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Assessing Land for Climate Resilience: A guide to The Nature Conservancy's resilient and connected network

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Abstract

Across the planet, climate change is exacerbating already-critical biodiversity loss that is degrading landscape connectivity, habitats, and livability across species. Motivated by the urgency of this crisis, The Nature Conservancy (TNC) identified a network of conservation sites designed to provide resilient habitats, while supporting dynamic shifts in ranges and ecosystem composition. TNC collaborated with over 280 scientists from every U.S. state to develop and map a conservation network for the nation based on principles of representation, resilience, connectivity, and recognized biodiversity value, with each factor mapped to anticipate climate change. The results delineate a network covering 35 percent of the U.S. Because the network connects climatic gradients across thousands of biodiversity elements, and targets multiple resilient sites in every ecoregion, it could form the spatial foundation for targeted land protection and other conservation strategies to sustain a diverse, dynamic, and adaptive world. The results are being used to inform land-acquisition and land-management decisions by The Nature Conservancy, state and federal agencies, and hundreds of land trusts. This paper introduces its key concepts and shows how users can access the information via the Resilient Land Mapping Tool to inform their work.

About the Author

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Mark provides science leadership, ecological analysis, and landscape assessments for conservation efforts across 50 states in the Eastern United States. He holds a Ph.D. in Ecology from University of New Hampshire and has worked as an ecologist for over 32 years – 30 with The Nature Conservancy. He has published widely on climate change resilience, large landscape conservation, biodiversity, and forest dynamics. A co-author of the National Vegetation Classification, his current research interests focus on the intersection between ecological services, biodiversity, and geophysical properties. He manages a team of six scientists specializing in landscape ecology, aquatic and terrestrial connectivity, marine spatial planning, and regional data management.

In 2017, Mark received TNC's Conservation Achievement Award for his work to identify climate resilient "strongholds" – areas where complex topographies, elevations and geologies allow them to withstand climate impacts and continue supporting people and nature. Mark and his team have created a comprehensive map of these strongholds across the continental United States which is being used by TNC, government agencies and other conservation organizations to prioritize the most important lands and waters to protect in order to sustain the diversity of life on Earth.

Acknowledgements

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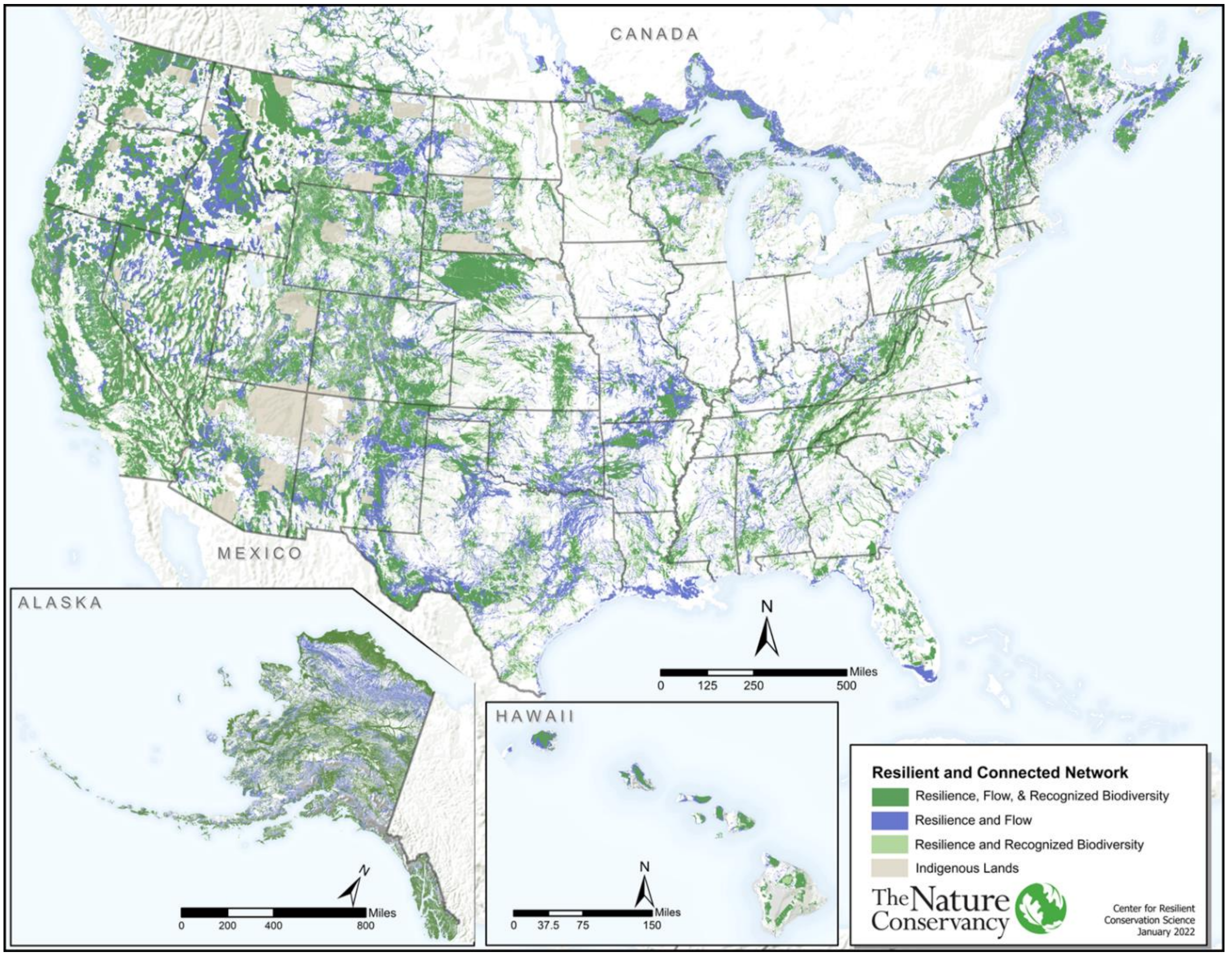

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I. Sustaining biodiversity under climate change

Motivated by declines in biodiversity exacerbated by climate change, The Nature Conservancy (TNC) and partners have identified a network of conservation sites which, if conserved, could provide resilient habitat for the full spectrum of United States wildlife and plants, while supporting dynamic shifts in ranges and changes in ecosystem composition. The network covers 35 percent of the contiguous U.S., and the decade-long process to identify and map it involved hundreds of scientists, representing all 50 states over 12 years (Anderson et al. 2023). TNC's intent was to create the information needed to support local-, regional-, and national-scale conservation decisions. Because the network touches down in every state and almost every county, it can enable the resulting actions to, collectively, achieve national-scale impact.

The goal of this document is to communicate the content and findings of this complex analysis in a form that makes it easy for land trusts and other conservationists to incorporate resilience science into their own decision making. The report is meant to be used in conjunction with TNC's Resilient Land Mapping Tool (RLMT) (https://maps.tnc.org/resilientland/), which allows users to view each component dataset, and explore the results within sites, landscapes and regions that they are familiar with. The science behind the study has been published in five peer-reviewed journal articles and 11 geographically specific reports. A list of all the publications and links to the complete documents appears in the Appendix. Each authoritative dataset can be downloaded from the CRCS website (https://crcs.tnc.org/), and the full study can be accessed here: https://www.pnas.org/doi/10.1073/pnas.2204434119.

Biodiversity loss and climate change

Conservationists envision a world where people and nature thrive, but over the last decade (2012-2022) it has become alarmingly clear that nature is being degraded. Despite broad public support and unprecedented bipartisan agreement on Earth Day 1970, followed by landmark environmental laws, expanded regulatory efforts, and the establishment of hundreds of private conservation organizations, the species and ecosystems that characterize the natural world continue to decline. In North America, the abundance of birds has fallen 29 percent since 1970; 32 percent of insect taxa are in decline; and 56 percent of mammalian carnivores and ungulates have shown notable range contractions since 1950 (Rosenberg et al. 2019., Crossley et al. 2020., Liebert & Ripple 2004). Amphibians have declined an average of 33 percent since 2002 (Muths 2012). Of the 51,936 species of plants, vertebrates, and macroinvertebrates tracked by NatureServe across the contiguous U.S., 9 percent are ranked vulnerable, 12 percent are imperiled, and 1 percent are possibly extinct (NatureServe 2022).

The primary causes of species declines are habitat loss and degradation (IPBES 2020), but changes in climate exacerbate the problem. As temperature and moisture patterns change, species' ranges are shifting with speed and magnitude that are unprecedented in recent millennia. In the eastern U.S., trees have shifted their centers of distribution 10 kilometers (km) north and 11 km west per decade since 1980 (Fei et al. 2017). Bird ranges have shifted north by an average of 24 km per decade (Hitch & Leberg 2007). This is on par with global shifts of 10 km north and 11 km upslope per decade across taxa groups (Chen 2011).

Range shifts are a natural response to climatic change. Similar periods of rapid climate change in the early Quaternary resulted in few extinctions (Botkin 2007), but today's landscape is heavily fragmented by roads, development, industrial agriculture, commercial forestry, and energy infrastructure, making adaptive movement a challenge. Fragmentation makes it increasingly risky for species to disperse, more challenging to find suitable habitat, and difficult to establish new populations. Unless we intentionally conserve areas for future habitat and maintain a permeable landscape or corridors for movement, it is unlikely that nature will be able to rearrange at the pace and scale needed. Some conservationists have concluded that we will likely need to assist with migration and dispersal.

In recognition of the twin crises of biodiversity loss and climate change, 19 prominent scientists in 2019 challenged the world to forge a Global Deal for Nature (GDN) in a landmark paper that advanced a science-driven plan to save the diversity and abundance of life on Earth (Dinerstein et al. 2019). The GDN aims to formally protect 30 percent of the earth by 2030, and to designate an additional 20 percent as climate stabilization areas to ensure global temperature change stays below 1.5°C. The authors argue that pairing the GDN and the Paris Climate Agreement would avoid catastrophic climate change, conserve species, and secure essential ecosystem services.

The 30 by 30 target is derived from five fundamental goals of conservation science: (1) *representation*, represent all native ecosystem types; (2) *biodiversity*, maintain viable populations of all native species in natural patterns of abundance and distribution; (3) *connectivity*, maintain ecological function and ecosystem services; (4) *carbon*, maximize carbon sequestration by natural ecosystems; and (5) *resilience*, address environmental change to maintain evolutionary processes and adapt to the impacts of climate change (Noss & Cooperrider 1994).

The 30 by 30 goal has been adopted by the Convention on Biodiversity (CBD 2020). Target 2 calls for the global protection of *well-connected* and *effective* systems of protected areas with a focus on *biodiversity* and covering at least 30 percent of the planet. Similarly, in the U.S., the Biden-Harris Administration has launched America the Beautiful (AtB), a call to work together to conserve, connect, and restore 30 percent of land and water by 2030, not only for nature but for the sake of its economy, health, and well-being (Biden Administration 2021). These initiatives challenge the nation to create the conditions needed to maintain a habitable planet and coordinate conservation actions for a larger impact.

Area-based land and water conservation can reverse declining trends in species abundance and allow for adaptive movement, provided the conservation areas are strategically located and supported by the necessary investments. In North America, billions of dollars spent on wetland restoration and management, combined with stringent hunting regulations, reversed bird-abundance declines in wetlands over the last 40 years (Rosenberg et al. 2019). On a global scale, strategically placed conservation investment from 1996-2008 reduced the extinction risk for mammals and birds by a median value of 29 percent (Brondizio 2019). Conservation plans based on current biodiversity patterns, however, may become less effective at sustaining species as climate change drives shifts in species distributions and ecosystem composition. In particular, the current configuration of protected areas may fail to adequately provide species with access to the diverse climatic conditions needed to persist, or the connections needed for dispersal and migration.

The key to sustaining biodiversity lies less in the total area than in the basic design and principles expressed in the CBD language as an *ecologically representative, well-connected, effective, and biodiverse* network. TNC's **Resilient and Connected Network** (RCN) is an attempt to map such a network for the U.S.

Below, Section I summarizes the results of the resilient and connected network analysis and examines the network's conservation status and implications for carbon storage and capture. It illustrates how users can explore the network in their local landscape, estimate its carbon value, and view its juxtaposition with local conservation lands. The mapping tool can also be used to explore results for the whole U.S including Alaska and Hawaii.

Section II dives deeper into the five network characteristics crucial to sustaining biodiversity under climate change. Each of these is described in detail, along with our methods for mapping the characteristic across the U.S and instructions for examining the results using the Resilient Land Mapping Tool (RLMT). The design goals include:

- Representation: Ensuring that the network contains multiple examples of all U.S. habitats;
- Resilience: Ensuring that individual sites have the maximum amount of microclimatic buffering;
- Biodiversity: Ensuring that the network contains exemplary natural communities and viable populations;
- Connectivity: Ensuring that the network is connected along natural flow lines and climatic gradients; and
- Network: Ensuring that the four preceding goals are integrated into an ecologically coherent network.

Resilient Land Mapping Tool (RLMT)
All the datasets and concepts discussed in this document are available to explore and quantify in the TNC Resilient Land Mapping Tool at maps.tnc.org/resilientland. This paper is best used in conjunction with the RLMT.

A Resilient and Connected Network

"Ensure that at least 30 per cent globally of land areas…especially areas of particular importance for biodiversity and its contributions to people, are conserved through effectively and equitably managed, ecologically representative, and well-connected systems of protected areas and other effective area-based conservation."
- Convention on Biological Diversity (CBD 2030 Target 2)

TNC's Resilient and Connected Network (RCN) is a mapped network of representative resilient sites which, if conserved, could sustain the biodiversity of the U.S. while allowing it to move and adapt to a changing climate (Anderson et al. 2023). The network was identified and mapped over a 12-year period through an open and transparent process led by TNC. The process also involved 289 scientists and conservation practitioners representing every U.S. state and 11 geographic regions.

Covering 35 percent of the contiguous U.S., the network can serve as a blueprint for measuring the national AtB and global 30x30 goals, because it meets stringent criteria for ecological representation, connectivity, and biodiversity importance. It satisfies these criteria by:

- Containing multiple resilient examples of every physical habitat within each United-States ecoregion;
- Encompassing over 250,000 sites recognized for their biodiversity value; and
- Maximizing connectivity between sites to allow for movement and adaptation.

Currently 44 percent of the network within the continental U.S. is protected from development. When Alaska and Hawaii are included, the network covers 37 percent of the nation and 49 percent of its area is protected against development.

Importance of the Network

As highlighted in the introduction, North America is experiencing an abundance crisis with birds, insects, mammals, and amphibians all showing dramatic declines in the last 40 years. At the same time, changes in climate are exacerbating species declines. As temperature and moisture patterns change, species need to move to adjust to the new conditions. To reverse these trends, scientists are calling on nations to conserve 30 percent of the earth. In the U.S., the Biden Administration responded to that call with its relatively popular America the Beautiful (AtB) initiative which has garnered bipartisan public support of about 76 Percent (Metz et al. 2022).

The AtB initiative does not identify where, across the U.S., the land should be conserved. This step will be critical to AtB's success, since conserved areas need to be representative, resilient, biodiverse, and well-connected to maximize their climate and biodiversity value.

The RCN maps the areas needed to encompass and reflect these network characteristics (Table 1). The process of creating the map began with identifying places and spatial configurations that meet each criteria, then calculating the area the network encompassed. What emerged, covered 35 percent of the contiguous U.S., independently confirming the 30-percent goal, while emphasizing that not all land is of equal conservation value.

Table 1. Characteristics of a climate smart conservation network. (Anderson et al. 2023)

Aspect	Characteristics	Strategy and Justification
Representation	Sites representing an ecologically meaningful portion of every ecoregion	Conserve ecological gradients by distributing conservation across ecoregions and among geophysical settings such as soil and bedrock

	distributed across geophysical settings.	types and elevation zones. Ensures capture of the full spectrum of biodiversity.
Site Resilience	Sites with a high diversity of connected topoclimates linked by natural cover and accessible to species.	Conserve representative sites with microclimatic buffering to help species persist longer and turnover more slowly under a changing climate. These sites serve as natural strongholds for current and future diversity.
Connectivity and Climate Flow	Sites positioned along climatic gradients within areas of low human modification (i.e., high climate flow).	Conserve connected corridors and zones of natural cover that follow climatic gradients to allow species to move in response to changing temperature and moisture conditions.
Recognized Biodiversity Value	Sites supporting biotic assemblages characteristic of their geophysical setting (i.e., vegetation types, natural communities, rare and specialist species).	Conserve places that have been recognized for their current biodiversity value to protect species and natural communities where they are already thriving and to provide source areas for dispersing populations.
Network	Co-occurrence of one or more of the above. Resilient sites overlapping with connectivity or biodiversity values	Integrate the above aspects into a resilient and connected network aimed at sustaining biodiversity while facilitating movement and adaptation to change.

Mapping the Network

To create the RCN, The Nature Conservancy resiliency science team (TNC team) developed four nationwide, spatially explicit datasets, each targeting an essential component of a climate-smart conservation network (See Table 1 and Section II). Each individual dataset was reviewed by a steering committee of scientists with expert knowledge of their study region to ensure that the foundational building blocks of the network were accurately mapped and assessed.

The TNC team then integrated the base maps into a single network using straightforward measures of co-occurrence. Using ecoregions as a stratification, the TNC team overlaid the three central datasets and identified the degree and type of co-occurrence for every point (30-m cell) in the U.S. (Table 2, Figure 1).

If a cell met criteria for all three characteristics (RFB = high resilience, flow and biodiversity), it was automatically included in the network. A full 21 percent of the contiguous U.S met all three. If a cell met criteria for resilience and flow (RF = high resilience and flow) but not biodiversity, it was also included in the network. This amounted to another 12 percent and, together, these two criteria covered 33 percent of the contiguous U.S.

The criteria for high resilience and recognized biodiversity (RB), or high resilience alone (R) were more problematic, as they included many single or isolated cell groups. These small patches of resilience may be important, but they require field confirmation before they can be added to the network. They were added to the network *only* if they were on land that was already secured against conversion (sRB, sR), which amounted to another 2 percent of the contiguous U.S. Altogether, the network covered 35 percent of the region.

