



## FINAL REPORT

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For the project entitled:

### **A landscape-level assessment of ecological values for 22 national monuments.**

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## Introduction

Fundamental principles of systematic conservation planning (e.g., Margules and Pressey 2000) suggest that an ecologically functional protected areas network requires a sufficient land base, should protect a variety of species and habitats, and—perhaps most critically—needs to be interconnected (DeFries et al. 2007, Cumming et al. 2015) and resilient to ongoing climate change (Dawson et al. 2011). Throughout the United States, there is a significant need to secure a network of protected areas to prevent further loss of biodiversity (Scott et al. 1993, Jenkins et al. 2015), maintain ecological connectivity (Dickson et al. 2016), and preserve ecological functions in the face of climate change (Heller and Zavaleta 2009).

In this context, we leveraged existing research and sources of readily available spatial data to conduct a rigorous assessment of ecological values across 22 national monuments currently under review, according to criteria in Executive Order 13792 (Appendix A). We focused our assessment on information that highlighted the ecological significance of each monument in a regional-scale, comparative analysis. This report details the data and methods used, as well as key results.

## Methods and Results

For our assessment, we mapped 12 landscape-level indicators of ecological value, i.e., potential connectivity and intactness, biodiversity, remoteness, and resilience to climate change (detailed in Table 1 and Appendix C). Specifically, we used readily available spatial data layers and published methods to model three indicators of landscape connectivity and intactness: ecological connectivity (Dickson 2016, Theobald et al 2012), ecological intactness (after Theobald 2013), and night sky darkness (NOAA 2012); eight indicators of biodiversity: ecological system diversity (Scott et al. 1993), ecosystem type rarity (USGS 2011), lithological diversity (Soller and Reheis, 2004), geophysical type rarity (Theobald et al. 2015), rarity-weighted species richness (Chaplin et al. 2000; updated in 2013), and mammal, bird, and reptile diversity (Jenkins 2013); and one indicator of resilience to climate change: climate resilience (Hamann et al. 2015). Data for each indicator was generated at a 270-m pixel resolution. Our indicator maps were regional or national in extent, permitting comparisons between ecological values found within individual monuments and equivalently sized areas within a given region (see below). For all monuments other than Katahdin National Monument, we restricted our analyses to the 11 western-most states in the conterminous U.S. Comparative analysis of Katahdin National Monument was restricted to the other 37 conterminous states.

We determined the values of the indicators relative to each region using a simple but robust scoring system based on percentile ranks. Specifically, the mean value of each indicator within a given monument was compared to the distribution of means of a large ( $n = 1000$ ) random sample of areas across the 11 western states or 37 eastern states, including all jurisdictions and ownerships. The area of each of the random samples was equivalent to the area of federal lands within the monument. Scores ranged from 0 to 100. For example, a score of 98 for a given indicator would indicate that the mean value of that indicator in a given monument was greater than or equal to mean values in 98% of the equivalently-sized random samples. Scores of 50 or higher suggest a relatively important indicator. Results for each monument are presented in Appendix B.

**Table 1.** Twelve indicators used to assess ecological values within 22 national monuments. See Appendix B for details on the source data and/or derivation of these data layers.

Indicator	Data source	Description
Ecological Connectivity (West)	Dickson et al. (2016)	Model of ecological flow among existing protected areas within the 11 western states in order to quantify the ability of currently unprotected areas to enhance potential connectivity across the existing protected areas network.
Ecological Connectivity (East)	Theobald et al. (2012)	Model of connectivity routes across the conterminous U.S. as a function of a continuous gradient of landscape permeability (naturalness), prioritized based on centrality, or importance to broader landscape configuration
Ecological Intactness	Theobald (2013); Theobald et al. (2016)	Characterizes the intensity and footprint of human modification across the West, based on 12 types of human activities.
Night Sky Darkness	NOAA (2012)	Artificial nighttime lights observed via satellite.
Ecological System Diversity	Ecological System Type, USGS (2011)	Richness of USGS GAP Ecological Systems (i.e., vegetation types) present within a given area averaged across multiple spatial scales.
Ecological System Type Rarity	Ecological System Type, USGS (2011)	Normalized rank of USGS GAP Ecological System types based on their relative areal extent.
Lithological Diversity	Soller and Reheis (2004)	Published map of lithological units. Lithological diversity is a fundamental driver of both ecological and evolutionary processes that generate species diversity.
Geophysical Type Rarity	Theobald et al. (2015)	Normalized rank based on relative areal extent of 188 unique geophysical types defined by an overlay of landforms and surficial lithology.
Rarity-weighted Species Richness	Chaplin et al. (2000); NatureServe (2013)	Species rarity and irreplaceability that identifies sites that contain critically-imperiled or imperiled species with restricted distributions.
Mammal Diversity	BiodiversityMapping.org; Jenkins (2013)	Data for mammal species richness based on range maps for the continental U.S.
Reptile Diversity	BiodiversityMapping.org; Jenkins (2013)	Data for reptile species richness based on range maps for the continental U.S.
Bird Diversity	BiodiversityMapping.org; Jenkins (2013)	Data for bird species richness based on range maps for the continental U.S.
Climate Resilience	Hamann et al. (2015)	Model of multivariate climate velocity to quantify the velocity (speed and direction) a species must migrate to persist in an area with the same climatic conditions, given projected changes in climate.

