculture or cities, or desertified due to unsustainable land use practices (e.g. Hoekstra et al. 2005). Increasing production of oil, gas, and wind energy further threatens grassland ecological integrity and connectivity in central North America.

In the southwestern United States, grassland ecosystems also provide critical connectivity between "Sky Islands," mountain ranges that rise to alpine elevations above the desert floor, with "seas" of grasslands and desert scrub between (Gottfried et al. 2005). The Sky Islands not only support remarkable biodiversity; they also provide climate refugia that connect habitat between the Sierra Madre Occidental of Mexico and the Rocky Mountains of the U.S. and Canada. Intact grasslands between ranges are required to maintain functional connectivity for species.

In addition to habitat conversion, remaining grasslands have been over-exploited, resulting in decreased productivity and excessive erosion that also impacts water quality and quantity downstream. Aggressive native and invasive exotic plant species are increasingly prevalent, including trees, shrubs, grasses, and forbs. These species are often better adapted to changing climate and atmospheric conditions such as increasing drought and wildfire, rising levels of carbon dioxide, and more flashy and unpredictable precipitation events.

To maintain connectivity of grassland ecosystems, managers need to preserve and enhance remaining native grasslands and restore and reconstruct previously converted grasslands, while increasing connectivity within and among grassland patches. Finally, grazing practices for working lands must be adapted to changing conditions to support the range of critical ecosystem services provided by grasslands.

Key Strategies

- Identify and maintain critical grassland corridors to allow migration and provide functional connectivity between climate refugia
- Establish and maintain partnerships with a diversity of landowners—grassland connectivity cannot be achieved without incorporating private lands
- Improve habitat connectivity within grassland patches by modifying or removing barriers to movement, including using "wildlife friendly" fencing
- Restore degraded grasslands to increase connectivity between high-value habitat patches and enhance functional connectivity:
    - Restore eroded gullies and channels to increase water retention on the landscape and decrease impacts to downstream waterways; consider using beaver dam analogs in degraded and incised streams
    - Improve the availability and affordability of native seed mixes to improve restoration results
    - Develop and implement best practices for invasive tree, shrub, grass, and forb removal, which may include prescribed fire, chemical, and/or mechanical treatment
    - Identify and implement strategies for improving habitat quality of farmland for birds and pollinators in all stages of their life cycles

KEY RESOURCES

North American Grassland Priority Conservation Areas. The Nature Conservancy. 2005.
Technical report identifying priority grasslands conservation areas and provide guidance for where conservation action is immediately needed due to transnational importance. Discussions the importance of coordination among multi-stakeholders, including from outside the United States.

Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment. Finch 2012.
This is a general technical report with relevant chapters on deserts and grasslands. Good resource for understanding climate change impacts in the West.

CASE STUDIES

Minnesota Prairie Conservation Plan. The Nature Conservancy. 2018.

Madrean Watersheds Landscape Conservation Design: Identifying Grassland and Desert Corridors and Connectivity Areas. Sky Island Alliance.

Grassland Conservation for Prairie Grouse. North American Grouse Partnership. 2007.

Preserving Habitat Linkages in the US-Mexico Borderlands. Wildlife Corridors LLC and Borderlands Restoration LLC.

Conservation Easements to Maintain Watershed Connectivity. US Fish and Wildlife Service.

Erosion Control to Maintain Water Resources in Working Grasslands. Cuenca los Ojos.

Fence Modification or Removal to Improve Connectivity within Grassland Patches: Southern Arizona and West Texas

Innovative Livestock Production: Rotational Grazing in Texas and Drought-Adapted Cattle

Building a Culture of Conservation within the Ranching Community. Natural Resources Conservation Service (Montana).

Removal of Invasive Shrubs and Trees: Mechanical, Chemical, and Prescribed Fire

DESERT SYSTEMS

MATTHEW GRABAU, US FISH AND WILDLIFE SERVICE

The four North American Deserts, the Great Basin, Mojave, Sonoran, and Chihuahuan, comprise over 550,000 square miles and support unique biodiversity adapted to harsh conditions. In addition to supporting numerous endemic species and grazing, deserts interspersed with riparian ecosystems are important migratory corridors for birds, pollinators, and large game and nongame mammals. Deserts also support some of the fastest growing urban areas and renewable energy facilities in North America while supporting over 1 million acres of irrigated agriculture. While large tracts of land will continue to be developed, millions of acres of military installations and expanses of public land in the United States provide unique opportunities for conservation.