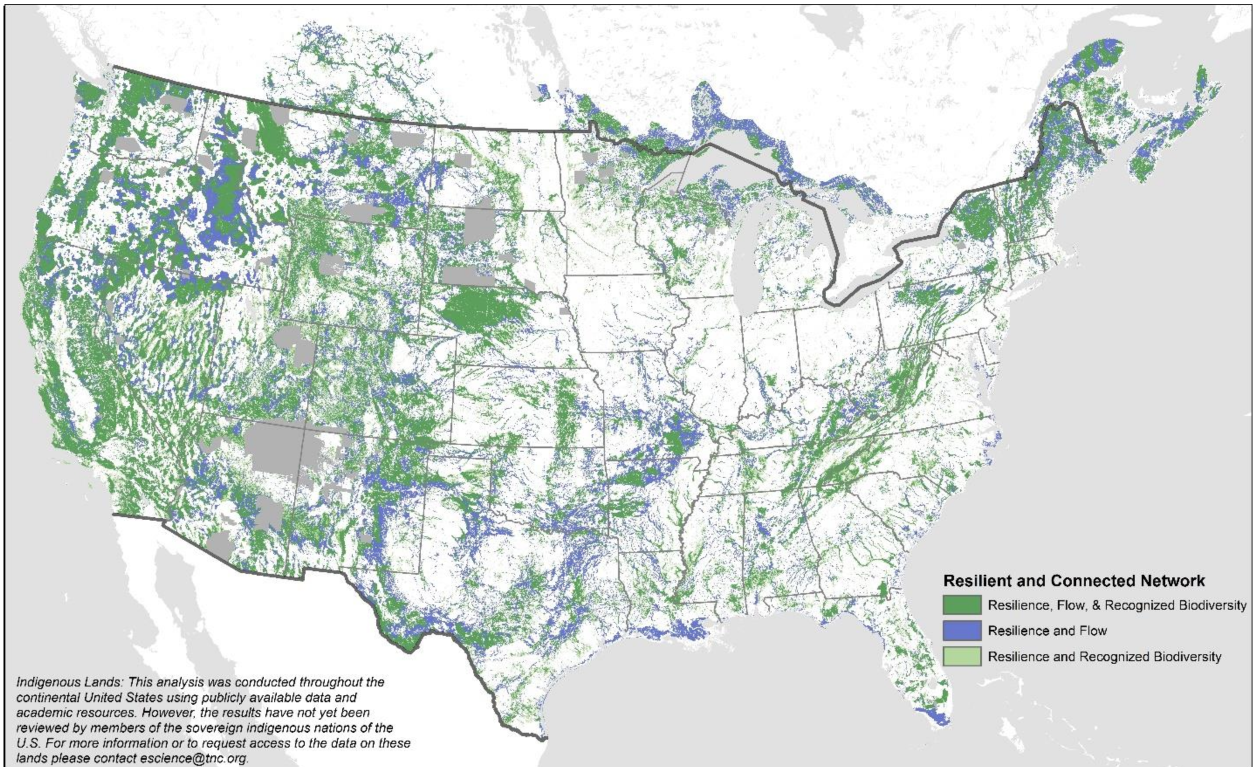
Table 2. Co-occurrence of network characteristics comprising the RCN

Resilient and Connected Network		**% Of CONUS**
RFB	Resilience, Climate Flow, Biodiversity	21%
RF	Resilience, Climate Flow	12%
sRB	Resilience, Biodiversity (secured)	1%
sR	Resilience (secured)	1%
Total		**35%**
Not in RCN but could be added after investigation		
RB	Resilient, Biodiversity (unsecured)	
R	Resilient only (unsecured)	
FB	Climate Flow, Biodiversity	

The RCN is a subset of the three other datasets and is restricted to areas where two or more values co-occur. As such, it represents the most area-efficient way to meet all the goals for a well-connected, representative network of resilient sites focused on biodiversity. Users who are interested in a specific site should examine the individual component datasets to understand and explore their implications. Many sites that are not included in the RCN may have multiple values, making them worthy of conservation and important additions to the network (Figures 1 & 2). Therefore, the TNC team has instituted a process to evaluate and augment the network where needed.

Areas identified by the analysis are important for conservation, but the RCN is not a conservation plan. Conserving the RCN will likely require hundreds of local conservation plans to be developed for specific places and which incorporate relevant data on threats, costs, benefits, unintended consequences, and feasibility. It will be critical to engage a diversity of voices, opinions, and stakeholders for each area identified on the map to balance the needs of the local human communities with those of the biodiversity targets. The TNC team anticipates the boundaries of the sites to expand or vary in substantial ways from the ecologically derived boundaries based on local input and information. Case studies that illustrate area-specific conservation are becoming available and TNC has begun to collect them so that users can learn from past outcomes.

Figure 1. The Resilient and Connected Network. The upper map uses three colors to highlight the co-occurrence of the RCN components (RFB, RF, sRB). The lower map shows the full detail of all the combinations of themes and principles.



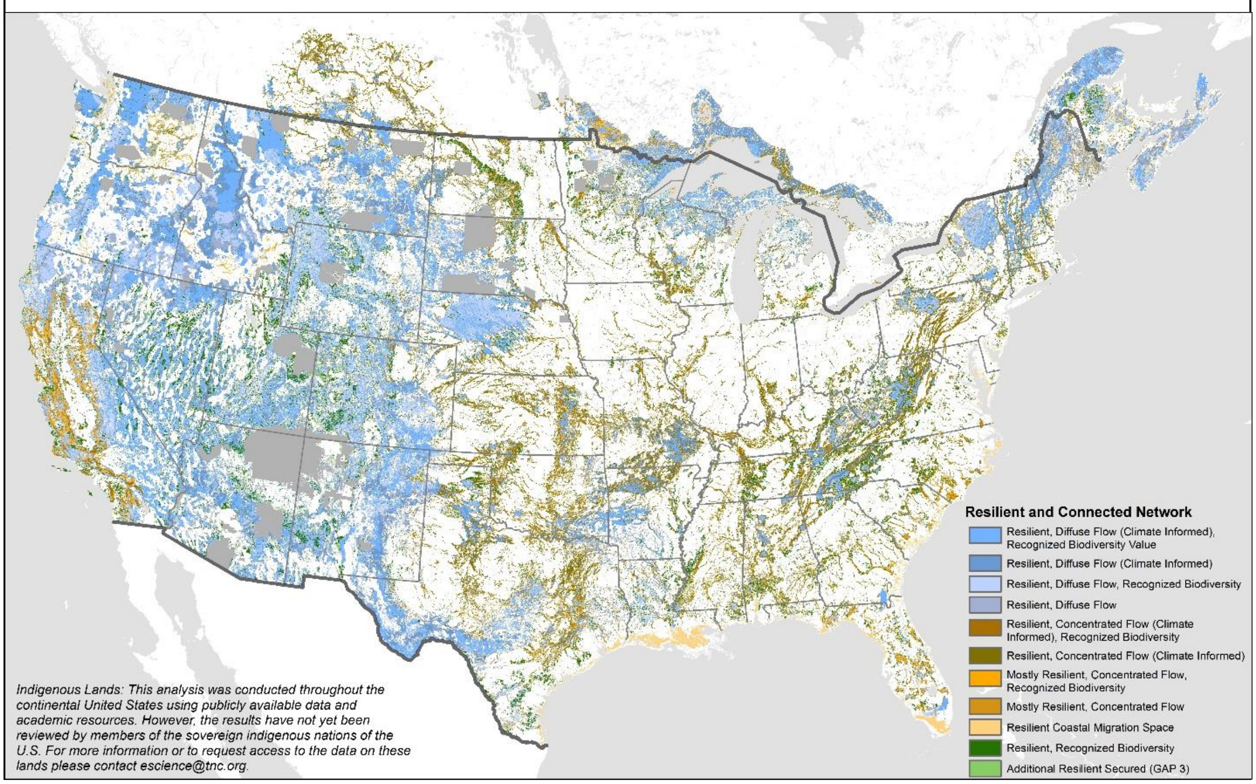
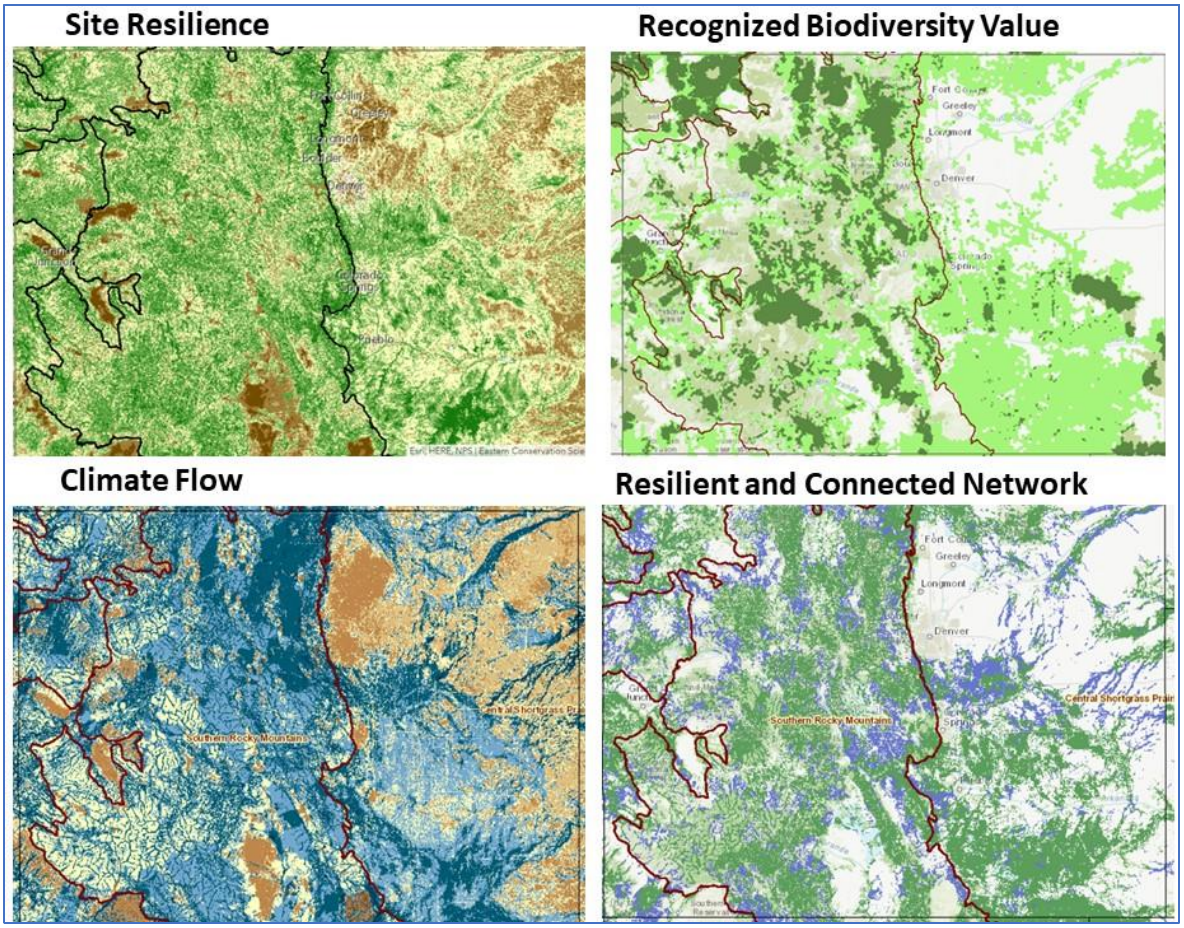


Figure 2. The three components of the Resilient and Connected Network for Colorado.



There is more to conserving nature than just getting the science right (Principle 1). In the TNC team's comments to the Administration, it argued that the AtB initiative (or any 30 by 30 goal) will be successful only if it is guided by the following five principles:

1. <u>Representation and Resilience</u>: the initiative must look at the diversity and quality of ecosystems represented, as well as the connectivity between and within ecosystems—not just a simple percentage of conserved lands and waters.
2. <u>Equity and Inclusion</u>: the AtB goal can only be achieved through strong, transparent, and collaborative engagement with all stakeholders. It must also include attention to diversity, equity, inclusion, and justice.
3. <u>Durability</u>: to last, conservation actions need support from local stakeholders. It is critical to represent a community's needs and perspectives.
4. <u>Effective Management</u>: long-term conservation must include transparent management goals along with specific measures of success and sufficient capacity – including workforce, policies, and incentives – to do the work.
5. <u>Assuring Adequate Funding</u>: for successful implementation, management, and restoration, initiatives must receive funding at a scale that can meet the need.

Conservation Status of the Resilient and Connected Network

"Protected areas remain the fundamental building blocks of virtually all national and international conservation strategies…They provide the core of efforts to protect the world's threatened species and are increasingly recognized as essential providers of ecosystem services and biological resources, and key components in climate change mitigation strategies"
- Nigel Dudley IUCN

Securement and Conservation Value

A secured area is defined as any land or water that is permanently secured against conversion to development. Securement may be achieved through a variety of binding legal means, such as designation by a federal or state entity, fee ownership by a non-government conservation organization (NGO), or a permanent conservation easement held by an individual, organization, or agency. Secured areas may also include tribal lands where cultural practices have sustained biodiversity over time.

Not all secured areas are equivalent in terms of their conservation value. In the U.S., they are further classified by GAP Status (Crist et al. 1998), a scheme developed by the U.S. Fish and Wildlife Service to account for major differences in owner intent and land management practices. GAP status is only applied to permanent conservation lands and is based on the aim of the owner or easement holder and the likelihood that their goals can be implemented. It is straightforward to assign GAP status to a conservation site if the owner's intent is documented:

<u>Protected</u>

- **GAP 1**: intended for biodiversity or nature conservation with solely natural processes.
- **GAP 2**: intended for biodiversity or nature conservation with manipulation and management.

<u>Multiple- Use</u>

- **GAP 3**: intended for multiple uses including recreation, forest management, mineral extraction, biodiversity, etc…
- **GAP 3/9:** intended for multiple uses with a focus on permanent farmland.

Assigning GAP Status to thousands of tracts of conservation land requires many assumptions and it is necessary to make judgement calls when deciding, for example, between GAP 1 or 2 when management mimics natural processes. The TNC team depended on reviews by hundreds of conservationists to calibrate the GAP status data for the U.S. The clearest distinction was between land conserved explicitly for nature (GAP 1 & 2) and multi-use land (GAP 3).

Condition and Management of Conservation Lands

Area-based conservation efforts can reverse declines in species abundance only if the conservation lands are of sufficient size and condition to provide high-quality habitat. In addition to space, thriving species depend on successful breeding and population growth that, in turn, requires ample food, clean water, structure for privacy and quiet, and safety from diseases and predators. The expectation that native species can thrive in marginal or heavily used habitat has proven unrealistic for all but a few species. Many species also depend on intact social networks through which individuals learn the fine points of survival, communication, and mating. If conservation lands provide source habitat, there are many ways to improve working-lands management to better sustain species and ecological services (Kremen & Merenlender 2018). Reversing abundance trends will likely require both an increase in resilient conservation lands and improved management of working lands.

Mapping Secured Lands for the U.S.

To evaluate the conservation status of the RCN and its components, TNC team compiled a national dataset of lands permanently secured against conversion to development (hereafter Secured Lands, Figure 3). These were compiled from 12 national, regional, and state data sources that included state and federally owned public lands as well as private fee-owned land, conservation easements, and permanent conservation restrictions (Table 3). The primary data source was the Protected Area Database US (PAD-US). The TNC team also worked with state agencies and the land trust community to supplement the PAD-US dataset with better information on state and private easements and fee lands. The team simplified its 12-source composite dataset into a non-overlapping single layer and distributed the results for review by the geographic steering committees. When information on Gap Status was missing, it was assigned by knowledgeable experts who knew the land in question.

Figure 3. Secured lands of the contiguous United States by GAP Status.

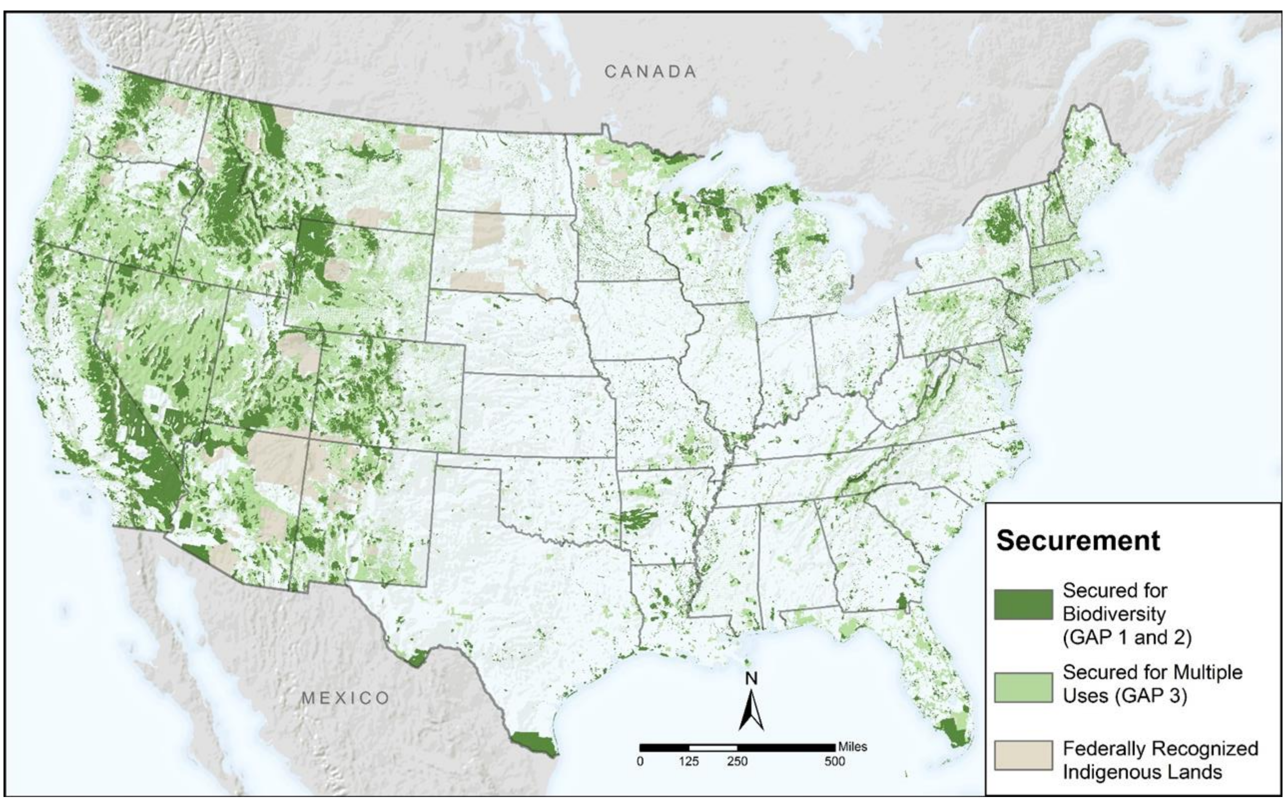
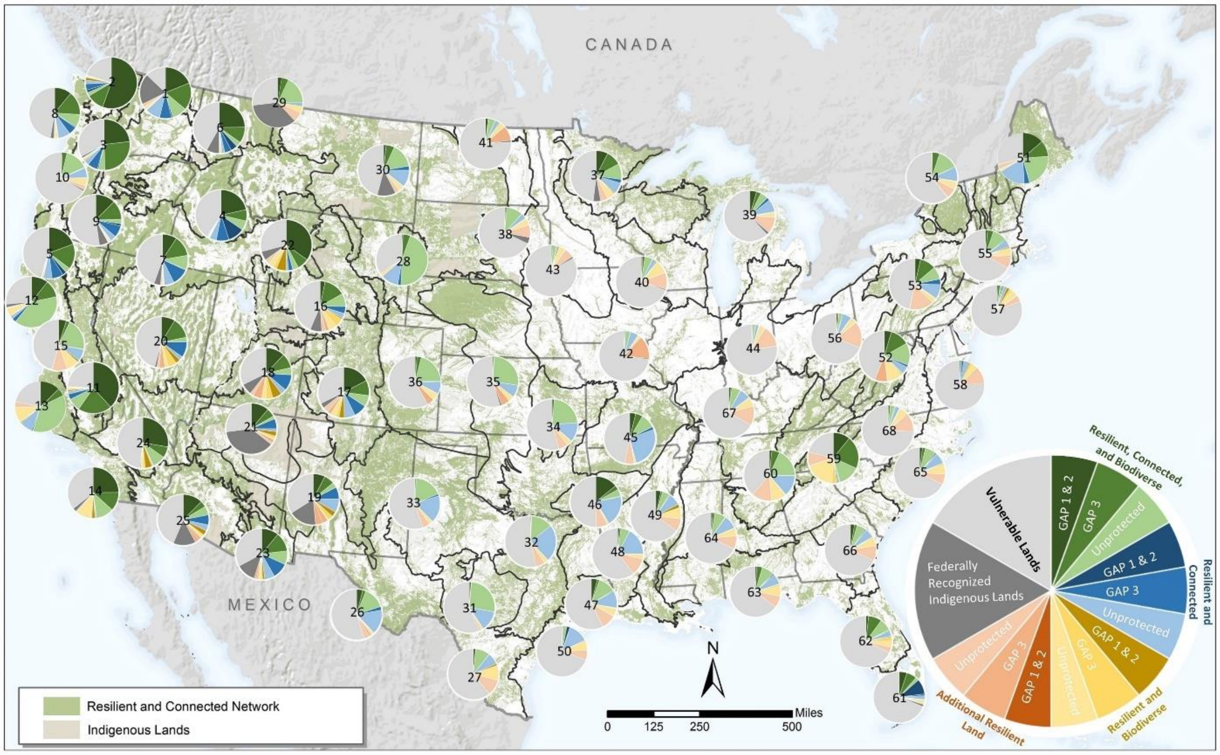


Table 3. Secured Areas Data Sources

National Sources
Protected Areas Database of the U.S. (PAD-US 2.1, 2, and 1). U.S. Geological Survey (USGS) Gap Analysis Project (GAP).
National Conservation Easement Database (NCED). Ducks Unlimited and Trust for Public Land.
TNC Lands. The Nature Conservancy. Boundaries of TNC owned and managed land.
Canadian Protected and Conserved Areas Database (CPCAD) 2020, Canadian Council on Ecological Areas (CARTS)
Regional Sources
Eastern U.S. Secured Areas. The Nature Conservancy (TNC), State Chapter GIS compilations and contributions covering 22 Eastern US states and Eastern Canada.
Conservation And Recreation Lands (CARL) in the Great Lakes Atlantic Region. Ducks Unlimited
State Sources
California Protected Lands Database (CPAD)
California Conservation Easement Database (CCED)
Illinois Protected Natural Lands,(I-view) Prairie State Conservation Coalition
Indiana Managed Lands. Indiana Dept. of Natural Resources
Public Lands for Conservation and Recreation in IOWA
Minnesota Dept. of Natural Resources: State Managed Public Lands

The results show that 44 percent of the RCN is secured against conversion, with 21 percent protected explicitly for biodiversity (GAP 1 and 2), and 23 percent secured on multiple-use public lands or conservation easements (GAP 3). The secured portion of the RCN covers 15 percent of continental U.S. by area, and the unsecured RCN covers 20 percent of CONUS. Within the secured RCN, 30 percent is on land with all three components (RFB), 9 percent RF, and 5 percent RB (Figures 4 & 5). Two percent of the network is on federally recognized tribal lands held by the 344 Sovereign Nations within CONUS. These lands are currently concealed on the TNC's web tool at the request of one Nation. The TNC team respects the sovereignty of Tribal Nations and is committed to undergoing review in collaboration with each Sovereign Nation for their determination as to whether the data for their lands may be shared.