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## Appendix A.

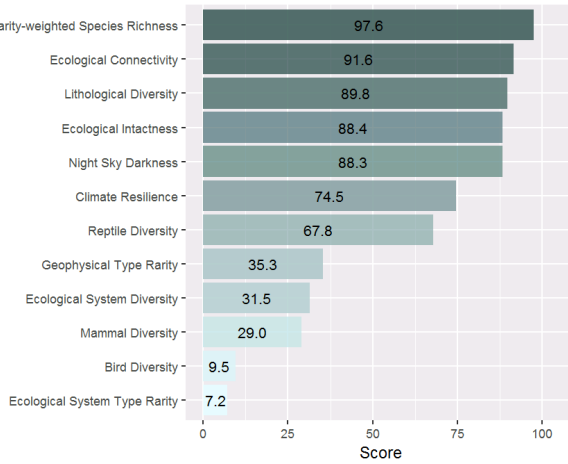
The location, time of establishment, and size of 22 national monuments under review, according to criteria in Executive Order 13792.

Monument	Location	Year(s) established	Acreage
Basin and Range	Nevada	2015	703,585
Bears Ears	Utah	2016	1,353,000
Berryessa Snow Mountain	California	2015	330,780
Canyons of the Ancients	Colorado	2000	175,160
Carrizo Plain	California	2001	204,107
Cascade Siskiyou	Oregon	2000/2017	100,000
Craters of the Moon	Idaho	1924/2000	737,525
Giant Sequoia	California	2000	327,760
Gold Butte	Nevada	2016	296,937
Grand Canyon-Parashant	Arizona	2000	1,014,000
Grand Staircase-Escalante	Utah	1996	1,700,000
Hanford Reach	Washington	2000	194,451
Ironwood Forest	Arizona	2000	128,917
Katahdin Woods and Waters	Maine	2016	87,563
Mojave Trails	California	2016	1,600,000
Organ Mountains-Desert Peaks	New Mexico	2014	496,330
Rio Grande del Norte	New Mexico	2013	242,555
Sand to Snow	California	2016	154,000
San Gabriel Mountains	California	2014	346,177
Sonoran Desert	Arizona	2001	486,149
Upper Missouri River Breaks	Montana	2001	377,346
Vermilion Cliffs	Arizona	2000	279,568

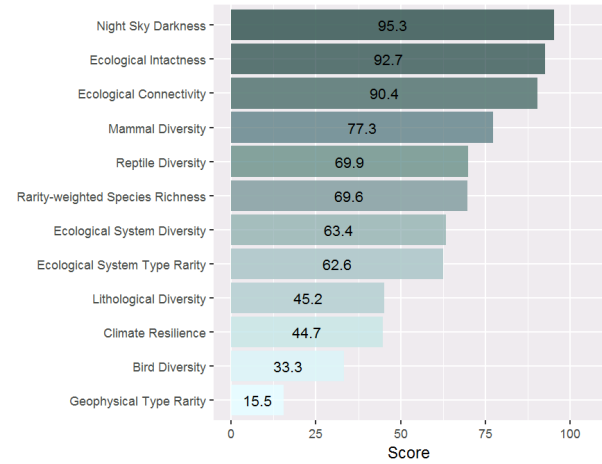
## Appendix B.

Scores received by each of 22 national monuments for each ecological indicator based on comparisons with a random set of equivalently-sized areas located across the 11 conterminous western states or, in the case of Katahdin National Monument, across the 37 conterminous eastern states.

