CONSERVATION SCIENCE PARTNERS

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An assessment of landscape-level ecological values and climate resilience associated with the proposed Greater Grand Canyon Heritage National Monument

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And

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EXECUTIVE SUMMARY

Under rapid climate and landscape change, there is a significant need to identify and expand protected areas to prevent further loss of biodiversity and preserve ecological functions across broad geographies. Basic principles of systematic conservation planning suggest that an ecologically functional protected areas network requires a sufficient land base, should protect a variety of habitats, and—perhaps most critically—needs to be resilient to ongoing climate change and interconnected. The proposed 1.78-million acre Greater Grand Canyon Heritage National Monument (GGCHNM) in northern Arizona presents an opportunity to conserve key elements of ecological function within the region and across the western U.S.

In this context, we leveraged existing research and sources of readily available spatial data to conduct a rigorous, landscape-level assessment of ecological features and values across the GGCHNM and adjacent lands. Specifically, we focused our assessment on information that highlighted the ecological importance, climate resilience, and ecological representativeness of the GGCHNM in a West-wide comparative analysis.

Our results indicated that designation of the proposed GGCHNM would substantially…

- **Enhance regional resilience to climate change and support regional climate adaptation**
- **Increase regional potential to facilitate high levels of ecological connectivity and ecological intactness**
- **Promote the geological and ecological uniqueness of America's protected areas network**
- **Encompass some of the most unfragmented and remote areas in the western U.S.**
- **Enhance the ecological diversity and representativeness of the U.S. protected areas network**

Our analysis of the GGCHNM indicated that this area far exceeded other western landscapes of equivalent size, in terms of ecological connectivity and intactness, geophysical uniqueness, and richness of rare and irreplaceable species.

Compared to a random sample of lands in the West, the GGCHNM scored in the…

- **98th percentile for ecological connectivity**
- **96th percentile for ecological intactness**
- **91st percentile for geophysical rarity**
- **85th percentile for rarity-weighted species richness**

Protective designation of the proposed GGCHNM would purposefully and strategically strengthen America's existing network of protected areas in the face of climate change, while supporting fundamental ecological processes, such as habitat connectivity, in the region. The value of the GGCHNM in sustaining the ecological function and large, contiguous landscapes that also support high levels of regional biodiversity should not be underestimated.

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 habitats, and—perhaps most critically—needs to be resilient to ongoing climate change (Dawson et al. 2011), and interconnected (DeFries et al. 2007, Cumming et al. 2015). Yet, in the United States, as is the case in other places in the world, protected areas have rarely been selected to meet these criteria (Scott et al. 1993, Jenkins et al. 2015). Existing protected areas in the U.S. are likely insufficient to guard against the long-term loss of species and the habitats they require (Scott et al. 2001). Thus, there is a significant need to expand and connect protected areas to prevent further loss of biodiversity and preserve ecological functions in the face of climate change.

In the western U.S., vast areas of unprotected and undeveloped public land currently serve to enhance the ecological effectiveness of the U.S. protected areas network (Dickson et al. in press). However, the expansion of energy development, mining, timber harvesting, and other extractive land uses threaten to fragment these areas, reducing their ecological function (Hansen and Defries 2007). These activities can also reduce the effectiveness of existing protected areas (e.g., Berger et al. 2014). Thus, careful selection of new areas for conservation and protection that are based on the area's ecological significance and context is an important step for both maintaining and enhancing the existing protected areas network (Dickson et al. 2014, Watson et al. 2016). Moreover, there is a critical need to address the impacts and conservation implications of ongoing climate change on vulnerable public lands (Stein et al. 2014). Federal agencies are attempting to address this need through recent environmental initiatives, such as the strategy for improving the mitigation policies and practices of the Department of the Interior (Clement et al. 2014) and the National Fish, Wildlife, and Plants Climate Adaptation Strategy (National Fish, Wildlife, and Plants Climate Adaptation Partnership 2012). Federal land managers are particularly well positioned to work across jurisdictional boundaries and coordinate their climate adaptation planning strategies and activities among agencies and stakeholders (Olliff and Hansen 2016). Concomitantly, nongovernmental organizations and other partners must continue working with agencies to develop collaborative approaches for addressing climate change and adapting their own conservation and stewardship strategies (GCT 2016).

In this context, the proposed 1.78-million acre Greater Grand Canyon Heritage National Monument (GGCHNM; Map 1) in northern Arizona presents a significant opportunity to conserve key elements of ecological function within this region and across the western U.S. A recent study by Dickson et al. (2014) was designed to provide a sound scientific basis for future proposals for conservation-based special designations in the western U.S., with an emphasis on unprotected, roadless BLM lands. Results from this study suggested that areas within and around the GGCHNM were among the most important in the West, in terms of their conservation value. Here, we leverage input data and results produced by this study, as well as other sources of readily available spatial data, to conduct an assessment of ecological features and values across the GGCHNM and adjacent lands. We focused our assessment on information that highlighted the ecological importance, climate resilience, and ecological representativeness of the GGCHNM in a West-wide comparative analysis.