Figure 4. Securement of the RCN by ecoregion. The pie charts show securement of the RCN by category combinations: Green = Resilience-Flow-Biodiversity, Blue = Resilience-Flow, Yellow = Resilience-Biodiversity, Orange = Resilience only, Dark Grey = Tribal, Light Grey=Vulnerable



PACIFIC NORTHWEST
1 Okanagan
2 North Cascades
3 West Cascades
4 Middle Rockies - Blue Mountains
5 Klamath Mountains
6 Canadian Rocky Mountains
7 Columbia Plateau
8 Pacific Northwest Coast
9 East Cascades - Modoc Plateau
10 Willamette Valley - Puget Trough

CALIFORNIA
11 Sierra Nevada
12 California North Coast
13 California Central Coast
14 California South Coast
15 Great Central Valley

ROCKY MOUNTAINS
16 Utah-Wyoming Rocky Mountains
17 Southern Rocky Mountains

ROCKY MOUNTIANS (CONT.)
18 Utah High Plateaus
19 Arizona-New Mexico Mountains
20 Great Basin
21 Colorado Plateau
22 Wyoming Basins

WARM DESERTS/TAMAULIPAN
23 Apache Highlands
24 Mojave Desert
25 Sonoran Desert
26 Chihuahuan Desert
27 Tamaulipan Thorn Scrub

GREAT PLAINS
28 Black Hills
29 Fescue-Mixed Grass Prairie
30 Northern Great Plains Steppe
31 Edwards Plateau
32 Crosstimbers /S. Tallgrass Prairie
33 Southern Shortgrass Prairie
34 Osage Plains/Flint Hills Prairie

GREAT PLAINS (CONT.)
34 Osage Plains/Flint Hills Prairie
35 Central Mixed-Grass Prairie
36 Central Shortgrass Prairie

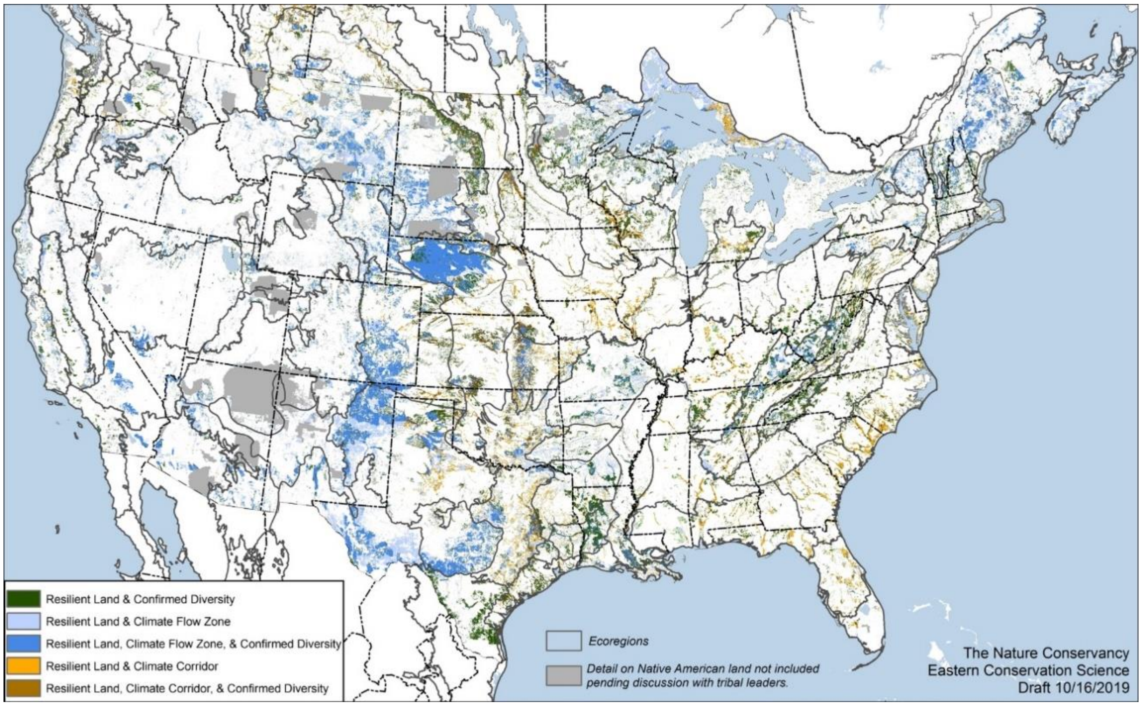
GREAT LAKES/TALLGRASS PRAIRIE
37 Superior Mixed Forest
38 Dakota Mixed-Grass Prairie
39 Great Lakes
40 Prairie-Forest Border
41 Aspen Parkland
42 Central Tallgrass Prairie
43 Northern Tallgrass Prairie
44 North Central Tillplain

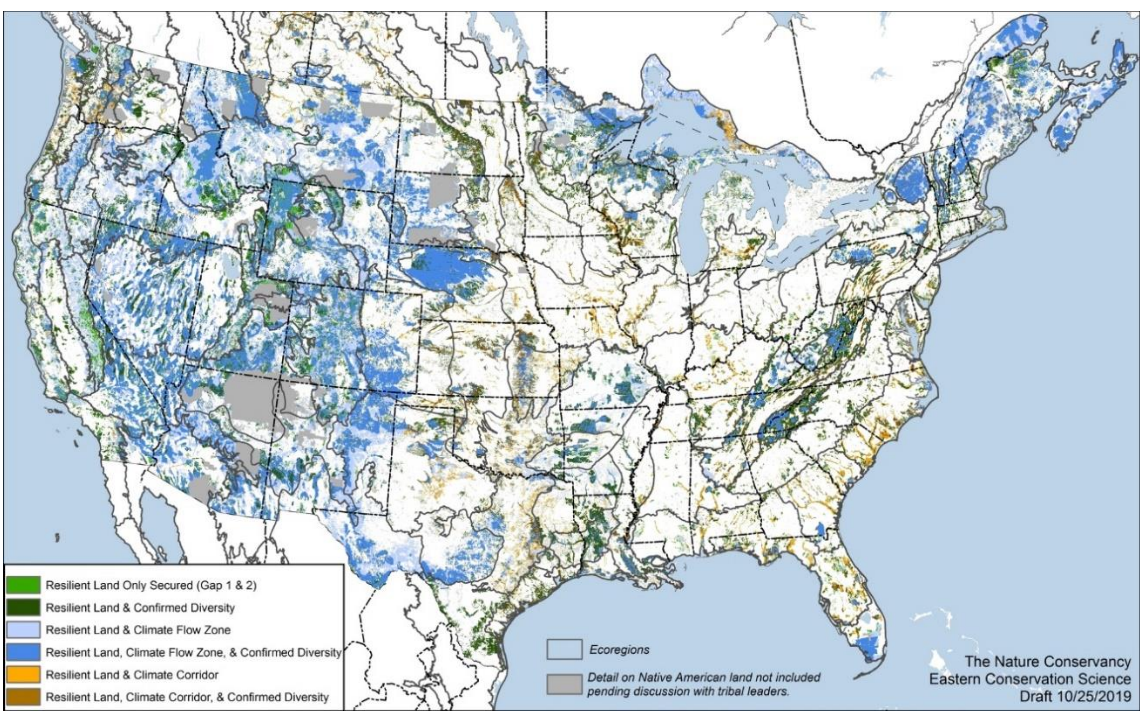
LOWER MISSISSIPPI AND OZARKS
45 Ozarks
46 Ouachita Mountains
47 West Gulf Coastal Plain
48 Upper West Gulf Coastal Plain
49 Mississippi River Alluvial Plain
50 Gulf Coast Prairies and Marshes

EAST
51 Northern Appalachian / Acadian
52 Central Appalachian Forest
53 High Allegheny Plateau
54 St. Lawrence - Champlain Valley
55 Lower New England/N. Piedmont
56 Western Allegheny Plateau
57 North Atlantic Coast
58 Chesapeake Bay Lowlands
59 Southern Blue Ridge
60 Cumberlands/ S. Ridge & Valley
61 Tropical Florida
62 Florida Peninsula
63 East Gulf Coastal Plain
64 Upper East Gulf Coastal Plain
65 Mid-Atlantic Coastal Plain
66 South Atlantic Coastal Plain
67 Interior Low Plateau
68 Piedmont

The secured areas dataset is dynamic and challenging to keep current as new conservation lands are added continuously and compiled annually. Their spatial distribution reveals that most of the RCN in the West is on public lands, while in the Midwest it is largely unconserved (Figure 5). In the East, conservation of the RCN is a mix of public and private lands. To view secured lands in the RLMT (https://maps.tnc.org/resilientland/), go to the reference section and turn on the Secured Areas layer. Click on a polygon to see the Area Name, Acreage, and GAP Status.

Figure 5. Secured and unsecured RCN. The upper map shows the full RCN with all its component categories. The lower map shows the unsecured RCN that remains after removing the protected (GAP 1 & 2) and multiple-use (GAP 3) lands. The results illustrate the importance of biodiversity-friendly management of multiple-use public lands in the West, and the need for extensive and creative conservation in the Midwest where the RCN is largely unsecured. Tribal lands are greyed out at the request of one Tribe.





Carbon Stock in the Resilient and Connected Network

"We cannot hope to either understand or to manage the carbon in the atmosphere unless we understand and manage the trees and the soil too." - Freeman Dyson

Carbon is an essential element of life that underlies all organic compounds like proteins, sugars, carbohydrates, and fats. Plants, animals, and people all need carbon to live and grow. Animals consume carbon indirectly when they eat plants or other animals that have already absorbed it. Plants extract carbon directly out of the air as carbon dioxide (CO^2), releasing the oxygen and converting the carbon to sugars and carbohydrates, which are used for metabolic processes or converted to biomass and stored. Burning stored carbon – often in the form of coal or petroleum – returns carbon to the atmosphere while releasing the energy that has fueled industrial growth.

To retain a habitable planet for people and nature, scientists agree that we must curtail excessive release of carbon molecules, which increase the atmosphere's heat-trapping capacity and alter the climate. The Intergovernmental Panel on Climate Change (IPCC) scenarios aimed at limiting global warming to below 2°C assume large-scale use of carbon dioxide removal methods in addition to reductions in emissions from human activities such as burning fossil fuels and land-use activities.

By far, the cheapest and most mature carbon dioxide removal method is permanent conservation and improved land stewardship (Griscom et al. 2017). Forests, bogs, swamps, marshes, grasslands, seaweed, and phytoplankton have evolved to sequester carbon and have been doing so for millions of years. Thus, the carbon benefits of land protection and improved management have risen to the forefront of conservation discussions.

Estimated Carbon Stock for the Resilient and Connected Network

To estimate the amount of carbon stock stored in the RCN and other natural lands, the TNC team compiled two recently released datasets that map carbon stock for the contiguous U.S. One dataset looks at forest carbon and applies only to forested areas, while the other looks at soil carbon and is applicable everywhere but only estimates carbon for the upper 30 centimeter (cm) of soil. If used together the datasets can provide a reasonable estimate of the land's carbon resources. Details on each are below.

Forest Carbon: Estimates of 2010 forest carbon stock and components—aboveground, coarse woody debris, and soil/other—are from Williams et al. (2021) following methods described for the Southeast U.S. in Gu et al. (2019). To estimate carbon stock, attributes were determined for all forested 30-m pixels in the contiguous U.S. A forest carbon cycle model trained to match Forest Inventory and Analysis (FIA) data was used to predict carbon stocks for 2010 based on site-level attributes of forest type group, years since disturbance, and site productivity class. Results were iterated backward in time to provide continuous, annual reporting of forest carbon dynamics for each pixel. Most prior studies lacked spatial detail on the age of forest stands that persisted in a forested condition during the satellite data era, but this study used remotely sensed biomass to estimate the stand age condition of these persisting, intact forests, distinguishing relatively young stands—those that are between 30 and 50 years old—from older stands.

Soil Carbon: Estimates of soil organic carbon (SOC) for 0-30 cm topsoil layer at 250-m resolution for the contiguous U.S. and Mexico are from Oak Ridge Lab (Guevara et al. 2020). The estimates are for the period between 1991-2010 and were derived using the USDA Rapid Carbon Assessment. The team used over 6000 field soil samples and multiple environmental variables representative of the soil-forming environment coupled with a machine learning approach for optimized soil organic carbon prediction. For most systems total soil carbon will be much greater than what is given for the topsoil.

Stock and Sequestration in the Resilient and Connected Network

Using these carbon datasets, the RCN retains an estimated 29.1 billion metric tons (mt) of total 2010 carbon stock, equivalent to 47 percent of the entire U.S. carbon stock. The largest RCN carbon stock is in California (2.7 billion mt) and the smallest is in Delaware (4 million mt). The total carbon stocks reflect the size of the state, while the highest per-acre stocks in the RCN are mostly in the Northeast: Vermont (95 mt/ac), Massachusetts (94 mt/ac), New Hampshire (92 mt/ac), and New York (92 mt/ac). The single highest RCN stock is in Washington (100 mt/ac). The largest carbon differential is in Michigan where the RCN covers 19 percent of the state but stores 38 percent of the total carbon.

Potential carbon sequestration from the RCN from 2010 to 2050 is 4.4 billion metric tons, equivalent to removing 439 million passenger cars from the road every year. The highest potential sequestration is again in California (370 million mt) with Oregon (349 million mt) and Washington (334 million mt) close behind. The highest per-acre sequestration rates are mostly in the Southeast: South Carolina (21 mt/ac), Alabama (19 mt/ac), Georgia (19 mt/ac), Mississippi (17 mt/ac), Washington (16 mt/ac), North Carolina (15 mt/ac), and Louisiana (15 mt/ac). The Washington RCN has the distinction of being in the top five states for total and per-acre carbon stock, as well as for total and per-acre sequestration.

TNC team added both datasets to the RLMT (https://maps.tnc.org/resilientland/) to allow users to estimate carbon for any area of interest by drawing an outline around it, importing a shape file delineating its boundary, and clicking the "Assess Carbon Box." For sites that are a mixture of forest and non-forest, a user can estimate total carbon by adding the total forest carbon plus the proportion of the site in non-forest (given in the NLCD landcover) times the total soil carbon (Figure 6).

In forested areas, users can estimate potential carbon sequestration through 2050 (Figure 7). The data used to calculate the 2050 carbon stocks was the same as for the 2010 stock, except that the model was run to 2050 assuming no disturbances to the forests after 2010. This can serve as a useful benchmark for sequestration, although it will not necessarily be a realistic estimate, as few U.S. forests grow undisturbed for 40 years given harvest, conversion to agriculture or development, and the increased frequency and intensity of climate-change disturbances. While conservation efforts can limit harvest and conversion, it is difficult to predict future disturbances and users should be aware that the actual sequestration may be less than predicted in the RLMT.

Figure 6. Estimating total carbon stock for Fakahatchee Strand State Preserve, Florida. The park's 65,576-acres—marked with a red outline—consist of Oak/Gum/Cypress forested wetland (63 percent) and emergent herbaceous marsh (37 percent). Total carbon stock is estimated as the sum of the total forest carbon plus the non-forest proportion of the soil carbon (Forest Carbon + (0.37* Soil Carbon)). In this case, 3,715,522 metric tons of total carbon stock.