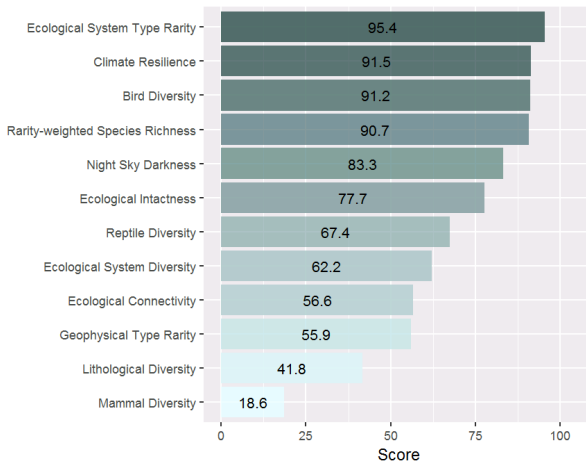
Basin & Range National Monument



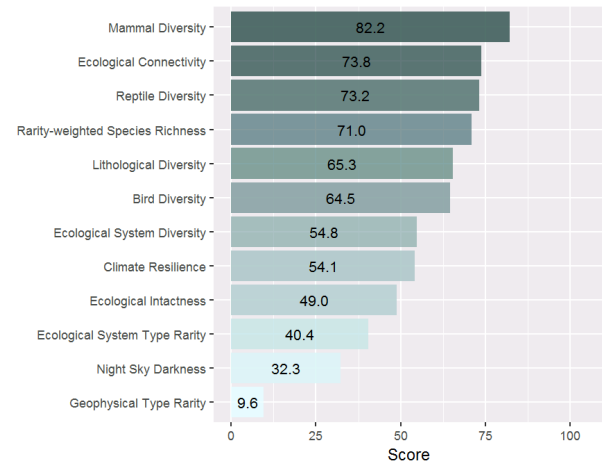
Bears Ears National Monument



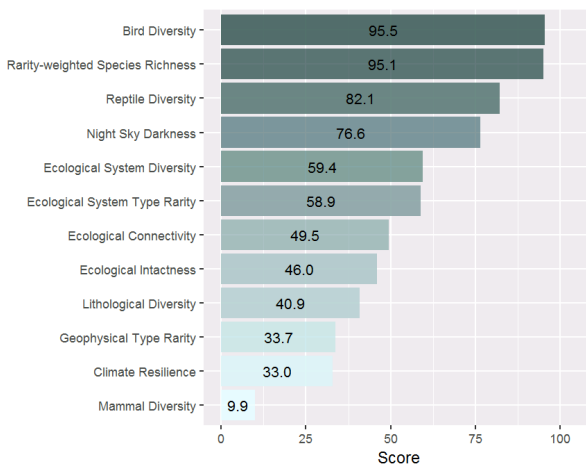
Berryessa Snow National Monument



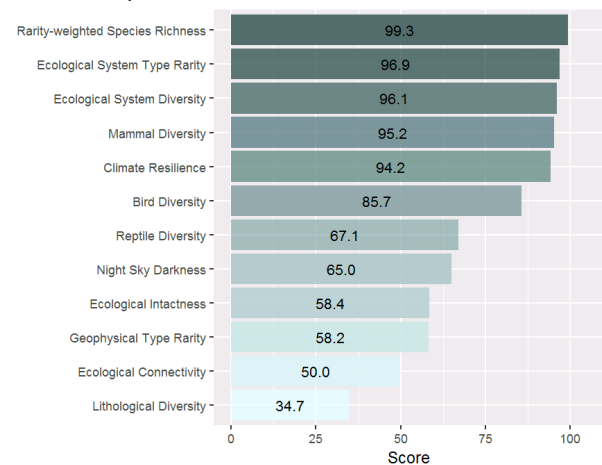
Canyons of the Ancients National Monument