Climate change effects on precipitation will vary for each of these deserts due to relative contributions of winter frontal storms, the North American monsoon, and tropical systems. However, all these deserts are anticipated to be warmer, dryer, and subject to longer fire seasons. Desert environments will therefore become more extreme. Biomes are likely to migrate north and/or to higher elevations. Different vegetation types may increase or decrease in area or become extirpated. Additionally, the prevalence of invasive herbaceous plants, both grasses and forbs, is likely to increase and continue increasing fire frequency and extent (Finch 2012).

To maintain functional connectivity of deserts, managers must optimize the location and types of development and implement strategies to mitigate fragmentation from roads and other linear infrastructure. Grazing practices for working lands will need to be adapted to changing conditions, while best management practices must be developed to address invasive species including cheatgrass (*Bromus tectorum*) in the Mojave and Great Basin Deserts and buffelgrass (*Pennisetum ciliare*) in the Sonoran and Chihuahuan Deserts. Artificial water catchments may also increase support for species that require open water. However, benefits of artificial water are not clear (e.g. Harris et al. 2020). Catchments may promote increased density of predators (e.g. Kluever et al. 2017) or provide opportunities for disease transmission if animals visit them in high densities (USDA - Natural Resources Conservation Service 2010). If not properly maintained, water quality in catchments may even harm animals they are intended to support (Griffiths-Kyle et al. 2014). Finally, increasing the efficiency of water use in agricultural and urban areas may increase the resilience of riparian corridors and wetlands that provide refugia and migration corridors. Supplemental water may be required to support some species if natural wetlands are lost.

In some cases, functional connectivity between high quality desert scrub habitat may not be recoverable. Assisted migration of key species can be considered. Recent successes include translocation of Sonoran pronghorn in southern Arizona. However, managers must be mindful of unintended disease transmission for species ranging from desert tortoises to bighorn sheep.

Key Strategies

- Identify and maintain critical desert corridors to allow migration and provide functional connectivity between blocks of high-quality habitat and climate refugia
- Consider assisted migration of desert species between habitat blocks when fragmentation cannot be overcome
- Develop and implement best management practices for detection and control of invasive herbaceous plants
- For restoration projects, use locally adapted plants material that will be resilient to warmer, dryer conditions
- Consider artificial water sources where needed for refugia or to increase functional connectivity
- Increase the efficiency of water use by farms and cities while maximizing beneficial use of stormwater and reclaimed water to increase the resilience of aquatic and riparian corridors

KEY RESOURCES

Climate change in grasslands, shrublands, and deserts of the interior American West: A review and needs assessment. Finch 2012.
This is a general technical report with relevant chapters on deserts and grasslands. Good resource for understanding climate change impacts in the West.

CASE STUDIES

Linkage Analysis for the Mojave Desert Tortoise. Averill-Murry et al. 2013.

Sonoran Pronghorn: Artificial Water, Military Partnerships, and Assisted Migration to Recover an Endangered Species. US Fish and Wildlife Service.

Highway Overpasses for Bighorn Sheep Corridors in the Mojave Desert. Arizona Department of Transportation, Arizona Game and Fish Department, Federal Highway Commission, Arizona Desert Bighorn Sheep Society.

Over- and Underpasses to Preserve Urban Corridors in the Sonoran Desert. Variety of partners.

Remote Sensing for Detection and Treatment of Invasive Grasses. National Park Service, US Geological Survey, USA National Phenology Network, Southern Arizona Buffelgrass Coordination Center.

Native Plant Materials for Restoration in the Mojave Desert. Bureau of Land Management.

Increasing Habitat Value and Habitat Connectivity in Solar Power Generation Facilities. Valley Electric Association, US Fish and Wildlife Service, Pacific Southwest Region, HDR Consulting, University of Nevada, Las Vegas Bombard Renewable Energy.

Community Engagement and Urban Habitat Creation. US Fish and Wildlife Service.

Using Stormwater to Create Refugia in the Sonoran Desert. US Army Corps of Engineers, Pima County Regional Flood Control District, Pima County Regional Wastewater Reclamation Department.

Urban Water Re-Use for Wetlands in the Mojave Desert. Las Vegas Wash Coordination Committee.