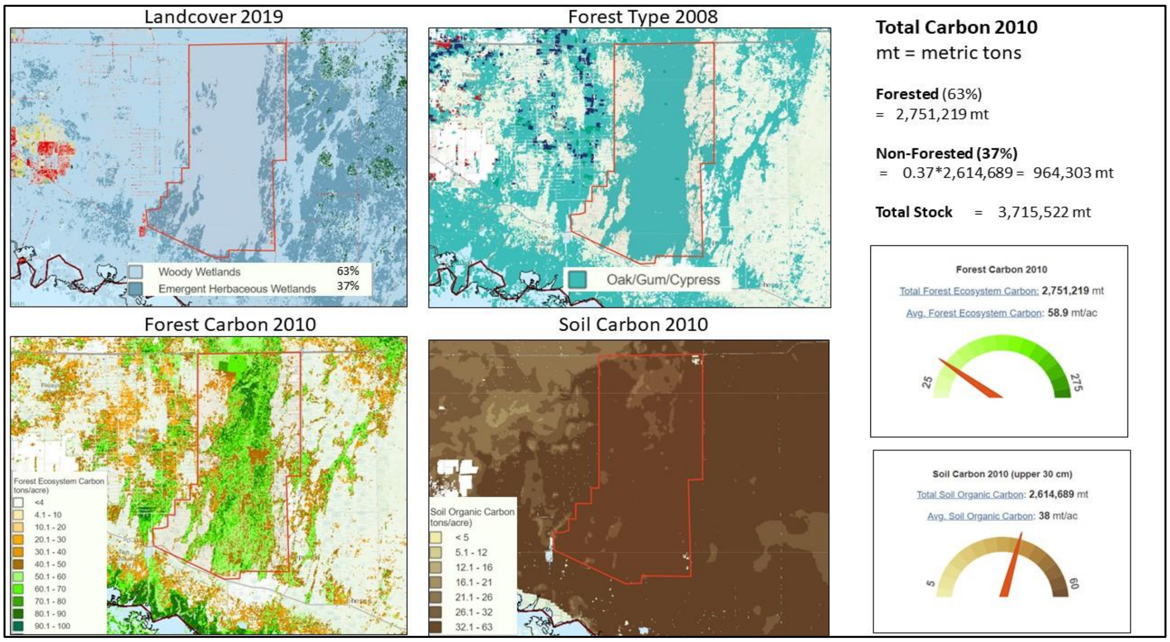
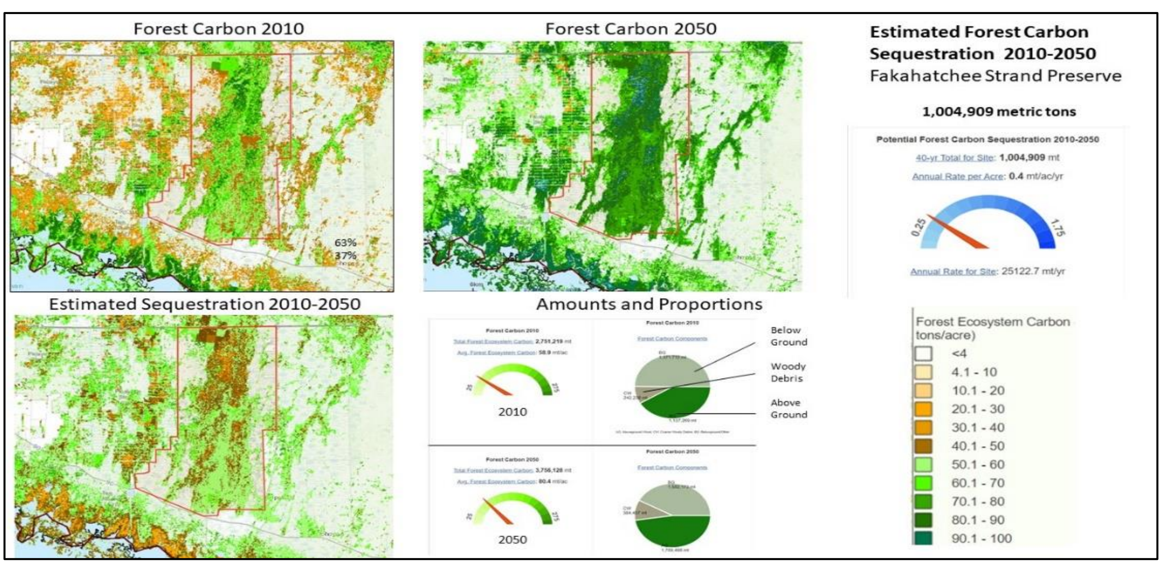


Figure 7. Estimating forest carbon sequestration for Fakahatchee Strand Preserve, Florida. The forested portion of the preserve—marked with a red outline—has an estimated sequestration rate of 251,227 metric tons per year. By 2050, the site would sequester over one million metric tons, corresponding to a proportional increase in the above-ground portion of the carbon stock.



Carbon Data available in the RLMT (contiguous U.S. only)

- Williams et al. 2021. Forest Ecosystem Carbon 2010
- Williams et al. 2021. Forest Ecosystem Carbon 2015
- Williams et al. 2021. Potential Forest Ecosystem Carbon Sequestration (2010-2050)
- Ruefenacht 2008. Forest Types
- Guevara 2020. Soil Organic Carbon 2010
- Dewitz 2019. National Landcover Dataset
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II. Characteristics of a Climate-Smart Conservation Network

This section explains the concepts, importance, and mapping methods for each component of the Resilient and Connected Network. Users of this science often find the components more useful than the final RCN when it comes to evaluating sites and understanding their outstanding characteristics and vulnerabilities. When used in conjunction with the RLMT, users can explore a site from the perspective of representation, resilience, biodiversity, and connectivity.

Representation

Ecological representation is a measure of how inclusive a set of conservation land and waters are with respect to the diversity of habitats, ecosystems, and species they are intended to conserve. To ensure the long-term persistence of all species and ecosystems and allow for natural environmental change, a conservation network should contain a representative sample of the full spectrum of biodiversity at all levels of organization (Norse & McManus 1980).

Nature has evolved to persist and thrive in an extraordinary variety of conditions and habitats. Representing the full range of those conditions and habitats in area-based conservation is the most basic way of ensuring that every species has a place to thrive. Achieving this is challenging because human values and interests are strongly biased towards certain habitats. Most protected lands, for example, are in areas that are difficult for people to exploit commercially such as high mountains or dry deserts. These environments have distinctive biodiversity, and it are important for conservation, however, fertile lowland valleys, open prairies, and floodplains also have distinctive biodiversity but are dramatically underrepresented in conservation.

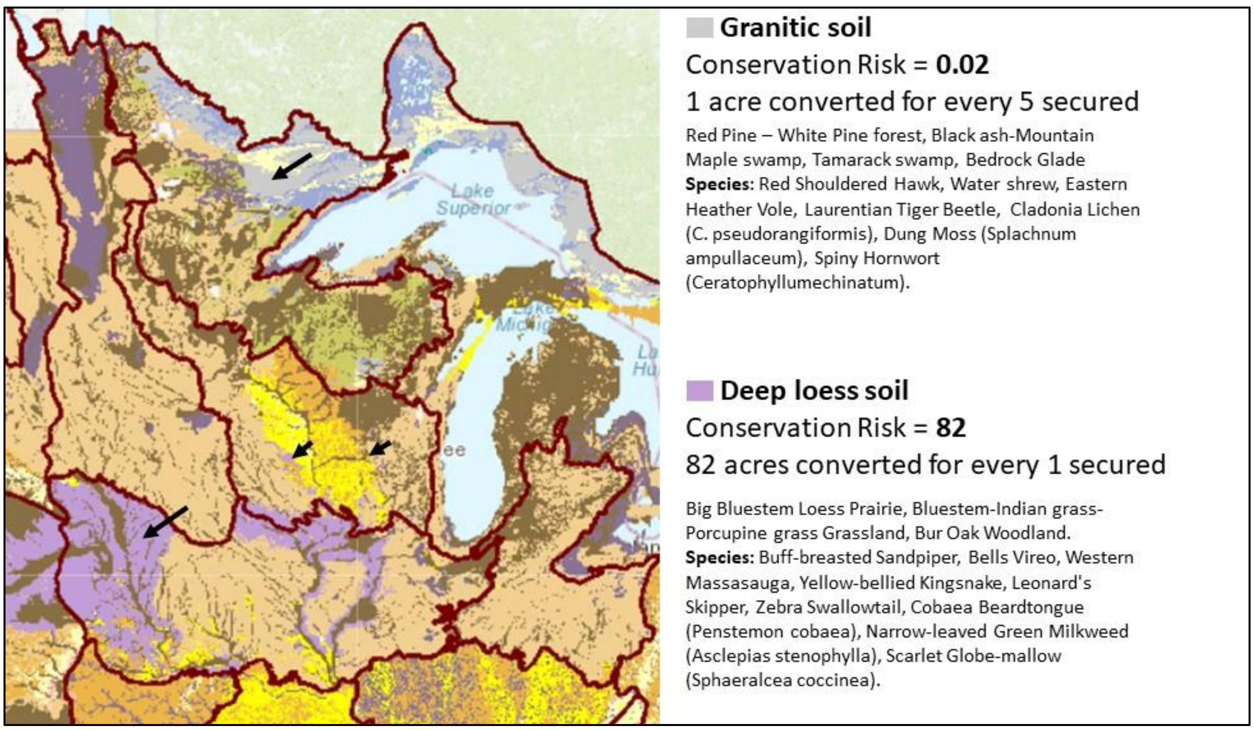
The same bias is evident even at an ecoregion scale. The Central Tallgrass Prairie ecoregion is over 80 percent converted to cultivated crops and less than 1 percent protected, while the high elevation Utah-Wyoming Rocky Mountains ecoregion is mostly natural and greater than 50 percent protected. With climate change, underrepresented habitats will likely grow more isolated and fragmented, increasing the risk of degradation, species loss, and habitat loss.

Assessing Representation

In area-based conservation, representation is measured as the distribution of land securement across a set of ecologically or politically meaningful units: ecoregions, states, habitats, or geophysical settings. A common metric is the Conservation Risk Index (Hoekstra et al. 2005), which summarizes risk as the ratio of land conversion to land securement for a given unit. For example, wind-deposited loess soils in the Great Lakes region have few secured examples of their native prairies and are at high risk because, for every one acre secured, 82 acres have been converted to agriculture or development (CRI=82).

In contrast, granitic soils in the northern end of the Great Lakes region show the opposite pattern, with over 20 percent secured, and a low conservation risk of five acres secured for every one acre converted (CRI=0.02). The two settings are not ecologically interchangeable and securing one does not sustain the biodiversity of the other (Figure 8). The CRI can be calculated for any of the units described below.

Figure 8. Comparison of the Conservation Risk Index between two geophysical settings. Habitats on granite derived soils have a low risk of conversion while those associated with deep loess are unlikely to persist unless society greatly increase the amount of securement.



Stratification Units

An easy way to ensure representation is to stratify the distribution of conservation lands across ecologically meaningful geographic units such as ecoregions, bedrock types, or climate zones. Ensuring a representative distribution of conservation lands is the most effective way to ensure these areas represent a wide spectrum of biodiversity. TNC's Resilient and Connected Network was designed to meet a complex stratification goal of distributing conservation across geophysical settings within Ecoregions.

The following section explores the pros and cons of several commonly used stratification units.

Ecoregions

Ecoregions are a common unit used to measure representation across conserved land in large, ecologically variable regions, such as the contiguous U.S. An ecoregion is a subdivision of these areas, defined based on lands' shared physical characteristics. In terrestrial systems, the physical characteristics can be physiography and topography, and/or vegetation structure (e.g., High Allegheny *Plateau* vs. Central Shortgrass *Prairie*). Terrestrial ecoregions have clear and distinct geographic boundaries, which make them easy to use for measuring the distribution of area-based conservation lands.

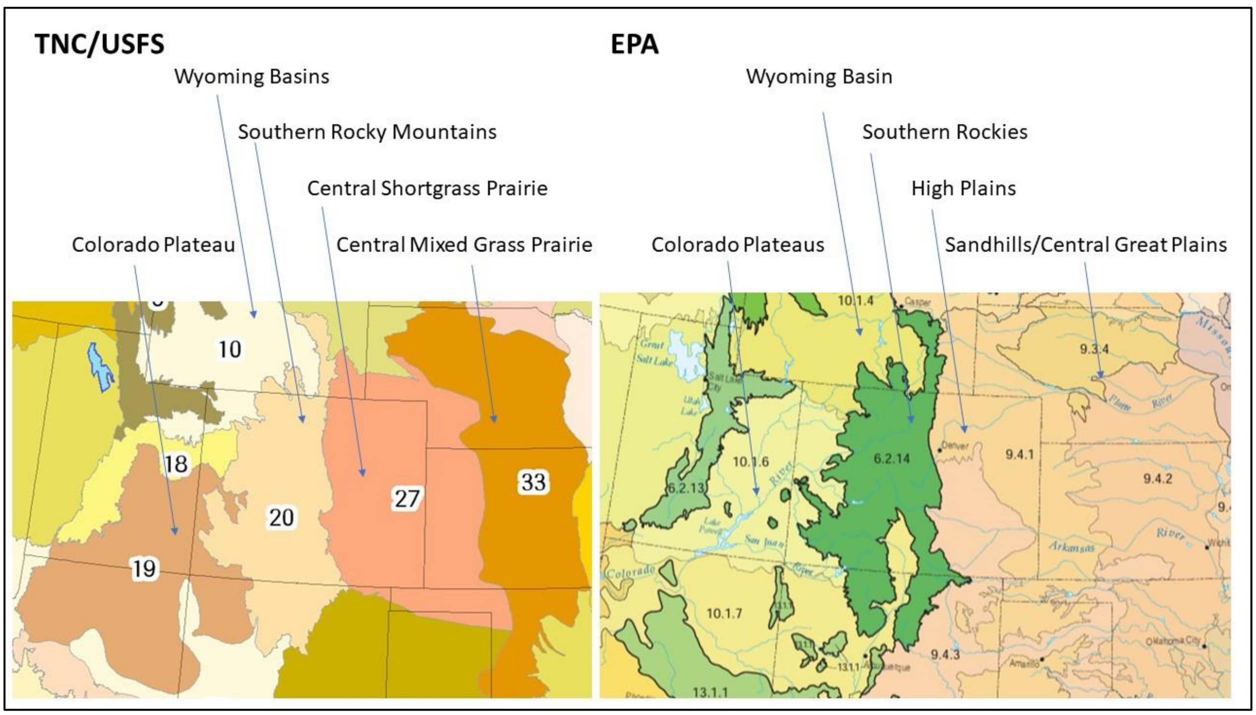
Several ecoregion schemes are available for the U.S. The U.S. terrestrial ecoregions defined and used by TNC to create the RCN are based on the geographic subsections developed by USFS for the continental U.S. (Cleland et al. 2007) and by USGS for Alaska (Nowacki et al. 2001). TNC and its partners used these ecoregions to identify and map a portfolio of conservation sites for each, representing characteristic habitats, rare species populations, and exemplary natural community occurrences. Descriptions of each ecoregion and details of the conservation targets found within it are available as individual ecoregion reports (see Biodiversity Value).

The U.S. EPA and USGS have developed a widely used ecoregion map of North America in conjunction with nine Canadian and Mexican agencies. The EPA/USGS ecoregions are similar in concept to the TNC/USFS ecoregions, and they often agree on the major ecoregions but differ in how they delineate the boundaries, the smoothness of the delineation, and the ecoregion name (Figure 9).

Figure 9. **Comparison between TNC and EPA Level 4 ecoregions in Colorado.** Both schemes recognize the Wyoming Basin and Southern Rocky Mountains, although the boundaries are slightly different. TNC's Central Mixed Grass Prairies is equivalent to EPA's Nebraska Sandhills and Central Great Plains. The TNC ecoregions tend to have smoother boundaries than the EPA's more finely delineated ecoregions which may have small discontinuous outliers. Freshwater and marine realms can also be divided into ecoregions. The freshwater ecoregions developed by the World Wildlife Fund (WWF) Conservation Science Program were created in partnership with TNC and 200 freshwater scientists from institutions around the world.

This framework is widely used for freshwater planning. Freshwater ecoregions use drainage areas and zoographic history. In practice, freshwater ecoregions are more heterogeneous than terrestrial ecoregions, as drainage areas always include higher elevation areas where streams originate as well as low valleys and flats where the streams converge into major rivers.

The world's marine ecoregions were defined in Spalding et al. (2007) and North American marine ecoregions have been developed by an international team of scientists led by McGill University for the Commission for Environmental Cooperation. These are incorporated into marine planning efforts and are considered in NOAA's *Representativeness of Marine Protected Areas of the United States* report. In coordination with multiple partner organizations, TNC has developed marine assessments for most U.S. estuarine and marine ecoregions.



States and Counties

States and counties can be useful units of representation, despite being political entities that are neither homogenous nor bound by ecological lines. This is because their internal constituents share policies, laws, and values, and they are often the geographies within which conservation decisions are made.

One way to involve states in representation is to divide each into its ecoregions as a template for conservation. For example, Colorado has two primary ecoregions: Southern Rocky Mountains, and Central Tallgrass (Figure 8). For these two ecoregions, Colorado has high responsibility conserving species and ecosystems and efforts can be made to ensure that the state's conservation lands are spread across both ecoregions.

Colorado also has four ecoregions for which the state contains only a small portion of a larger shared ecoregion: Wyoming Basin, Utah-Wyoming Rocky Mountains, Utah High Plateau, and Colorado Plateau. For these, the state could work to ensure that some of its conservation efforts are distributed across each ecoregion and collaborate with neighboring states to guarantee that the ecoregion is adequately represented in conservation.

Nature's stage (geophysical settings)

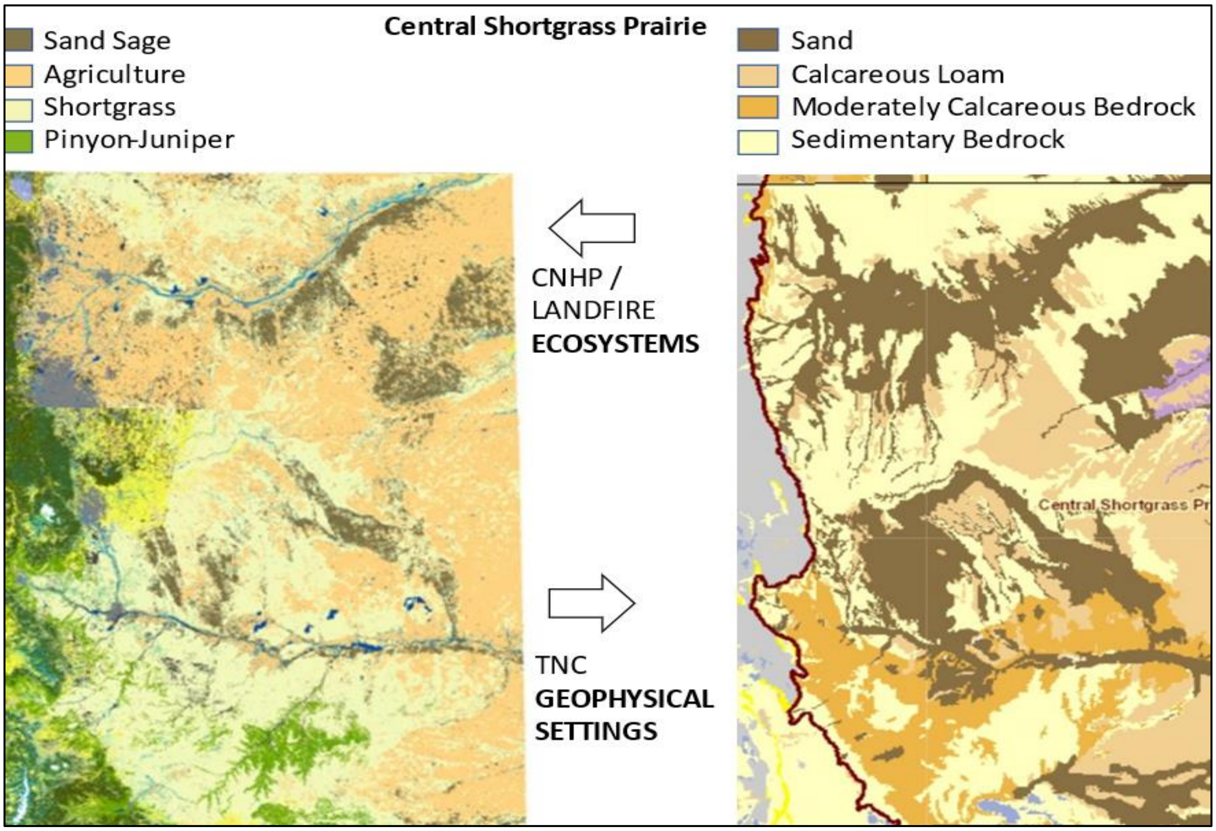
Ecoregions are relatively homogenous, but most contain a range of soils, geology types, and elevations. To fully sustain the biodiversity of an ecoregion, conserved land and water can be further distributed across relevant environmental gradients. These may be identified using a classification of major ecosystems and/or vegetation types, or by mapping the geophysical properties that underpin their distribution.

TNC helped establish a tool for mapping geophysical properties, known as Conserving Nature's Stage (Anderson & Ferree 2010, Bier et al. 2015, Lawler et al. 2015, Schrodta et al. 2019). The software ensures that all ecosystems are represented under both current and future climates by mapping the geophysical gradients that underlie current patterns of diversity, and that are likely to endure into the future under any climate.

Although climate factors may drive diversity at continental scales, within a state or ecoregion, factors like soil, geology, topography, and hydrology often take precedence over regional climate in explaining diversity patterns. Using this approach, conservationists can assess ecosystem representation using commonly available geophysical datasets that reveal major differences in soils, bedrock, or elevation. Overlays of current habitats, ecological systems, or vegetation types can be used to further study the correspondence between sites and habitats.