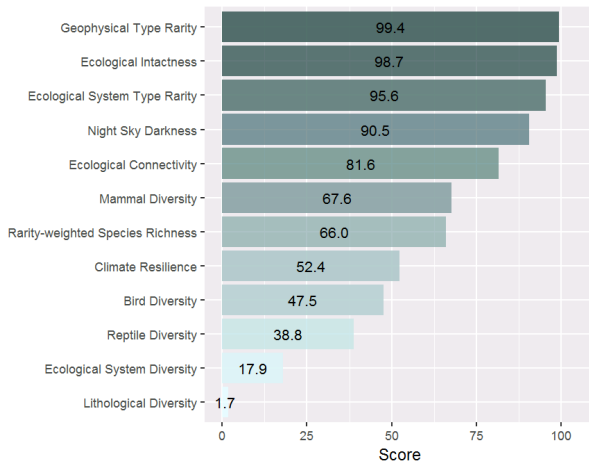
Carrizo Plain National Monument



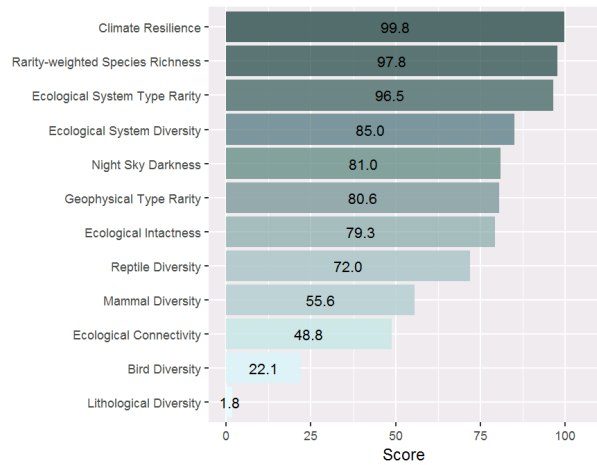
Cascade Siskiyou National Monument



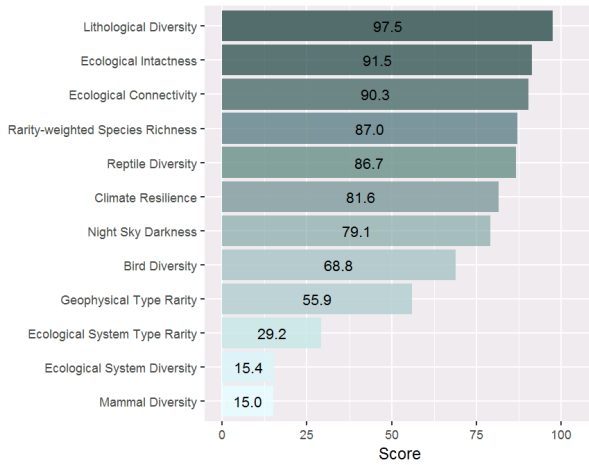
### Craters of the Moon National Monument



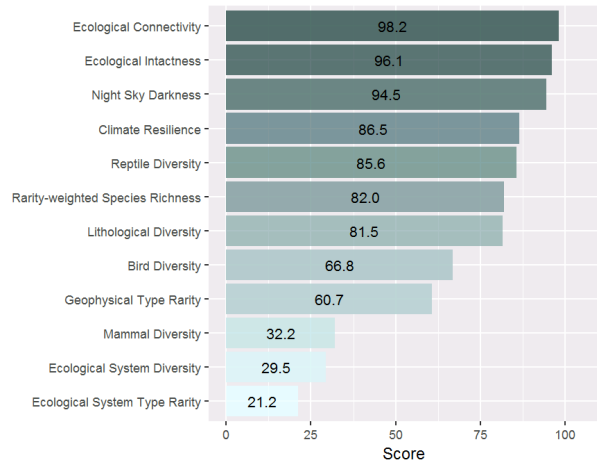
### Giant Sequoia National Monument



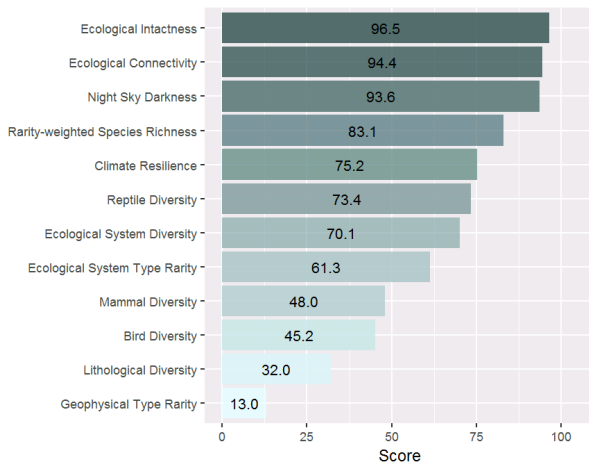
### Gold Butte National Monument



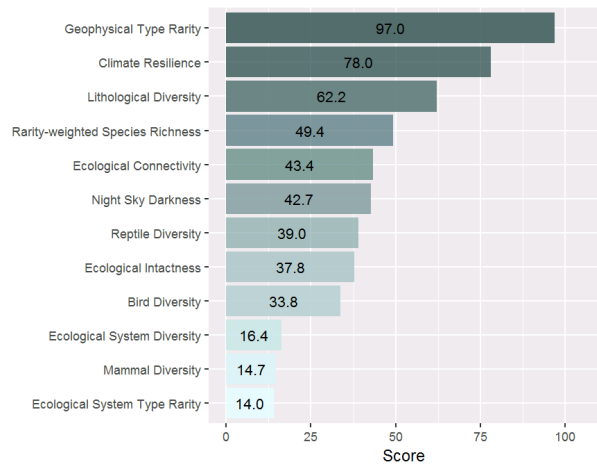
### Grand Canyon-Parashant National Monument