METHODS

Assessing the ecological importance of the GGCHNM

For our assessment, we mapped and summarized nine landscape-level indicators of resilience to climate change, ecological connectivity and intactness, biodiversity, and remoteness (detailed in Table 1). Specifically, we used readily available spatial data layers and published methods to model two indicators of resilience to climate change: climate velocity (Hamann et al. 2014) and geophysical diversity (Theobald et al. 2015); three indicators of potential landscape connectivity and intactness: ecological flow (Dickson et al. in press), ecological integrity (after Theobald 2013), and proximity to the nearest protected area (USGS 2012); three indicators of biodiversity: vegetation community diversity (Scott et al. 1993), rarity-weighted species richness (Chaplin et al. 2000; updated in 2013), and geophysical rarity (Theobald et al. 2015); and one indicator of remoteness: night sky darkness (NOAA 2012). Notably, some of the variables used in our analysis could be used to simultaneously indicate different categories of ecological or conservation value. For example, geophysical diversity is expected to promote climate resilience and biodiversity. Data for each indicator was generated at a 270-m pixel resolution. Although we focused our assessment on the GGCHNM, our indicator maps extended across all 11 western states, permitting comparisons between the GGCHNM and equivalently sized areas within these states, regardless of jurisdiction.

We derived a model and map of ecological flow among existing protected areas (Dickson et al. in press) 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. 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 (updated after 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.

We determined the values of each of the indicators relative to the larger landscape using a simple scoring system based on percentile ranks. Specifically, the mean value of each indicator within the GGCHNM was compared to the distribution of means of a large (n = 1000) random sample of areas across the 11 western states, including all jurisdictions. The size of the random samples was equivalent to the size of the proposed GGCHNM. 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 the GGCHNM was greater than or equal to 98% of the equivalently-sized random samples. Scores of 50 or higher suggest a relatively important indicator.

As a final step in assessing ecological importance, we summarized the amount of currently unprotected, roadless BLM lands within the proposed GGCHNM boundary that were identified as having particularly high conservation value. This analysis was based on the approach and results described in Dickson et al. (2014), namely the conservation priority areas and high conservation value areas they identified.

Assessing the ecological representativeness of the GGCHNM

The ability of any protected areas network to capture biodiversity and maintain ecological function will depend on the variety of ecosystem components (e.g., vegetation and landform types that contribute to habitat) that are represented within the network (Aycrigg et al. 2013). In the U.S., only 12% of lands have protected status (USGS 2012), and these lands have typically not been selected on the basis of representation (Pressey 1994). Thus, as a second step, we assessed the degree to which the GGCHNM diversifies the existing protected areas network by increasing representation of different ecosystem components. We compiled spatial data on major ecosystem (USGS 2011) and landform (Theobald et al. 2015) types across the western U.S. and within the proposed GGCHNM (Table 2). Next, we calculated the percentages of different ecosystem components in the western U.S. that are represented in the current protected areas network, including lands managed specifically for conservation of species (IUCN 2008; categories I-IV) and those within the BLM National Conservation Lands (NCL) system. We also calculated the percentages of ecosystem components that would be represented within the protected areas network following any designation of the proposed GGCHNM.

RESULTS AND DISCUSSION

The designation of GGCHNM would enhance regional resilience to climate change and support regional climate adaptation

Based on the model of climate resilience we used, which considered projected changes in 11 biologically relevant climate parameters including average and extreme seasonal temperatures and precipitation amounts (see Table 1), the proposed GGCHNM exhibits relatively high values for climate resilience (i.e., low climate velocity; see Table 2), scoring in the top 30%, as compared to a random sample of all other similarly size landscapes in the West (Fig. 1, Map 2). Indeed, permanent protection of the GGCHNM would address *five* of the seven climate adaptation strategies developed by a consortium of experts, including representatives from seven federal natural resource management agencies (Stein et al. 2014; Table 3). Specifically, this designation would further *protect key ecosystem features*, including a high diversity of geophysical features that have the potential to serve as *refugia* and facilitate ecological and *evolutionary processes* that promote biodiversity as individual species shift their ranges in response to climate change (Lawler et al. 2015). Compared to other western lands, the GGCHNM is in the 61st percentile for geophysical diversity (Fig. 1, Map 2). Further, the proposed GGCHNM would *reduce non-climate stresses* by minimizing the risk of water quality degradation associated with uranium mining (BLM 2012), which has the potential to be exacerbated as water availability declines under changing climate. This is particularly important in an area that can *ensure connectivity* between Grand Canyon National Park and Grand Staircase-Escalante National Monument. Indeed, the area is one of the most ecologically connected and intact landscapes of its size in the West (see below).