The land's geophysical properties influence nutrient availability, pH, soil texture, wetness, and solar radiation. As a result, dominant vegetation types and species complexes often reflect the distribution of soils and topography. In the Central Shortgrass Prairie region of Colorado, sand sage communities are found in deep sandy outwash soils, while shortgrass prairie communities are more common on shallow sedimentary and moderately calcareous deposits. Agriculture is concentrated on, although not limited to, calcareous loams (Figure 10).

Figure 10. Comparison of an ecosystem map to a geophysical setting map. The maps show the Colorado portion of the Central Shortgrass Prairie where the distribution of the enduring geophysical settings and the LANDFIRE ecological systems match relatively closely. This comparison can help develop an understanding of what is relatively stable in the landscape and what could be changing in response to climate.



Ecosystems

Ecosystems are a practical way to assess representation, as conservationists are often familiar with their local types and interested in how well conserved they are. Challenges arise because ecosystems have been defined and mapped in a variety of ways and do not always have clear distinct boundaries. Moreover, ecosystems come in a variety of forms, with vegetation types, natural communities, and ecological systems being the most common.

Vegetation Types are recognizable plant assemblages defined by their dominant species and life forms such as a Black Oak Savannah, Spruce-Fir Forest, or Little Bluestem Prairie. Their distribution often matches that of the dominant species, and they can be broadly defined or subdivided into numerous subtypes. Ruefenacht et al. (2008) Forest Type Mapping, is a good example.

Natural Communities are widely described and inventoried by the state Natural Heritage Programs who define them as recurring assemblages of plants and animals found in a particular physical environment, such as shale barren, limestone fen, or loess prairie (NatureServe 2022).

Natural communities tend to be smaller in scale than vegetation types and correspond most directly to geophysical settings. The TNC team used natural community element occurrence points extensively in testing and creating the geophysical settings and landform models because of their clear definitions and precise locations, but they do not exist as a spatially comprehensive map.

Ecological Systems are larger scale classification units described as multiple plant communities that tend to co-occur based on recurrent similarities in environmental setting and ecological dynamics. TNC's Terrestrial Habitat Map for the Northeast US and Atlantic Canada (Ferree & Anderson 2017) is an example of a spatially comprehensive dataset of ecological systems that has proven useful for assessing representation, current condition, and alterations of natural systems.

Ecological systems have been nationally standardized by NatureServe (Comer et al. 2003) and used as a mapping unit by the LANDFIRE program. LANDFIRE's national biophysical settings (BpS) dataset (LANDFIRE 2016) depicts the distribution of 403 ecological systems that may have been dominant on the landscape before Euro-American settlement and is based on both the current biophysical environment and an approximation of the historical disturbance regime.

The TNC team used LANDFIRE data to test whether representation based on geophysical settings would also capture all ecosystems. The team overlaid the RCN on the LANDFIRE BpS data and found that it captured 99.8 percent of the 403 possible types, reinforcing the correspondence between geophysical settings and ecosystem types. By distribution, 99 percent had over 5 percent of their total area in the RCN, 97 percent had over 10 percent, 94 percent had over 15 percent, and 77 percent had over 30 percent. Only one setting, the 923-acre Mississippi Delta Maritime Forest, was not represented in the RCN, because none of its area had a high resilience score.

Despite their differences, most representation units can be combined to create more detail, especially when done thoughtfully. The NLCD **Landcover/Land use** (Dewitz 2019) maps broad physiognomic cover types—needle-leaved evergreen forests—can be useful to measure representation when combined with the geophysical settings to create landcover-soil types such as forested wetlands on coarse sand.

Representation Datasets

Datasets in the RLMT:

- The Nature Conservancy. 1999. Terrestrial Ecoregions of the United States
- CRCS 2020. U.S. Geology and Soils
- NLCD 2019. Landcover/Land Use
- Ruefenacht et al. 2008 Forest Type Mapping using Forest Inventory and Analysis Data
- LANDFIRE Biophysical Settings

Ecoregions:

- Bailey et al. 1994. Ecoregions and subregions of the United States (map). Washington, DC: USDA Forest Service
- Cleland et al. 2007. Ecological Subregions: Sections and Subsections for the conterminous United States. U.S. Department of Agriculture, U.S. Forest Service
- Environmental Protection Agency. 013. Level III and Level IV Ecoregions of the Continental United States
- Abell et al. 2008. Freshwater Ecoregions of the World
- Spalding et al. 2007. Marine Ecoregions of the World
- Wilkinson et al. 2009. Marine Ecoregions of North America
- NOAA. 2015. Representativeness of Marine Protected Areas of the United States

Geophysical and Ecosystems:

- Horton et al. 2017. U.S. Geological Survey State Geologic Mapping Compilation
- Natural Resources Conservation Service 2014a, b. SSURGO
- Chaney et al. 2019. POLARIS
- LANDFIRE Remap 2016 Biophysical Settings of CONUS. Earth Resources Observation and
  Science Center, U.S. Geological Survey. (And counterparts for Alaska and Hawaii)
- U.S. Geological Survey Gap Analysis Program, 20160513, GAP/LANDFIRE National Terrestrial Ecosystems 2011: U.S. Geological Survey, https://doi.org/10.5066/F7ZS2TM0.
- U.S. Geological Survey. 2019. National Land Cover Database for the Conterminous U.S.
- Ferree C. and Anderson, M.G. 2015. A Terrestrial Habitat Map for the Northeast
- United States and Atlantic Canada. Report and dataset. TNC
- California Department of Forestry and Fire Protection. 2004. Wildlife Habitats: Multisource Land Cover Data. Statewide and county maps

Site Resilience

Site resilience is the capacity of a site to support biological diversity and ecological functions even as the biotic composition changes in response to climate change (Anderson et al. 2014). If adequately conserved, resilient sites are expected to sustain their species and communities for a longer time, and have a slower turnover rate, than less resilient sites.

As climate change drives rapid shifts in species distributions, land and water conservation based on current biodiversity patterns may become less effective in sustaining diversity. Resilient sites are places where microclimatic buffering allows species to persist longer by providing local climatic variability, slowing the rate of turnover, and helping species flourish under a changing climate. These natural strongholds also improve connectivity because thriving populations create dispersal pressure, the engine that powers movement across the landscape. Moreover, because the characteristics that create climatic options are features of the land (topography, hydrology, elevation), the sites could benefit biodiversity under many future climate scenarios.

Assessing Site Resilience

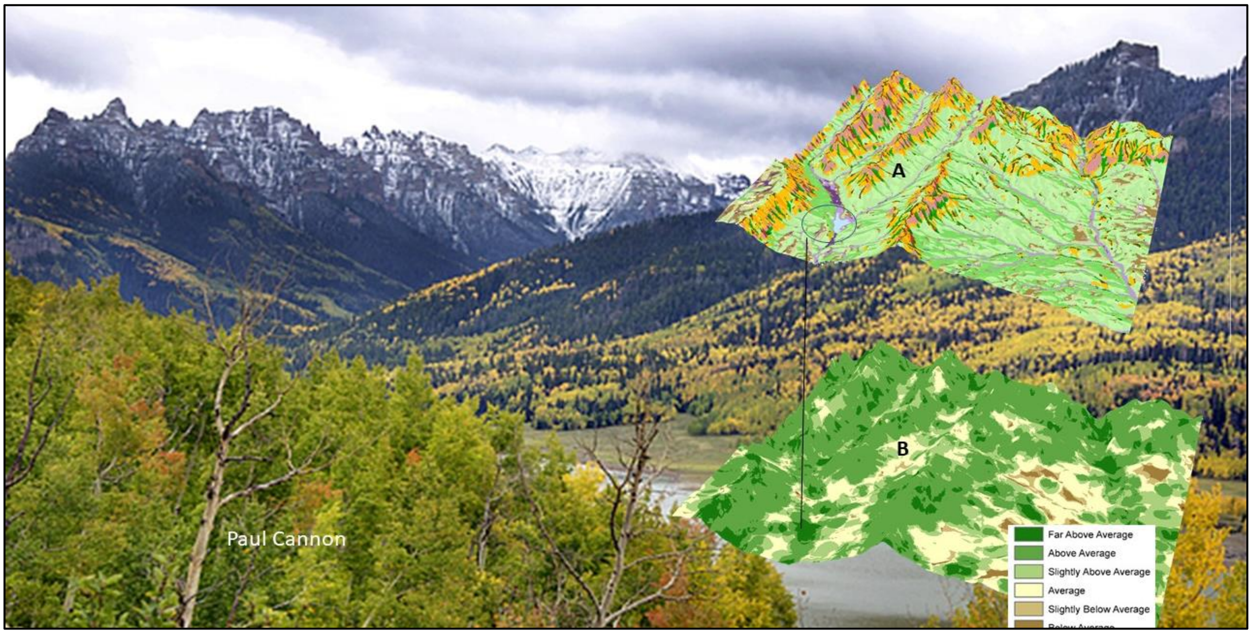
In the RCN analysis, site resilience is measured as a function of landscape diversity that creates persistent microclimates, and local connectedness that ensures access to the microclimates (Anderson et al. 2014, Anderson et al. 2023).

Landscape Diversit**y:** Resilient sites are those that provide resident species with the maximum opportunity to respond on-site to climate change. Microclimate buffering, created by the terrain, provides climatic options for resident species, and slows down the rate of transition as new species arrive and establish. Evidence continues to grow that such properties represent an important buffer for species in response to climate change (Weiss et al. 1988, Willis & Bhagwat 2009, Dobrowski 2010, Suggitt. et al. 2018).

Most species have a preferred temperature and moisture regime—a preferred microclimate—to which they are adapted. As precipitation and temperature patterns change, organisms disperse along moisture and temperature gradients, presumably to stay within their preferred climatic regimes. By having a greater diversity of microclimates, resilient sites are more likely to offer microsites that these organisms find suitable for establishment and growth. Thus, the variety of microclimates present in a landscape is positively correlated with the capacity of the site to maintain species and functions.

Our landscape diversity metric estimates the number of local climatic options, defined as the number of topoclimates, density of wetlands, and range of elevations surrounding a given point on the landscape. To evaluate local climatic variation, the TNC team used standard geospatial algorithms in a GIS applied to a 30 meter DEM to generate terrain-surface indices that evaluate local variation in slope, aspect, land position, and moisture accumulation. The team classified the continuous terrain into a 20-unit landform model where each unit was a distinct temperature-moisture combination—such as a south-facing side slope, north-facing cove, wet flat—and used the count of landforms to estimate the number of topoclimates (Figure 11. See Anderson et al. 2014 for details).

Figure 11. Landscape diversity model. The figure shows the landform model (A) for Silver Jack Reservoir in Colorado. The photo is focused on the open water in the lower left of the landform model. The landscape diversity model (B) estimates the relative number of microclimates for every point on the landscape. For every 100-acre circle around a point, the analysis counts the number of unique microclimates (north-facing slope, south-facing slope, wet basin, ridgetop, cove etc.) and scores the point (30-m cell). The cell is then compared to every cell in the ecoregion and given a z-score relative to the mean score of the ecoregion.



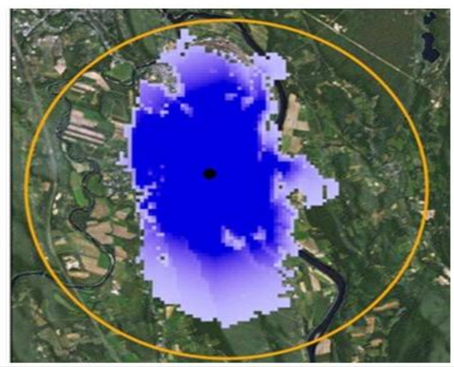
Local Connectedness: A permeable site is necessary to enable movement as species disperse to take advantage of the diversity of local microclimates. The TNC team's measure of site resilience, thus, combines landscape diversity (the presence of microclimates) with a measure of local connectedness (permeability). Meiklejohn et al. (2010) defined permeability as the degree to which regional landscapes, encompassing a variety of natural, semi-natural and developed land cover types, will sustain ecological processes and are conducive to the movement of many types. The local connectedness metric is not based on the unique needs of individual species, but is a measure of the hardness of barriers, the connectedness of natural cover, and the arrangement of land uses, summed into an integrated metric (Anderson et al. 2014).

To evaluate local connectedness, the TNC team compiled detailed spatial information on roads, powerlines, energy infrastructure, industrial forest, commercial agriculture, mining, and other fragmenting features and assigned each feature a weight reflecting its relative resistance to the movement of wild species (Figure 12). For each point on the landscape, a statistical model (resistant kernel) was used to measure how far in all directions a species could move before meeting or accruing too much resistance. Using a maximum distance of 3 km around every point, the area of movement constrained by resistance is compared with the theoretical area of unconstrained movement (Figure 12).

Figure 12. Resistance weights for measuring local connectedness. The table lists the human modification features compiled in a GIS dataset and the resistance weights assigned to each feature (1 = no resistance to 20 = very high resistance). Resistant kernel analysis measures the distance a species could spread in all directions accounting for resistance (blue blob) divided by the theoretical spread if no resistance (orange circle 3 km).

Category	Weight
Developed	
-Low intensity	8
-Mid intensity	9
-High intensity	20
-Mine	9
Roads/Linear	
-Major	20
-Minor	10
-Unpaved	+1
-Transmission	9
-Pipelines	9
-Railroads	9
Agriculture	
-Corn/Soy	9
-Other Ag	7
-Hay Pasture	3
-Forestry (indust.)	4
Energy	
-Oil & Gas	7+
-Wind	+1

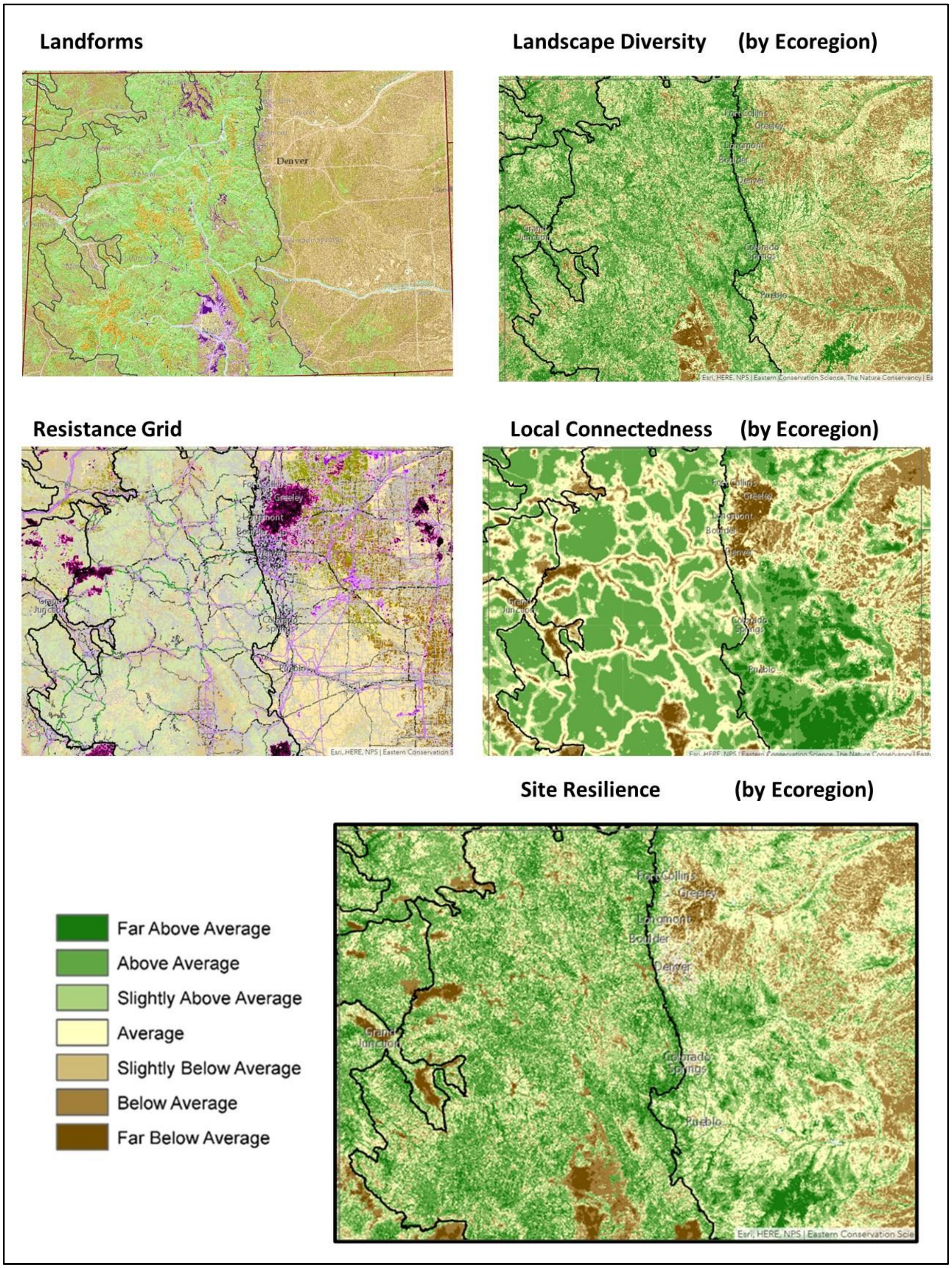
Natural	Weight
All Vegetation Types	1
Barrens	1
Water (by size)	1-3



The resistant kernel method (Compton et al. 2007) has proven to be a sensitive and effective way to measure local connectedness, and because it generates a score for every cell, it creates a wall-to-wall map (Figure 13). It is closely related to metrics of ecological intactness.

Site Resilience: Resilient sites are areas with a high number of connected microclimates, buffering species from climatic change and allowing them to persist. Also known as climate refugia, resilient sites play an outsized role in sustaining species. In the RCN analysis, site resilience is an equally weighted combination of landscape diversity and local connectedness evaluated for every cell and scored relative to all cells in the ecoregion (Figure 13). High scoring cells tend to be clustered and highlight relatively large sites, but they can occur as single cells.

Figure 13. Site resilience components for Colorado. The upper row shows the landform model and the landscape diversity map. The middle row shows the resistance grid and the local connectedness map. The bottom row shows the site resilience map which is a combination of the two maps above it.



Resilience and Refugia: Morelli et al. (2020) defined refugia as areas relatively buffered from contemporary climate change over time that enable persistence of valued physical, ecological, and sociocultural resources. Thus, resilient sites are a form of climate refugia that anticipate a slow turnover of species over time. The literature on refugia has much to offer conservationists interested in using land protection to sustain individual species. Microclimate management, for example, is being investigated in agricultural systems where it offers the potential to build ecosystem resilience and bring positive impacts (CRG 2020). Similar strategies for holding soil moisture or creating temperature variation have applications in conservation stewardship.

Managing ecosystems to increase their inherent resilience is complementary to identifying and managing sites. Ecosystems have their own biotic characteristics that build stability and persistence. In the past, land management and restoration approaches tended towards protecting or recreating historical site conditions. However, changes to ambient conditions (temperature, moisture, timing) brought by climate change will fundamentally shift sites away from the historical condition, diminishing its utility as a management goal. Instead, managers now emphasize management that bolsters the natural resilience of sites and systems to environmental changes allowing for species and habitats to adapt (Lombard et al. 2019).

A coarser scale approach to identifying resilience and refugia is to map climate change projections for a geography of interest and identify areas that are predicted to have less change, or where current and future distributions overlap. Climate models are widely used to predict the rates of future change and are useful for understanding the direction and potential magnitude of change in temperature or precipitation.

Spatial maps of climate projections are available through web viewers like climate wizard (http://climatewizard.org/) or the U.S. climate resilience toolkit (https://toolkit.climate.gov/) that allow users to assess potential temperature changes, drought, sea level rise, precipitation, and flooding. These models make informed estimates about what may happen in the future based on explicit scenarios of greenhouse gas emissions. A discussion of climate models is beyond the scope of this paper but be aware that although useful for envisioning the future, applying climate models directly to fine-scale land management can be tricky as the models have high degrees of uncertainty and are often run at coarse scales of 1 to 100 kilometers.