### Grand Staircase-Escalante National Monument

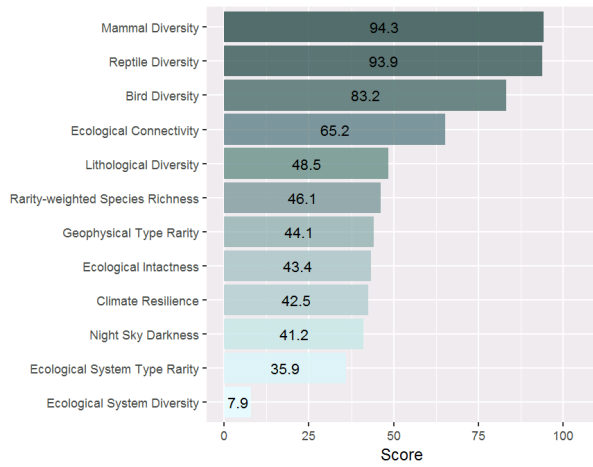


### Hanford Reach National Monument

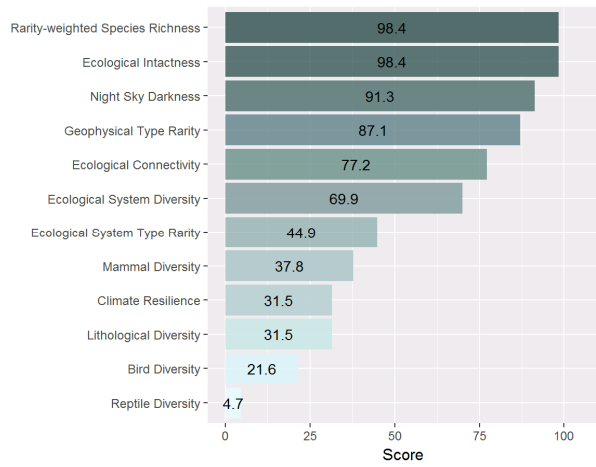




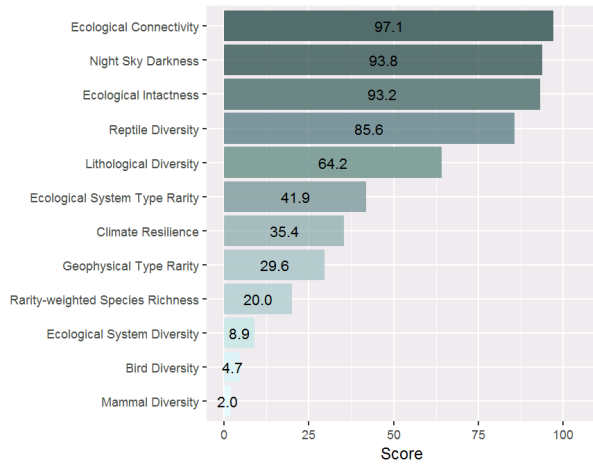
### Ironwood Forest National Monument



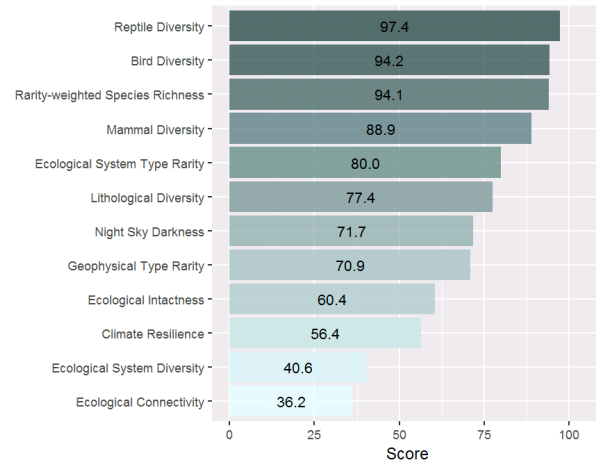
### Katahdin Woods & Waters National Monument