COASTAL SYSTEMS

BETH STYS, FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION

Saltwater marshes, mangrove forests, beaches, dunes, and coastal grasslands and forests are important components of the coastal ecosystem, providing breeding and foraging grounds, and cover for a wide variety of wildlife. These systems provide connectivity along the coastline (seascape connectivity) as well as shore to inland system connectivity. Coastal systems have the natural ability to adapt to the dynamic conditions that formed and maintain them. Beaches may be washed away during a storm, new inlets may appear between, old inlets may close, widen, or migrate, sand dunes may build or erode, and sandbars may form seaward of the existing beach to create a new string of barrier islands. However, these capacities are being overwhelmed by sea level rise and increased storm events, particularly in areas that have already been damaged by development, coastal armoring, and other activities.

Coastal systems and the species that depend upon them will be impacted by increases in storm surge associated with storm events. Inundation and impacts from storm events will lead to increased fragmentation and changes in the structure (geomorphology) of the system. Changes in wind circulation patterns and increases in wave actions due to storms will lead to increased erosion and alterations to sediment transport and deposition. Dune systems will become more fragmented as low-lying areas become inundated due to sea level rise, creating more isolated/disjunct habitats. Saltwater marshes have considerable capacity to adjust to sea level rise and under moderate rates may be able to keep pace and move inland, given minimal barriers (e.g., roads, developed land uses). However, under more rapid rates of sea level rise there could be significant loss of saltwater marsh. Similarly, mangroves are expected to be able to keep pace with more modest rates of sea level rise, moving inland as the seas rise. In coastal areas with low elevation gradients mangroves are likely to be overwhelmed by a rapid rate of sea level rise. Relatively small changes in winter temperature (e.g., increasing minimum temperature) can result in dramatic mangrove range expansion. It is projected that mangroves will expand their range inland and northward as temperatures increase and cold weather events decrease. In areas where mangroves can migrate, within their existing range and potential expansion, it may be at the expense of saltwater marsh. Mangroves typically out-compete saltwater marsh where there is overlap. However, large expanses of mangroves could be fragmented into smaller, more isolated patches in areas where mangroves won't be able to migrate. Additionally, loss of sediment (peat) due to erosion following storms can lead to collapse of mangroves when the vegetation is compromised. Increased soil salinity in coastal uplands will lead to changes in species composition as salt-intolerant plants decline and plants with higher salt tolerances increase. Coastal forests are already being impacted by saltwater intrusion, longer periods of root inundation, salt spray, and coastal erosion. Changes in system composition and structure could change the suitability of these areas as corridors for certain species.

Key Strategies

- Restore connections through addressing hydrological alterations, such as filling mosquito ditches, removing roads, and replacing culverts with types/sizes that will accommodate future flows.
- Increase connectivity of natural shorelines by replacing hardened shorelines with natural vegetated shorelines.
- Restore coastal vegetation to reduce potential fragmentation due to the impact of increased disturbance events (intense storms, increased erosion) and encourage aeolian sand capture.
- Reduce fragmentation by working with communities and landowners to choose vegetation, living shorelines, oyster reef restoration, or hybrid approaches in favor of traditional hard armoring.
- Establish a connected network of protected areas across the shoreline through coordinated foreshore habitat management plans.
- Increase upslope/inland connectivity by removing impediments/barriers to upslope habitat movement.

- Educate planners on the importance of healthy resilient coastal systems to protect against coastal hazards.

KEY RESOURCES

Guide for Considering Climate Change in Coastal Conservation. NOAA.

This guidance is intended to provide information on NOAA's perspective and roles regarding living shorelines implementation. It starts by describing NOAA living shorelines guiding principles, then highlights NOAA's role in providing science, tools, and training to help inform the selection of appropriate techniques. It also discusses the agency's role in reviewing living shoreline projects, depending on their location and potential effect on habitats of concern to NOAA, such as critical habitat, essential fish habitat, or protected areas. This guidance also provides a conceptual framework of 12 questions to help NOAA and our partners when planning a shoreline stabilization effort.

Living Shorelines Online Resources/Publications.

This list provides a collection of some of the online resources about the Living Shorelines.

Managing Mangroves for Resilience to Climate Change. IUCN.

This paper provides an overview of mangrove ecosystems, discusses the benefits of mangroves to people, and the human and global threats that compromise mangrove ecosystems. This document describes the impacts of climate change on mangroves and outlines tools and strategies that enhance mangrove resilience.

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