Site Resilience Datasets (all of these can be viewed in the RLMT and downloaded individually here: https://crcs.tnc.org/pages/data)

- CRCS 2020. Resilient Sites for Terrestrial Conservation
- CRCS 2020. Landforms of the U.S.
- CRCS 2020. Landscape Diversity of the U.S.
- CRCS 2020. Resistance Grid (fragmenting features) for the U.S.
- CRCS 2020. Local Connectedness for the U.S.

Recognized Biodiversity Value

"We have forgotten that we ourselves are dust of the earth; our very bodies are made up of her elements, we breathe her air and we receive life and refreshment from her waters."

- *Pope Francis*

Biodiversity refers to the totality of biological life on earth in all its organized forms: species, communities, and ecosystems (Norse & McManus 1980). Collectively, biodiversity underlies all the earth's life processes and the cycling of organic materials, from living plants that extract carbon and produce oxygen, to the insects, birds, and bats that pollinate crops, to the fungi that decompose waste and recycle nutrients to build healthy productive soils and clean water. Human health is dependent on a healthy natural world. Biodiversity is often measured with respect to the services it provides. Here "recognized biodiversity value" is a measure of the quality and condition of biodiversity features for their own intrinsic value, such as the viability of a species population or the intactness of an ecosystem.

The Importance of Biodiversity Value

Nature is changing, and measures of site resilience and connectivity have become integral to identifying places for maintaining nature's dynamics, but to sustain plants and animals a conservation network must include sites that support living biotic assemblages of sufficient quality to persist. Including high-quality ecosystems, exemplary communities, and viable species populations in a conservation network ensures that the network is embedded with elements of biodiversity that provide the capacity to adapt to climate change (Anderson et al. 2023).

In the U.S., NatureServe tracks over 50,000 species of vertebrates, plants, and macro-invertebrates, and there are likely an equal or greater amount of untracked microinvertebrates. Because there are so many species and so many unknowns, conservationists typically organize biodiversity into complementary "**coarse-filters**" such as natural communities, habitats, and ecosystems and "**fine-filters**" that target rare or wide-ranging species.

Fine-filter species targets require specific recovery plans to assure viability, growth, and persistence. Coarse-filter community targets, such as a Maple-Beech-Birch Northern Hardwood Forest, need to be conserved as large high-quality examples if they are to contain the common and unknown species associated with them, and the interactions and relationships on which they depend. Thus, detailed assessments are needed to ensure that a species population is viable, or a community occurrence's size, condition, and landscape context are sufficient to provide the benefits to other species that we expect (Anderson 2008).

Assessing Biodiversity Value

Evaluating a species population or community occurrence in the field is a time intensive process requiring inventory and training. In the U.S., this work is largely performed by the state Natural Heritage Programs, which use a systematic process to track and evaluate rare species and natural communities in their state. The information is entered and stored in a database that is co-managed with NatureServe to allow cross referencing between states. Subsequently, over the last two decades, this information has been used by federal and state agencies and non-governmental organizations (NGOs) to identify over a thousand areas with biodiversity value.

In the RCN analysis, the TNC team used "recognized biodiversity value" or RBV to refer to sites identified through a comprehensive ecoregional or state-based assessment that used ground-based data to evaluate community occurrences and species populations. To map these areas, the team compiled data from 104 published assessments representing two main sources: TNC Ecoregional Assessments done in partnership with the Natural Heritage programs and State Wildlife Action Plans.

The primary evaluation criteria in the RCN for identifying places for conservation action are representation and site resilience. RBV is used as an independent overlay to indicate where a site has been documented as having significant or intact biodiversity in the last two decades. The assumption was that if the site has high site resilience, then it is likely that many of those biodiversity values persist. This has been tested informally at hundreds of sites and found to hold true, particularly where the site is under some form of securement.

It is important to recognize that the RLMT biodiversity data is a screening tool to inform site selection and planning. In places where ground-based conservation is likely to proceed, sites should be field surveyed for current biodiversity value and interested parties should contact their local Natural Heritage program for the most recent data on the biodiversity elements present.

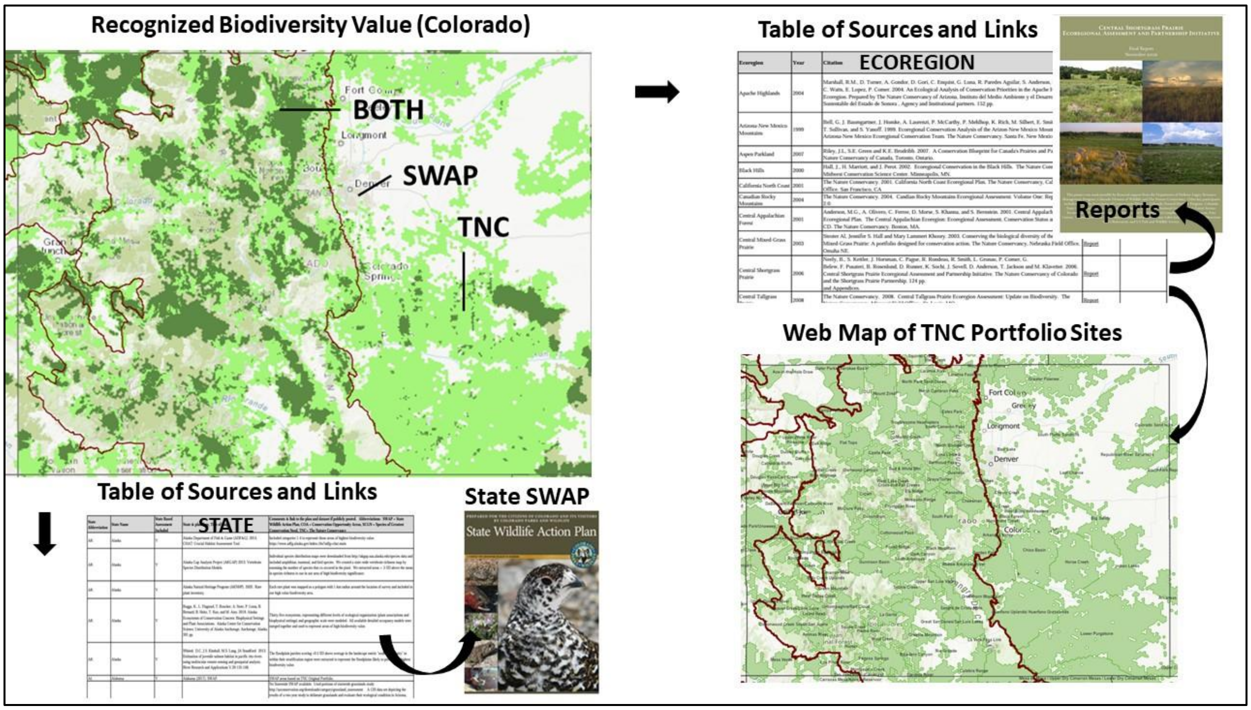
Ecoregional Assessments: In the early 2000s, TNC and partners implemented a decade-long project to assess the species and communities that characterized each U.S. ecoregion and identify a portfolio of sites that, if conserved, would protect the biodiversity of each. The team identified and mapped high quality examples of the ecoregion's characteristic ecosystems and unique natural communities, and located viable populations of its rare species. Natural Heritage Program element occurrences were used to identify multiple locations of each target, and viability criteria based on the size, condition, and landscape context were used to rank each occurrence.

Representation goals were set based on the distribution, rarity, and spatial pattern of the targets. A spatial portfolio of sites was identified that aimed to meet representation goals for all viable target occurrences. A portfolio of sites that collectively met all the goals was assembled into a map that represented a blueprint for future conservation (Groves et al. 2003). Completed between 1998-2010, the portfolio of sites focused on the current distribution of biodiversity and has a high degree of consistency because the targets and sites were reviewed by experts in the taxa groups.

The TNC team assembled the TNC ecoregional portfolios into a single dataset covering the U.S., except for Northern Alaska, where no plans were completed. The sites are displayed in the RLMT in the Recognized Biodiversity Value layer (Figure 14), and links to all the individual ecoregional reports are provided on the tool. To fully understand and use the data, the TNC team recommends that users read the report that accompanies the dataset for each ecoregion. Each of the 70 TNC ecoregional plans can be accessed via the Excel table embedded in the Recognized

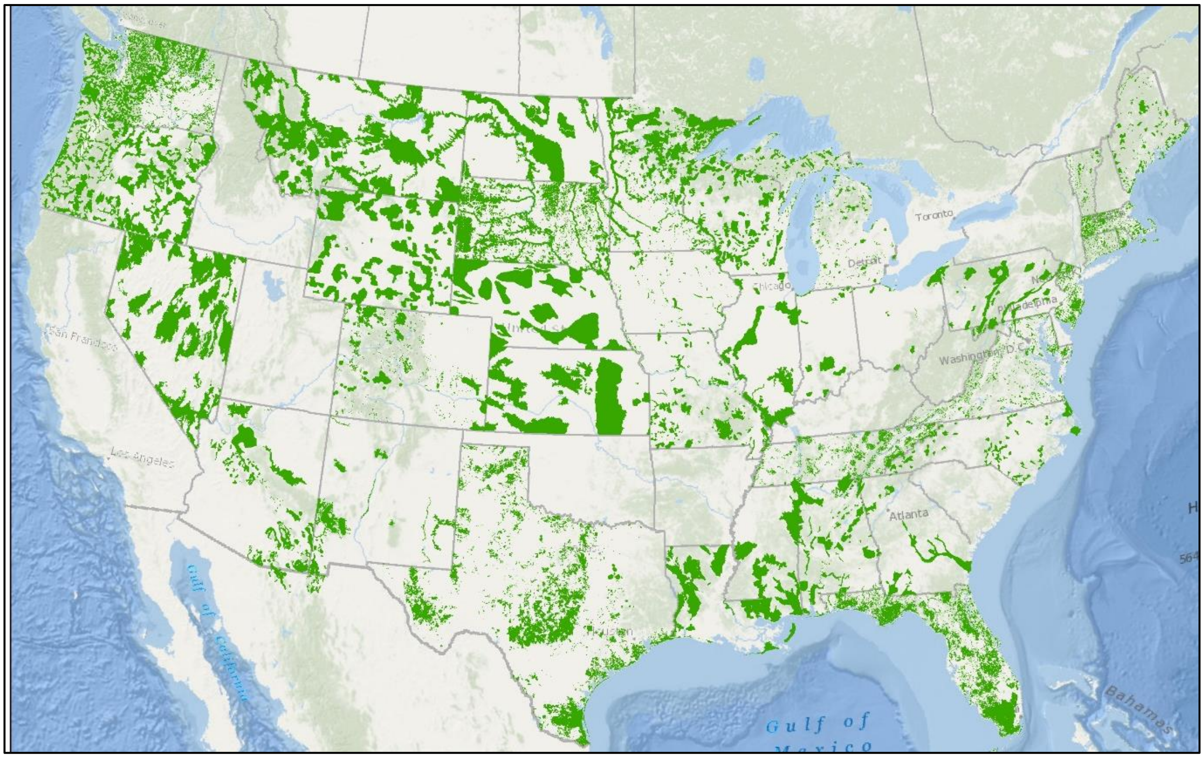
Biodiversity Value theme. Simply click on the theme to get the Data Source List and click Ecoregion-Based to find the links.

Figure 14. Recognized biodiversity value. This figure shows the information available to users in the RLMT. Colors on the RBV map indicate whether the site was identified in a TNC ecoregional plan, a state-based assessment (SWAP), or both. For the TNC sites, nested in the table of Ecoregion-based Sources is a link to all the individual reports and a link to a TNC web map viewer of the portfolio sites where users can find the name of the site and a list of communities and species. Nested in the table of State-Based sources is a link to the State Wildlife Action Plan where users can find information on the site.



State-Based Assessments: The TNC team also incorporated sites recognized in 38 state-based wildlife and habitat assessments (Figure 15). The majority were Conservation Opportunity Areas (COAs) mapped as part of each state's Wildlife Action Plan, but where COAs had not been mapped, the team also compiled comparable state-wide assessments if they were spatially explicit and had clearly defined terrestrial targets. The state datasets vary widely in terms of conservation targets and expansiveness. Some COAs are identical to the TNC portfolio, while others incorporate different priorities identified through multiple assessments with their own objectives and methods. Most COAs focused on non-game animal species and habitats. Click on Recognized Biodiversity Value in the RLMT to access an Excel table of all 38 State-Based data sources.

Figure 15. The distribution of state-based biodiversity assessments.



The TNC team supplemented the TNC and COA data in some study regions with additional sources of biodiversity data, such as more recent NHP element occurrences and state or regional assessments of priority species such as Sage Grouse. Lands protected for biodiversity (GAP 1 or 2) were added as examples of intact natural habitat, because TNC portfolios in Western ecoregions had been developed to complement, not include, existing conservation lands.

Users can explore the details of the recognized biodiversity dataset in the RLMT to develop an understanding of what it contains. The site labeled as TNC in Figure 14 is in the Central Shortgrass Prairie. The link in the source table takes users to “Central Shortgrass Prairie Ecoregional Assessment and Partnership Initiative” (Neeley et al. 2008), and in the report this site is #26 Horse Creek (pages 49-50), and its basic statistics are in Table 13. The million-acre site has:

- 40 Conservation targets
- 8 Ecological systems
- 2 Unique communities
- 192 Playas
- 17 Rare or uncommon species
- 1 Wide-ranging species (pronghorn)
- 1 Shorebird aggregation

Clicking on the web map link at the bottom of the Excel table allows a user to view the Horse Creek site on an interactive web map and get more detail on the communities and species that were present at the site in 2012:

- Communities: Inter-Mountain Basins Greasewood Flat, Fourwing Saltbush/Alkali Sacaton Shrubland, Alkali sacaton Herbaceous Vegetation, and Black-tailed Prairie Dog Community;
- Animals: American Bison, Cassin's Sparrow, Ferruginous Hawk, McCown's Longspur, Western Snowy Plover, Mountain Plover, Bald Eagle, Long-billed Curlew, Least Tern, Texas Horned Lizard, Plains Leopard Frog, Massasauga;
- Plants: Linear-leaf Bursage, Sandhill Goosefoot, Sidebells Beardtongue.

The overlapping state-based areas within Horse Creek are in the Colorado State Wildlife Action Plan (Pages 384-402) as Tier 2 sites that contain at least one documented occurrence of a Candidate or G3 species, or two G4 species.

Biodiversity and Resilience.

The TNC team assessed recognized biodiversity value to evaluate sites for evidence that they support rare or specialized species and characteristic communities. Subsequently, this allowed the team to identify areas where these representative targets were provided with microclimatic buffering to help them persist under a changing regional climate (Figures 16 and 17). Incorporating these sites into a connected network ensures that it contains species and habitats to serve as source material for movement and rearrangement. Further, integrating the footprint of these sites with spatial information on connected topoclimates and representative geophysical features helps confirm that the sites are collectively distributed across all abiotic “stages” needed to sustain biodiversity into the future.

Figure 16. Recognized biodiversity value with high site resilience in Colorado. The map on the right shows the portion of the recognized biodiversity sites that have site resilience scores (>0.05 SD). This is the portion of the site where species are most likely to persist under climate change due to the many connected microclimates that offer options and refuge.

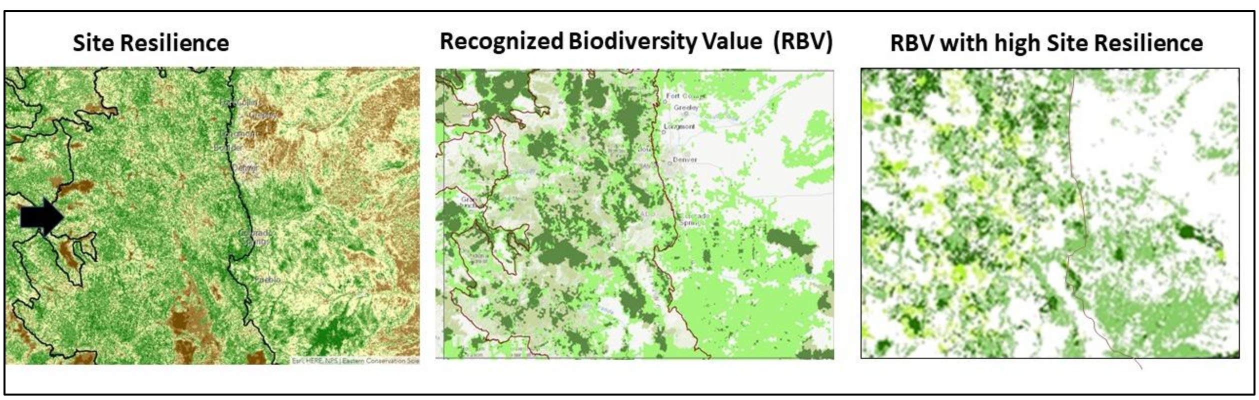
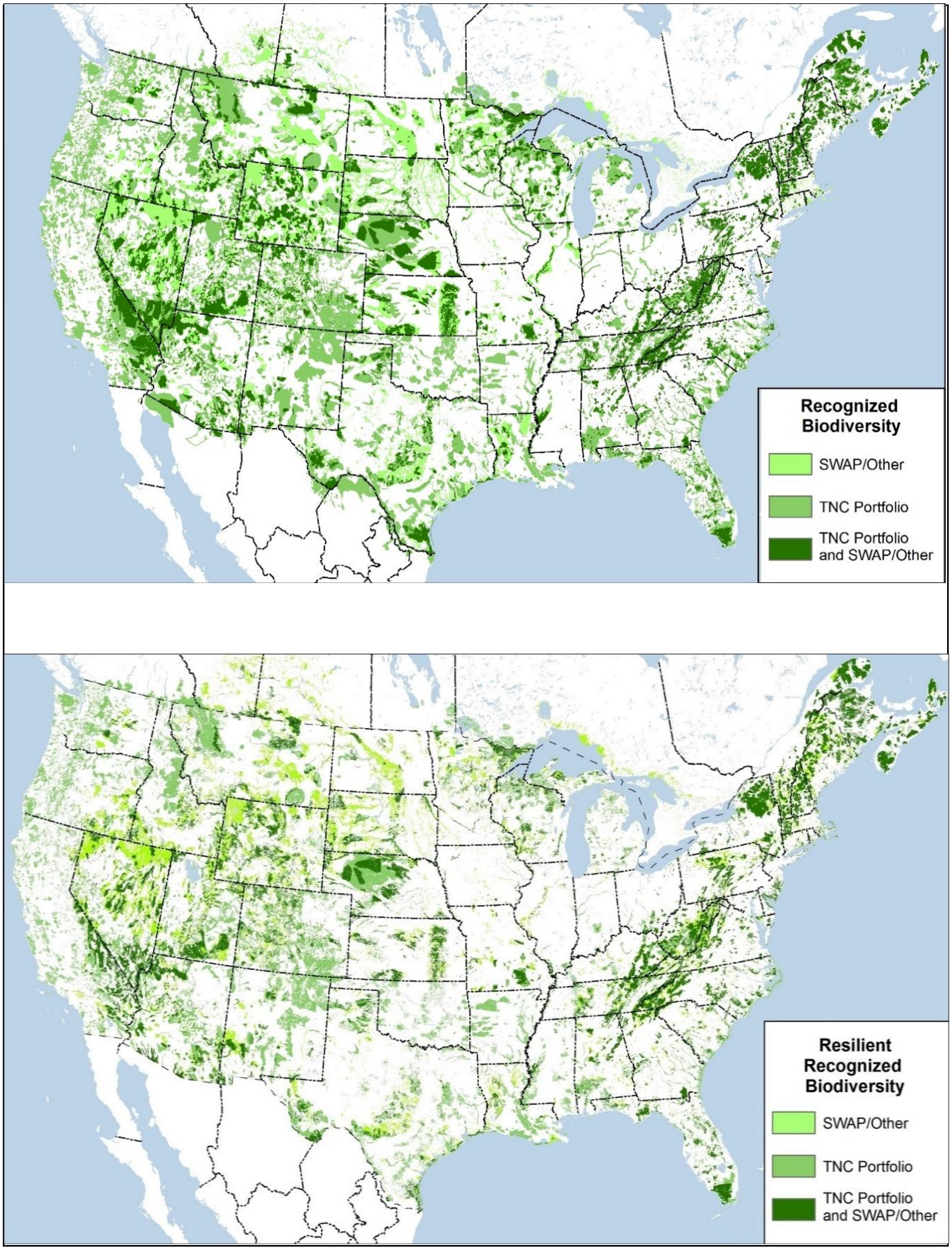


Figure 17. Recognized biodiversity value filtered by site resilience. The upper map shows the compiled dataset for 104 ecoregion or state-based studies. The lower map shows the same information filtered by site resilience so only resilient and biodiverse sites are included.