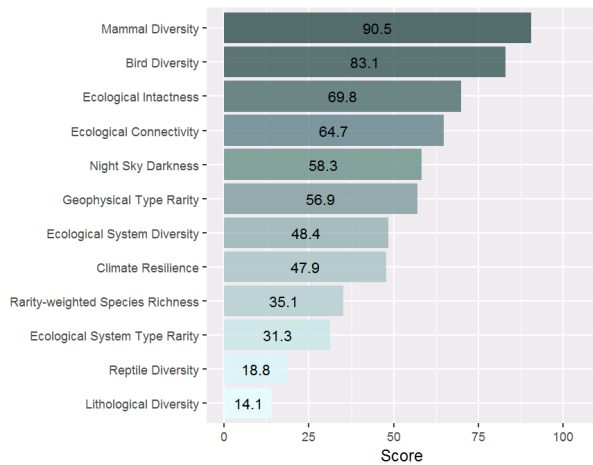
### Mojave Trails National Monument



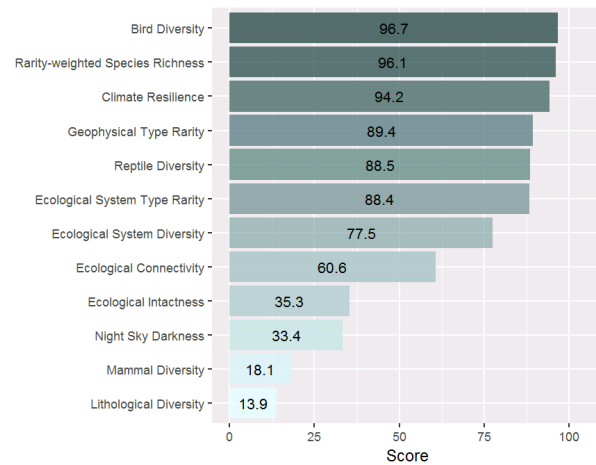
### Organ Mountains-Desert Peaks National Monument



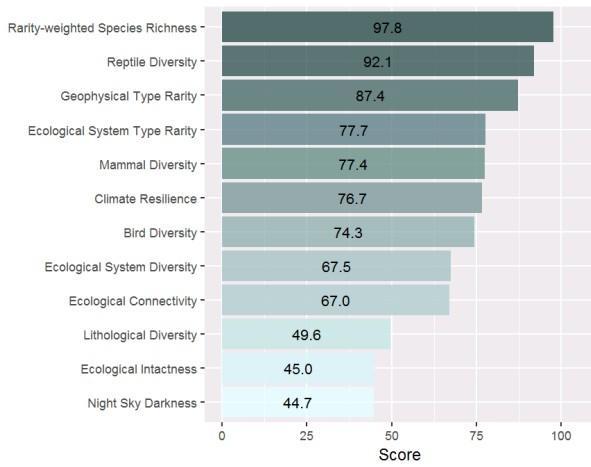
### Rio Grande del Norte National Monument



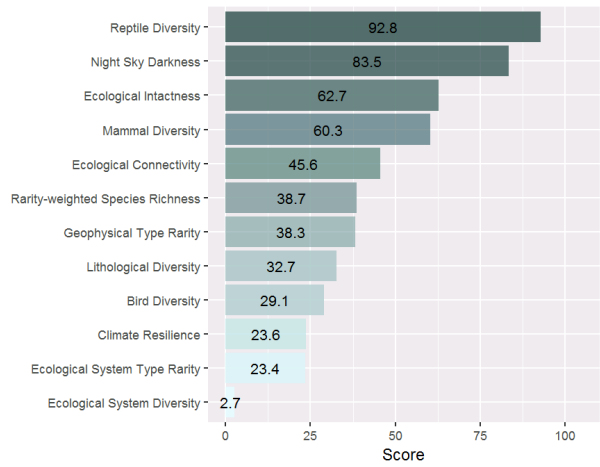
### San Gabriel Mountains National Monument