Connectivity and Climate Flow

"In nature we never see anything isolated, but everything in connection with something else which is before it, beside it, under it and over it."

- *Johann Wolfgang von Goethe*

Connectivity: In conservation, connectivity refers to actions that maintain or increase the permeability of the landscape, allowing species to move and facilitating the rearrangement of ecosystems. Species move to find resources both daily, for food and water, and seasonally in migrations that follow changing resources. Adolescents disperse to find mates and establish new territories, and adults migrate when existing habitat becomes unsuitable. **Climate flow** refers to connectivity across climate gradients that is most likely to facilitate adaptive movements in response to changing climatic conditions.

Climate change is an ambient change in the condition of the earth, particularly the temperature and moisture regimes that limit the distribution of many species. In response to new conditions, species move and population ranges shift. This leads to changes in community composition or the rearrangement of whole ecosystems. Species persisted under past climatic changes by using *in situ* refugia combined with range shifts to track suitable climates (Gill et al. 2015, Jackson & Overpeck 2000, Krosby et al. 2010). Rapid warming projected for the next century will likely require many species to adapt in a similar way (Moritz & Agudo 2013, Thuiller et al. 2005, Nunez et al. 2013).

Species' ranges are already shifting (Chen et al. 2011, Hitch & Leberg 2007). However, elevated levels of habitat loss and fragmentation due to anthropogenic activities are isolating populations and creating barriers to species movement that were not present during past periods of rapid climate change (Thomas et al. 2004, Peters & Darling 1985, Corlett & Westcott 2013). Conserving connectivity is essential for effective conservation under climate change, as connectivity facilitates movement and gene flow, bolstering adaptive capacity by maintaining genetic diversity (Hoffmann & Sgro 2011, Sgro et al. 2011, McRae & Beier 2007).

Assessing Connectivity and Climate Flow

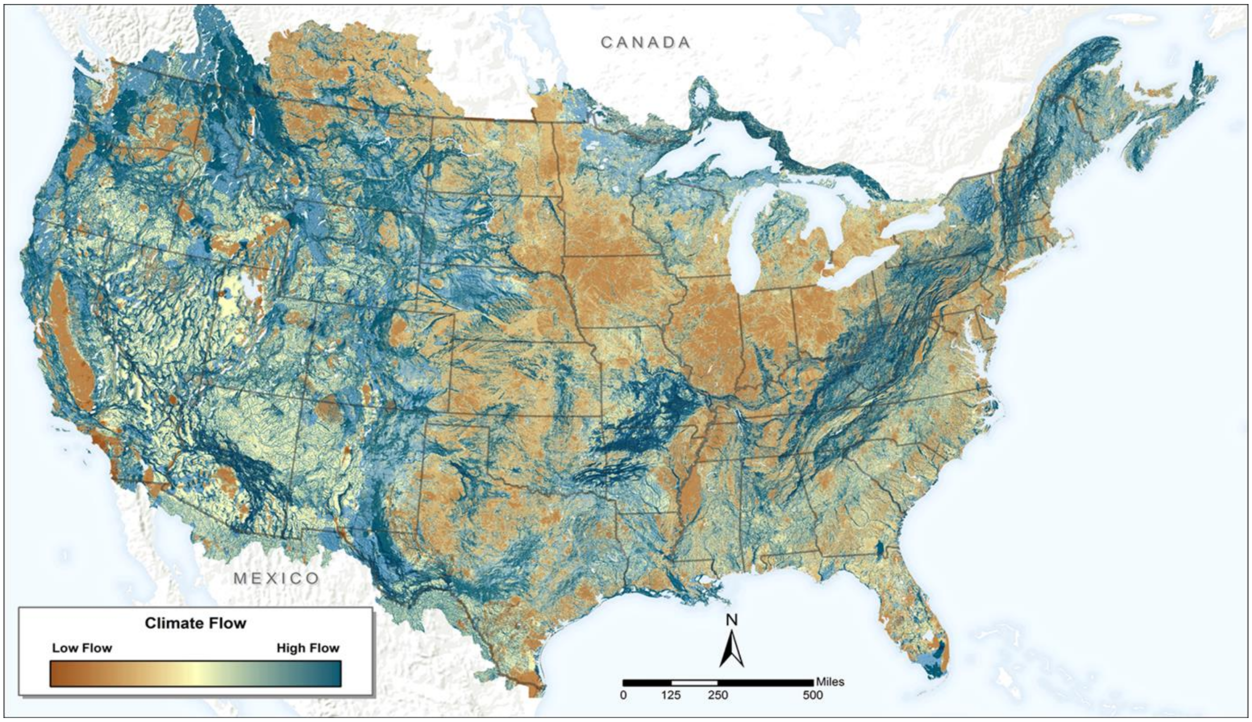
Climate flow is the gradual movement of species in response to climate change across a human-modified landscape (Anderson et al. 2023). To identify areas potentially important for climate flow, the TNC team used an approach that modeled movement potential as a continuous surface based on degree of human modification and geographical climatic gradients. This was done with a minor adaptation of the software program Circuitscape (Shah & McRae 2008), which models movement as if it were an electric current flowing across a surface of mixed resistance.

This approach allows users to create wall-to-wall connectivity maps that emphasize variations in the density of current flow corresponding to variations in resistance by barriers, roads, and other fragmenting species. The TNC team's intention was to locate land areas that had relatively unfragmented natural cover connecting topographically and hydrologically derived climatic gradients and that were positioned to intercept a large quantity of potential movement in response to climate change.

To create the climate-flow models for each study region, the team started by creating a model of anthropogenic flow using the same resistance grid described in the Site Resilience section for Local Connectedness. In brief, the team divided the country into hundreds of individual tiles, and, for each, it set one side as source and the opposite as ground. Next, "current" was passed across the resistance surface. This was repeated in all four cardinal directions (E to W etc.) and summed to create an omnidirectional map of current density (see Pelletier et al. 2014).

The overlapping tiles were stitched together and calibrated to create a wall-to-wall data layer of current density that provides a continuous view of current flow across the region in all directions (Figure 18). Variations in current flow are driven by interacting and directional resistance factors and reveal both diffuse flow zones (broad regions of high flow) and concentrated corridors (narrow regions where flow converges due to reduced flow in neighboring areas).

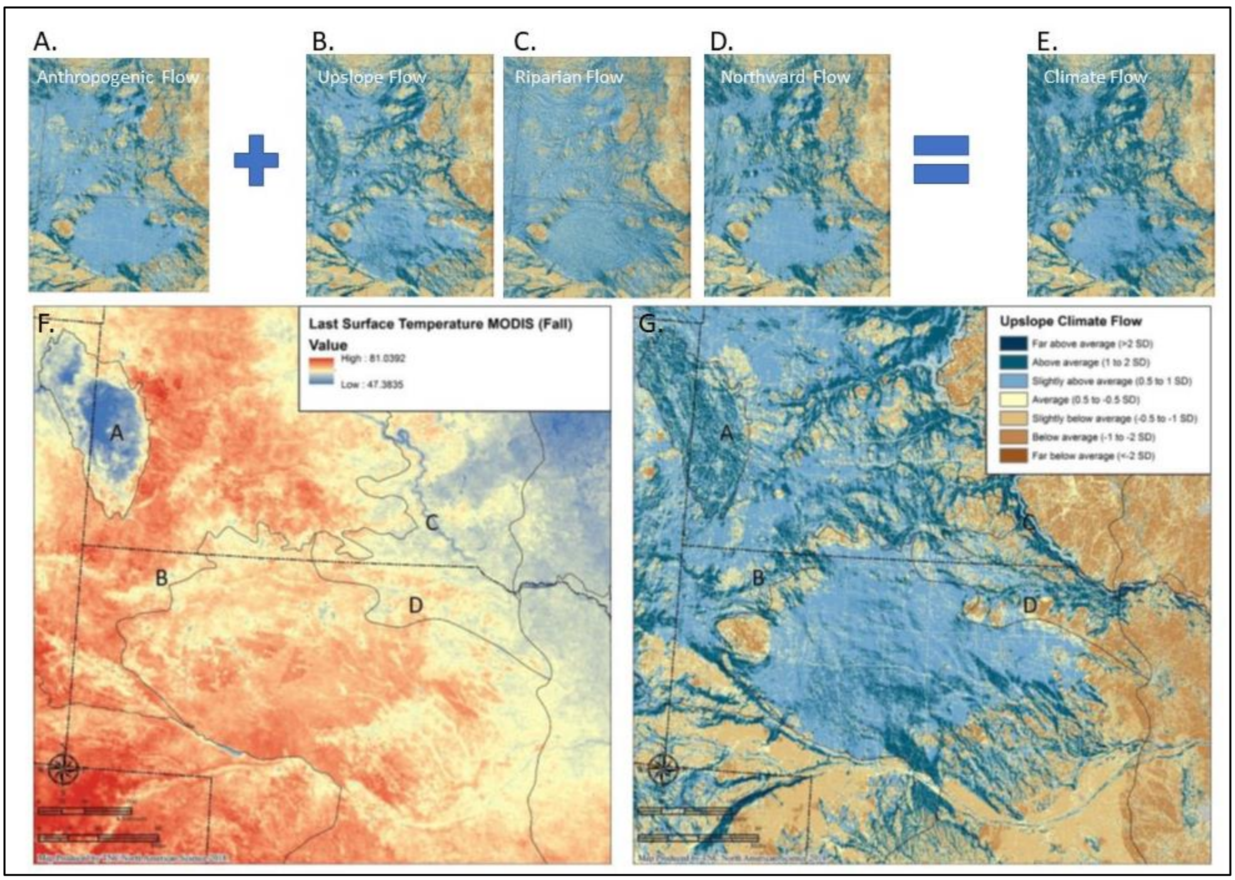
Figure 18. Connectivity and climate flow for the contiguous U.S.



The TNC team's first model of current flow was based solely on fragmenting features reflecting human modification of the landscape. To introduce climatic gradients, the team created a second resistance grid based on slope, gradient, land position, and elevation. This was done by assigning varying resistance values to each unit in the landform model, based on its slope and gradient. Weights were assigned so that the least resistance was given to units that promoted gradual upslope movement and more resistance to gradients that were very steep or too flat to provide climate relief (change in temperature or moisture).

The TNC team augmented this resistance grid by intersecting it with the results of a downslope model and giving low resistance to downslope movement that simulated moisture channels and riparian areas. Finally, the team merged the anthropogenic and climate-gradient resistance grids into one surface, giving equal weight to each factor. Current was passed along the surface in all four directions; but, to simulate populations moving northward in response to climatic change, the northward directional grid was given 50 percent more weight than other directions. The results were recombined into a continuous surface that showed variation in resistance due to barriers and fragmenting features as well as climatic gradients that favored upslope, northward, and riparian flow (Figures 19 and 20).

Figure 19. Introducing climatic gradients into regional flow. Map A shows the current flow based solely on human modification. Maps B-C introduce climatic gradients by giving less resistance to upslope (B), riparian (C), or northward (D) flow. Maps E and G show the integrated map of climate flow. Map F shows land surface temperature in fall, illustrating many of the gradients captured by the climate flow map.



The climate flow maps reveal areas that are likely to be important for movement as species expand or shift their ranges in response to climatic change. Areas of high flow in the intact parts of the Western U.S. are broad and diffuse, suggesting that improving management practices, especially on public land, may be sufficient to sustain flow. In the Central and Eastern U.S., flow is concentrated into distinct narrow corridors suggesting that permanent land protection may be needed to maintain these important but vulnerable connections. To help identify where different strategies may apply, the TNC team classified the flow types into a categorical map (Figure 21).

Figure 20. Resistance grid and climate flow for Colorado. The left figure shows a map of the resistance grid with each fragmenting feature assigned a resistance score between 1 and 20. Using Circuitscape, "current" is passed across the grid in each of the four cardinal directions, each directional pass creating its own flow pattern. Flow is summed across all directions (right) revealing the natural flow patterns created by human modification and climatic gradients.

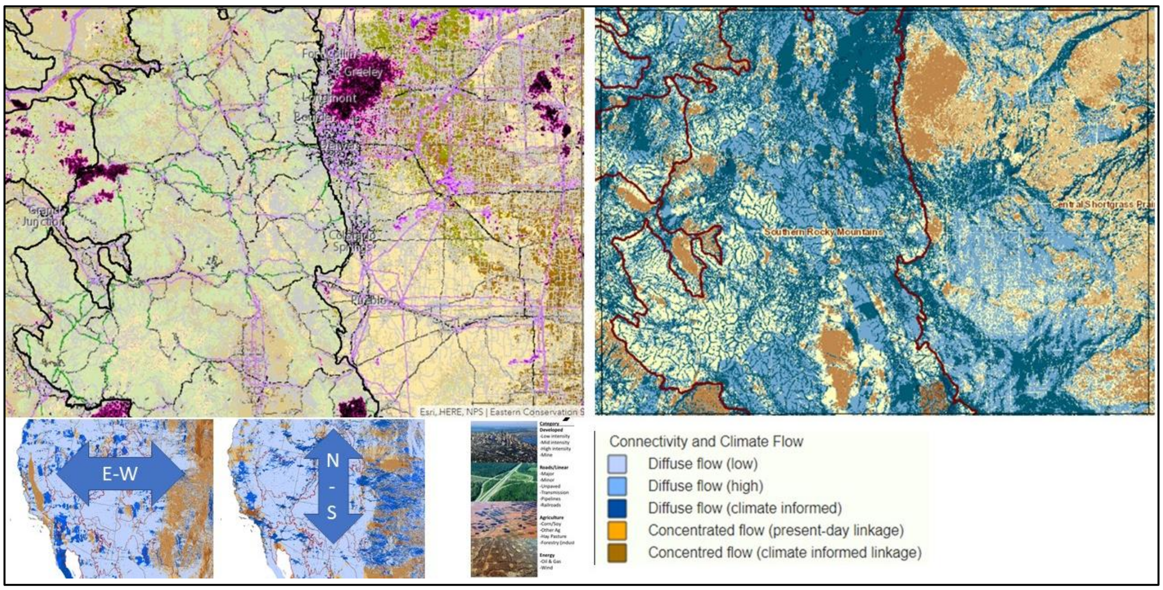
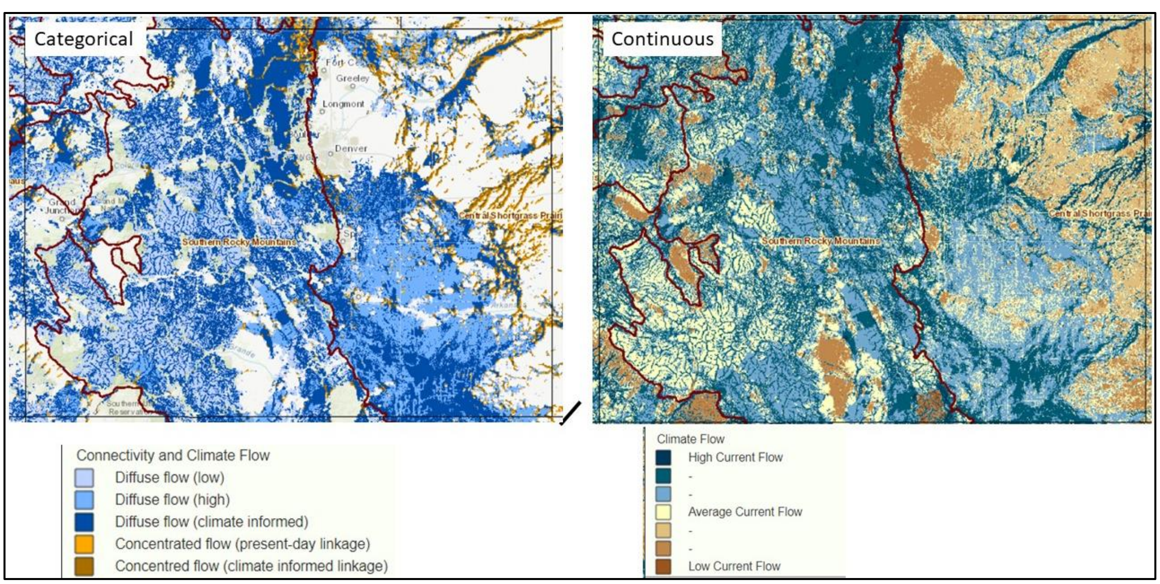
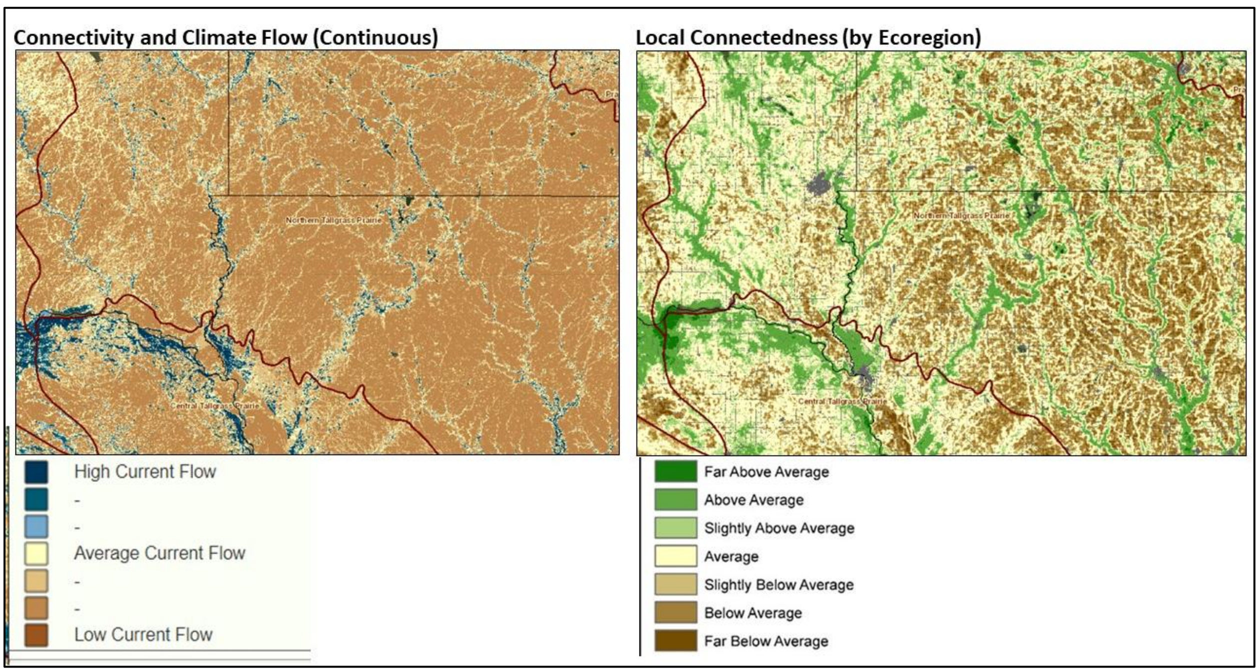


Figure 21. Continuous and categorical climate flow for Colorado. This figure compares the wall-to-wall continuous map of climate flow to a classified map that distinguishes between diffuse flow and concentrated flow.



For planning within ecoregions, the continuous flow dataset can be used in conjunction with the local connectedness dataset. The first is directional and scaled to national flow patterns, while the latter is non-directional and scaled to ecoregional patterns (Figure 22). They are both based on the same resistance grid; so, together, they show the relative importance of the location (amount of climate flow) and the relative intactness of the feature (local connectedness) (Figure 22). This method can also give users a sense of what “average” means relative to the ecoregion because in very intact ecoregions, “average” can indicate substantial flow. The “above average” high flow is usually concentrated by human modification, making it more vulnerable and important for conservation attention.

Figure 22. Climate flow compared to local connectedness. In this figure for the Northern Tallgrass Prairie, the climate flow map reveals the relative strength of the flow through the region while the local connectedness map illustrates how intact the potential corridors are.

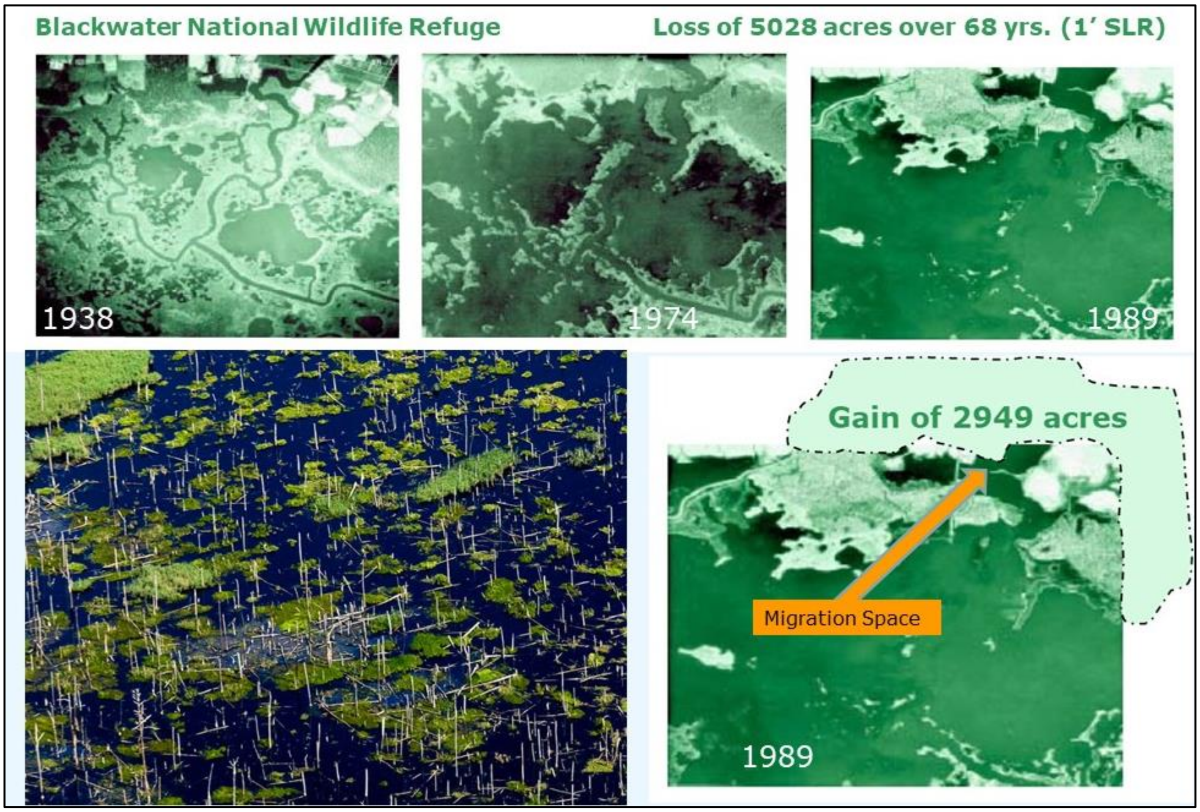


Coastal Migration Space

A unique and important type of connectivity occurs in coastal areas that are increasingly inundated by sea level rise. In places like Blackwater National Wildlife Refuge, salt marsh has migrated inland, in this case establishing 2000 acres of new marsh in low lying lands with increased tidal inundation (i.e., migration space) that will support salt marsh in the future (Figure 23).

Although climate change affects the entire coastal region, some places have more available migration space and higher natural resilience due to their physical properties (orientation, elevation, geology, topography, exposure) and current condition (sediment inputs, freshwater inflow, and barriers in the surrounding lands). It is important to identify, protect, and restore these natural strongholds as they will become increasingly important in sustaining salt marshes and tidal flats, two of our most productive and essential natural ecosystems, into the future.

Figure 23. Migrating saltmarsh in Blackwater National Wildlife Refuge. Adapted from USFW Blackwater National Wildlife Refuge: Marsh loss and Restoration, 2009.

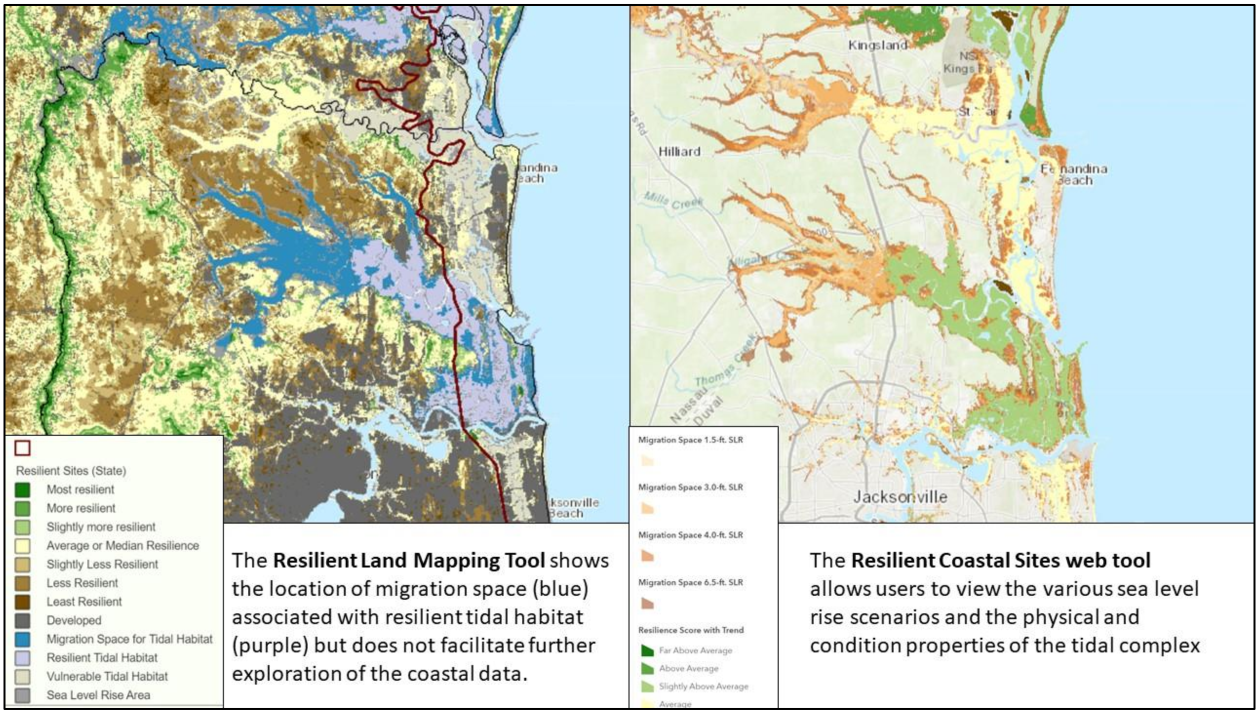


The TNC team comprehensively mapped the existing tidal complexes along the U.S. coastline and evaluated their resilience to sea level rise based on the size, condition, and availability of migration space. For marshes with above-average resilience, the team identified the migration space that would need securement to ensure that the area remained available for establishing future marsh.

Although tidal marshes are relatively well secured, the same cannot be said for the adjacent migration space. Anticipating the potential conflicts that will increasingly arise in these lands—most of which are already flooding regularly—the TNC team created story maps where users can explore census data, repetitive flooding claims, and potential productivity for each salt marsh area (See Appendix).

Resilient marsh migration areas are shown in the RLMT, but the TNC team highly encourages users to explore the separate web maps and story maps listed in the appendix, as they provide more detail on the factors and strategies needed to sustain coastal marshes in an equitable way (Figure 24).

Figure 24. Resilient coastal sites data on marsh migration space



Datasets

Connectivity and Climate Flow (all of these can be viewed in the RLMT)

- CRCS 2020 Fragmenting Features
- CRCS 2020 Connectivity and Climate Flow (continuous)
- CRCS 2020 Connectivity and Climate Flow (categorical)
- CRCS 2020 Local Connectedness
- CRCS 2020 Landforms of the U.S.
- CRCS 2020 Marsh Migration Space

The dataset and source for each dataset is available via the interactive map on the authoritative data page:

https://tnc.maps.arcgis.com/home/item.html?id=e033e6bf6069459592903a04797b8b07

Conclusion

The conservation problems all of society faces today are huge, but they are not insurmountable. The emerging science of resilience can help practitioners understand the scope of these problems and uncover solutions that support healthy nature, while also enriching the lives of people today and ensuring diversity of life for generations to come. The science and tools presented here aim to allow anyone, from a small land trust to a large agency, to access this information and make decisions based on a growing body of reviewed and tested science. There is plenty of room for flexibility, interpretation, and local knowledge in decision making but used thoughtfully, the information presented here will help ensure that every local project contributes to a growing portfolio of sites that could collectively sustain natural diversity across the United States.

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Appendix

List of Terrestrial Resilience Study Region Reports

TNC's Resilient and Connected Network (RCN) is a proposed conservation network of representative climate-resilient sites designed to sustain biodiversity and ecological functions into the future under a changing climate. The network was identified and mapped over a 10-year period by scientists in eleven geographic study regions. Methods and results for each region are described in an illustrated report reviewed by members of the steering committee.

All region's resilience reports can be accessed from the Interactive Reports and Resources Map found on http://nature.org/climateresilience or from the individual websites and direct links below.

Eastern U.S. Region: Website

https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/edc/reportsdata/terrestrial/resilience/Pages/default.aspx

> **Resilient and Connected Landscapes: Report**
> Anderson, M.G., Barnett, A., Clark, M., Prince, J., Olivero Sheldon, A. and Vickery B. 2016. Resilient and Connected Landscapes for Terrestrial Conservation. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA. http://easterndivision.s3.amazonaws.com/Resilient_and_Connected_Landscapes_For_Terrestial_Conservation.pdf
>
> **Resilient Sites: Report**
> Anderson, M.G., A. Barnett, M. Clark, C. Ferree, A. Olivero Sheldon, J. Prince. 2016. Resilient Sites for Terrestrial Conservation in Eastern North America. The Nature Conservancy, Eastern Conservation Science. http://easterndivision.s3.amazonaws.com/Resilient_Sites_for_Terrestrial_Conservation.pdf

Central U.S. Region: Website

https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/centralUS/ConnectedLandscapes/Pages/default.aspx

> **Resilient and Connected Landscapes Central U.S.: Report**
> Anderson, M.G., M. Clark, A. Olivero Sheldon, K. Hall, J. Platt, J. Prince, M. Ahlering, and M. Cornett. 2018a. Resilient and Connected Landscapes for Terrestrial Conservation in the Central U.S.. The Nature Conservancy, Eastern Conservation Science, Eastern Regional Office. Boston, MA. https://tnc.app.box.com/s/50r22xaf7aaxhs5tx4ep1hsuc24pfg0c
>
> **Resilient Sites Great Plains Region: Report**
> Anderson, M.G., M.A. Ahlering, M. M. Clark, K.R. Hall, A. Olivero Sheldon, J. Platt and J. Prince. 2018b. Resilient Sites for Terrestrial Conservation in the Great Plains. The Nature Conservancy, Eastern Conservation Science and North America Region. Boston

MA.
https://easterndivision.s3.amazonaws.com/GP_Resilience/Great_Plains_Resilience.pdf

Resilient Sites Great Lakes and Tallgrass Prairie Region: Report
Anderson, M.G., M. M. Clark, M.W. Cornett, K.R. Hall, A. Olivero Sheldon, J. Prince. 2018c. Resilient Sites for Terrestrial Conservation in the Great Lakes and Tallgrass Prairie. The Nature Conservancy, Eastern Conservation Science and North America Region.
https://easterndivision.s3.amazonaws.com/Terrestrial/Great_Lakes_Resilience/Great_Lakes_and_Tallgrass_Prairie_Resilience_05_11_18.pdf

Lower Mississippi-Ozark Region: Website
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/centralUS/lowerMississippiOzarks/Pages/default.aspx

Resilient Sites and Connected Landscapes: Report
Anderson, M.G., M. M. Clark, A. Olivero, and J. Prince. 2019b. Resilient Sites and Connected Landscapes for Terrestrial Conservation in the Lower Mississippi-Ozark Region. The Nature Conservancy, Eastern Conservation Science.
https://tnc.app.box.com/file/612375896177

Rocky Mountains and Desert Southwest Region: Website
https://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/westernUS/Pages/Rocky-Mountains-Desert-Southwest-Resilient-and-Connected-Lands.aspx

Resilient Sites and Connected Landscapes: Report
Anderson, M.G., M. M. Clark, A. Olivero, and J. Prince. 2019a. Resilient Sites and Connected Landscapes for Terrestrial Conservation in the Rocky Mountain and Southwest Desert Region. The Nature Conservancy, Eastern Conservation Science.
https://tnc.app.box.com/file/622379073752

Pacific Northwest: Website: http://nature.org/resilienceNW
Pacific Northwest Resilient Terrestrial Landscapes: Report
Buttrick S, Popper K, Schindel M, McRae BH, Unnasch B, Jones A, Platt J. 2015. Conserving Nature's Stage: Identifying Resilient Terrestrial Landscapes in the Pacific Northwest. The Nature Conservancy, Portland, Oregon. 104 pp.

Pacific Northwest Connectivity for Resilient Terrestrial Landscapes: Paper
McRae BH, Popper K, Jones A, Schindel M, Buttrick S, Hall K, Unnasch RS, Platt JT. 2016a. Conserving Nature's Stage: Mapping Omnidirectional Connectivity for Resilient Terrestrial Landscapes in the Pacific Northwest. The Nature Conservancy, Portland Oregon. 47 pp.

California:

California: Resilient and Connected Network Report
Schloss, C.A and Cameron, D.R. 2021. The Resilient Connected Network in California Technical Documentation. The Nature Conservancy, California.
https://tnc.box.com/s/a4bd75ogf5dlah6jds66lxgbnyd29ho9

California: Connectivity Papers
Schloss, C.A., Cameron, D.R., McRae, B.H., Theobald, D.M. and Jones, A. 2022. "No-regrets" pathways for navigating climate change: planning for connectivity with land use, topography, and climate. Ecological Applications, 32(1), p.e02468.
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Cameron, D. R., Schloss, C. A., Theobald, D. M., & Morrison, S. A. 2022. A framework to select strategies for conserving and restoring habitat connectivity in complex landscapes. Conservation Science and Practice, 4(6), e12698.
https://conbio.onlinelibrary.wiley.com/doi/full/10.1111/csp2.12698

Alaska
http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/alaska/Pages/Resilient-and-Connected-Landscapes-of-Alaska.aspx

Resilient Sites and Connected Landscapes for Terrestrial Conservation in Alaska: Report
Anderson, M.G., A. Barnett, M. M. Clark, J. DePasquale, A. Olivero, J. Prince, and C. Shanley. 2021. Resilient Sites and Connected Landscapes for Terrestrial Conservation in Alaska. The Nature Conservancy, Center for Resilient Conservation Science.
https://tnc.app.box.com/s/1ir5xanw83ge7m6hqvaz603gl1buubyu

Hawaii
http://www.conservationgateway.org/ConservationByGeography/NorthAmerica/UnitedStates/hawaii/Pages/Resilient-Coastal-Sites.aspx

Resilient Sites and Connected Landscapes for Terrestrial Conservation in Hawaii: Report
Anderson, M.G., A. Barnett, M. M. Clark, S. Gon, A. Olivero, J. Prince, and S. Thom. 2022. Resilient Sites and Connected Landscapes for Terrestrial Conservation in Hawaii. The Nature Conservancy, Center for Resilient Conservation Science.

List of Coastal Resilience Study Region Reports

Coastal Northeast and Mid-Atlantic U.S.
Anderson, M.G. and Barnett, A. 2017. Resilient Coastal Sites for Conservation in the Northeast and Mid-Atlantic U.S. The Nature Conservancy, Eastern Conservation Science. Boston, MA
View the interactive map, download the data, and read the report at:
https://www.nature.org/resilientcoasts

Coastal South Atlantic U.S.
Anderson, M.G. and Barnett, A. 2019. Resilient Coastal Sites for Conservation in the South Atlantic US. The Nature Conservancy, Eastern Conservation Science.
View the interactive map, download the data, and read the report at:
https://www.nature.ly/SEcoast

Gulf of Mexico U.S.
Anderson, M.G. and Barnett, A. 2019. Resilient Coastal Sites for Conservation in the Gulf of Mexico US. The Nature Conservancy, Eastern Conservation Science.
View the interactive map, download the data, and read the report at:
https://www.nature.ly/Gulfcoast

Alaska U.S.
Barnett, A. and Anderson, M.G. 2022. Resilient Coastal Sites for Conservation in Alaska. The Nature Conservancy, Center for Resilient Conservation Science.
View the interactive map, download the data, and read the report at: http://nature.org/AKcoast

Hawaii U.S.
Barnett, A. and Anderson, M.G. 2022. Resilient Coastal Sites for Conservation in Hawai'i. The Nature Conservancy, Center for Resilient Conservation Science.
View the interactive map, download the data, and read the report at: http://nature.org/HIcoast

Published literature by TNC Authors on the Resilience Work.

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Anderson, M.G. and Johnson, N. 2016. Maintaining Forest Diversity in a Changing Climate: a geophysical approach, in Sample, V.A., Bixler, R.P. and C. Mille eds. *Forest Conservation in the Anthropocene: Science, Policy, and Practice*. U of Colorado Press. Boulder. 346 p. https://www.fs.fed.us/rm/pubs/rmrs_p071/rmrs_p071_273_296.pdf

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Pelletier, D. Clark, M., Anderson, M.G., Rayfield, B., Wulder, M.A., Cardille, J.A. 2014. Applying Circuit Theory for Corridor Expansion and Management at Regional Scales: Tiling, Pinch Points, and Omnidirectional Connectivity. *PLOS ONE* 9 (1) http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0084135

Anderson, M.G., M. Clark, and A. Olivero Sheldon. 2014. Estimating Climate Resilience for Conservation across Geophysical Settings. *Conservation Biology* 28 (4) 1523-1739. http://dx.doi.org/10.1111/cobi.12272

Groves, C.R., Game, E.T., Anderson, M.G., Cross, M, Enquist, C, Ferdana, Z, Girvetx, E, Gondor, A, Hall, K.R, Higgins, J., Marshall, R, Popper, K, Schill, S, and S.L. Shafer. 2012. Incorporating climate change into systematic conservation planning, *Biodiversity and Conservation* 20 (1). https://adapt.nd.edu/resources/275/download/Groves_ClimateChangeinConservationPlanning_2012.pdf

Anderson, M.G., and C.E. Ferree. 2010. Conserving the Stage: climate change and the geophysical underpinnings of species diversity. *PLOS ONE* July (5): 7 e11554: http://dx.plos.org/10.1371/journal.pone.0011554.