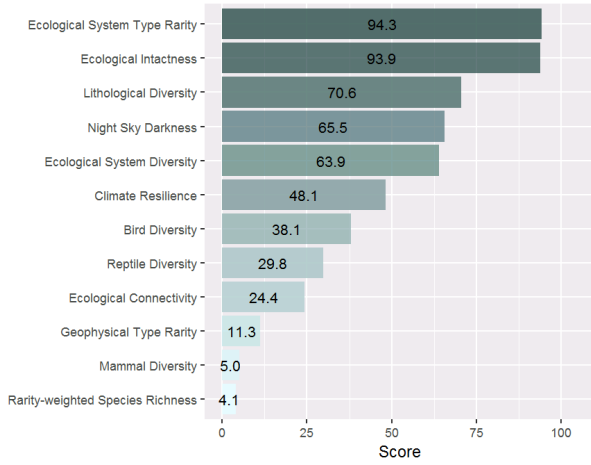
**Sand to Snow National Monument**



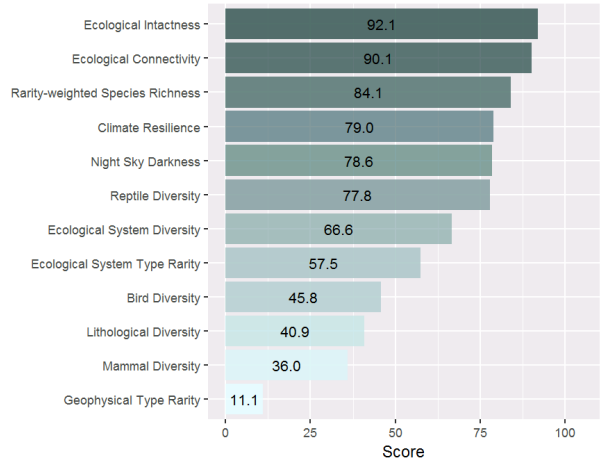
**Sonoran Desert National Monument**



**Upper Missouri River Breaks National Monument**



**Vermilion Cliffs National Monument**



## **Appendix C.**

Descriptions of source data (and original pixel resolution) and derivation methods for 12 indicators used to assess ecological values within 22 national monuments.

### **Ecological Connectivity**

Areas with high ecological connectivity have high capacity to facilitate natural processes such as dispersal, migration, and gene flow (Dickson et al. 2016). Fundamental principles of systematic conservation planning (e.g., Margules and Pressey 2000) suggest that an ecologically functional system of protected areas (PAs) needs to be interconnected (DeFries et al. 2007; Cumming et al. 2015), and maintaining ecological connectivity is the most frequently recommended strategy for maintaining biodiversity in a changing climate (Heller and Zavaleta 2009). We derived a model and 270-m resolution map of ecological flow among existing protected areas within the 11 western states in order to quantify the ability of currently unprotected areas to enhance potential connectivity across the existing protected areas network (Dickson et al. 2016). This connectivity model was designed to inform land use planning and policy efforts concerned with the maintenance of connectivity processes (e.g., migration and dispersal, gene flow) for multiple terrestrial species simultaneously. Specifically, we used a model of human modification (Theobald 2013) to estimate landscape resistance (see Krosby et al. 2015) and concepts from electronic circuit theory (McRae et al. 2008) to estimate the flow (as measured by current density) of ecological processes across the region. For comparison of Katahdin National Monument with the eastern 37 states, we relied on an earlier, national-extent model (Theobald et al. 2012) of connectivity routes across a continuous gradient of permeability to movement, which was defined by degree of human modification (similarly to Theobald 2013, above). Connectivity routes were prioritized based on a metric of centrality a path's relative importance to the broader landscape configuration. We converted connectivity route lines to a 270-m resolution raster, then identified the maximum centrality value within a 65,000-acre moving window.

### **Ecological Intactness**

Ecologically intact landscapes are those with minimal to no influence from human activities that are thereby able to support natural evolutionary and ecological processes (Angermeier and Karr 1994; Parrish et al. 2003). These landscapes are able to support and maintain communities of organisms that have species composition, diversity, and functional organization comparable to those of natural habitats within a region (Parrish et al. 2003). Degree of human modification of a landscape thus represents the inverse of ecological intactness. We used an updated version (Theobald et al. 2016) of a human modification model derived at 30-m resolution (Theobald 2013), which characterizes the intensity and footprint of human modification across the West, based on 12 parsimonious types of human activities.

### **Night Sky Darkness**

Places with high night sky darkness have low levels of light pollution, which confers high scenic value. The absence of night light pollution is also likely to indicate low levels of human activity and disturbance in these areas. We used an existing dataset representing the presence of artificial nighttime lights at 740-m resolution observed via satellite (NOAA 2012).

### **Ecological System (Vegetation) Diversity**

Diverse ecological systems, defined as "groups of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates and/or environmental gradients" (Comer et al. 2003), provide a variety of habitats essential for maintaining species diversity (Noss 1990). Ecological system diversity may stem from the presence of diverse vegetation types, strong elevation gradients,

ecotonal transitions among biome types, and/or interspersions of unique water-associated communities, such as wetlands, marshlands, meadows, and riparian zones. We followed methods in Theobald et al. (2015) to derive an estimate of ecological systems diversity at multiple spatial scales, equivalent to average sizes (1.2 – 115.8 km radii) of HUC 4-16 watersheds and using the Shannon-Weaver Equitability Index. We used the 30-m resolution USGS Gap Ecological Systems Units (USGS 2011) as the basis for calculating ecosystem diversity and assigned null values to all developed and invasive species land cover types prior to running the analysis, so that these lands would not contribute toward the diversity calculation.

### **Ecological System Type Rarity**

Areas with high ecological system rarity are those that support rare, unique, or irreplaceable natural systems. These systems are likely to consist of species that are rare, unique, or irreplaceable. Ecological systems are defined as “groups of plant community types that tend to co-occur within landscapes with similar ecological processes, substrates and/or environmental gradients” (Comer et al. 2003), thus they incorporate physical components such as landform position, substrates, hydrology, and climate in addition to vegetation. To characterize ecological system type rarity, we calculated the areal extent of USGS GAP ecological system types at 30-m resolution (USGS 2011), ranked them by areal extent, then normalized the values based on the maximum value so that they ranged from 0 (least rare) to 1 (most rare).

### **Lithological Diversity**

Lithological diversity, or diversity of soil parent materials, is a fundamental driver of both ecological and evolutionary processes that generate species diversity (Lawler et al. 2015). Areas with high lithological diversity offer heterogeneous conditions to support diverse vegetation types that thrive on different substrates. Lithological diversity is closely related to geological diversity (above), but the two indicators are derived from different datasets. To characterize lithological diversity we converted a published map of lithological units (1:5,000,000) (Soller and Reheis 2004) to a 270-m grid and calculated the number of unit types within a 65,000-acre moving window.

### **Geophysical Type Rarity**

Ensuring the protection of a regionally diverse array of geophysical settings, including the rarest features, is an important strategy both for conserving a variety of species, as well as ecological and evolutionary processes such as species diversification, particularly in the face of climate change (Lawler et al. 2015). Unique geophysical types that are likely to offer unique habitat conditions can be defined by combining landform (e.g., ridge, slope, valley) and lithology (i.e., soil parent material). To characterize geophysical type rarity, we calculated the areal extent of each of 188 unique geophysical unit types at 30-m resolution based on an overlay of landforms and surficial lithology (Theobald et al. 2015) across the western US, ranked them by areal extent, then normalized the rank values based on the maximum value so that they ranged from 0 (least rare) to 1 (most rare).

### **Rarity-weighted Species Richness**

Rarity-weighted species richness provides a relative measure of the concentration of rare and irreplaceable species across the US (Chaplin et al. 2000). High rarity-weighted species richness is often indicative of the presence of numerous endemic species and/or sites that contain critically-imperiled or imperiled species with restricted distributions (i.e., G1-G2 –ranked species). These sites are essential for maintaining species diversity, particularly rare, sensitive, and irreplaceable species. We used NatureServe’s rarity-weighted richness index (refreshed in 2013) 1-km resolution data layer as an

indicator of species rarity and irreplaceability (see Chaplin et al., 2000 for references and description of methods). Additional information on this metric is available [here](#).

### **Bird, Mammal, and Reptile Species Diversity**

We used published data on bird, mammal, and reptile species richness to quantify vertebrate species diversity within each taxonomic group. These data are based on overlap among species range maps in the continental U.S. represented at 10-km resolution, as tabulated by Jenkins et al. (2013).

### **Climate Resilience**

Areas with high climate resilience are those that contribute to the ability of species to adapt to climate change through both local and long-distance movements. Climate velocity represents the speed and direction a species must migrate to keep pace with shifts in climate conditions to which they are suited, given projected changes in climate (Loarie et al. 2009). Low velocities indicate that the climate conditions currently occupied by a given species are projected to occur nearby in the future, whereas high velocities indicate that the species will have to migrate longer distances more quickly to keep up with changing climate. Places with low climate velocity, if left intact, may function as important strongholds of species diversity under changing climate, and thus have high climate resilience. We used a published model of multivariate climate velocity (Hamann et al. 2015) derived at 1-km resolution to quantify potential resilience to climate change. The estimate was based on the averages of model projections from an ensemble of 15 CMIP5 models and the Representation Concentration Pathway (RCP) 8.5 scenario (IPCC: Pachauri et al. 2014), and included 11 biologically-relevant climate metrics related to changes in both temperature and precipitation between 1996 and 2055.