The GGCHNM has exceptionally high potential to facilitate ecological connectivity and maintain ecological intactness

The maintenance of connectivity processes is one of the most important aspects of biodiversity and landscape-level conservation (Taylor et al. 1993, Noon et al. 2009). Considering all other western lands and jurisdictions, we observed exceptionally high values for ecological connectivity and intactness within the proposed GGCHNM, scoring in the 98th and 96th percentiles, respectively (Fig. 1, Maps 3 and 4). Similarly, the area scored in the 90th percentile for its high adjacency to existing protected areas (Fig. 1, Map 4). The GGCHNM would serve to facilitate the flow of multiple ecological processes, such as dispersal, migration, and gene flow (Dickson et al. in press). The area also would secure the connection of habitats between Grand Canyon National Park and Grand Staircase Escalante National Monument, enhancing their overall value (Berger et al. 2014). For example, the GGCHNM would form a critical piece of an important complex of well-connected and intact habitats for multiple wide-ranging species, including, but not limited to: mule deer (*Odocoileus hemionus*), pronghorn antelope (*Antilocapra americana*), and desert bighorn sheep (*Ovis Canadensis nelsoni*). Moreover, because BLM lands dominate much of the area within and surrounding the proposed GGCHNM, relatively unmodified landscapes in this domain may be key to the movement of fundamental ecological processes between existing protected areas and the GGCHNM (Dickson et al. in press). The designation of the GGCHNM could help to build a true network of protected areas that enhance landscape connectivity (Krosby et al. 2010) and integrity (Theobald 2013), as well as the associated capacity for adaptation to future climate change (Heller and Zavaleta 2009; Dawson et al. 2011).

The ecological and geological uniqueness of the GGCHNM contributes to its high value for biodiversity conservation

Our results indicate the West-wide importance of the proposed GGCHNM to sustaining an imperiled but wide diversity of species, given its high values with respect to geophysical rarity, rarity-weighted species richness, and vegetation community diversity. The area scored in the 91st percentile for geophysical rarity (Fig. 1, Map 5). This geophysical uniqueness gives rise to ecological uniqueness (Lawler et al. 2015). For example, limestone geologies, such as those found on the Kaibab Plateau, are well-recognized to promote species diversity given that they harbor unusually high numbers of endemic species (Krukeberg 2002), including extremely rare *Pediocactus* species (Hannemann and Foster 2014). At the same time, the GGCHNM scored in the 85th percentile for rarity-weighted species richness, a relative measure of the concentration of rare and irreplaceable species for the conterminous U.S. (Chaplin et al. 2000) (Fig. 1, Map 5). There are 82 special status species occupying areas within or immediately adjacent to the proposed monument (BLM 2011). Thirty-six of these species are federally listed, including the California condor (*Gymnogyps californianus*), Mexican spotted owl (*Strix occidentalis lucida*), and Apache trout (*Oncorhynchus apache*). In addition, the GGCHNM scored in the 52nd percentile for vegetation community diversity (Fig. 1, Map 6), owing in part to its > 6000-ft elevational gradient. Our results point to the highly distinctive nature and irreplaceable value of this area with respect to rare and endemic species, as well as the diverse habitats they depend on.

The GGCHNM encompasses some of the most unfragmented and remote areas in the western U.S.

Our analysis suggests that the GGCHNM includes some of the most unfragmented BLM lands remaining in the western U.S. Based on the results derived by Dickson et al. (2014), the GGCHNM contains over 225,000 acres of unprotected, roadless BLM lands with high conservation value (Map 1). Protection of these landscape features, in particular, would promote climate resilience and facilitate key ecological connections with protected areas immediately to the north and south of the GGCHNM boundary. The GGCHNM also has some of the lowest levels of light pollution in the western US, and as a result, one of the darkest night skies of any equivalently sized areas in the western U.S. (Fig. 1, Map 6). In North America, light emissions have historically increased at an estimated rate of 6% annually, resulting in a rapid increase in light pollution (Cinzano and Elvidge 2003). Considering our results, the GGCHNM may afford one of the best opportunities in the U.S. to preserve remote environmental assets of both human and ecological significance (Watts et al. 2007).

The GGCHNM would enhance the diversity of the U.S. protected areas network

Based on our assessment of representation, the proposed GGCHNM stands to increase the variety of vegetation and landform types in the U.S. protected area network, a number of which are currently underrepresented. The majority of protected areas in the western U.S. occur within high montane and alpine ecosystems (Fig. 2). This underrepresentation presents a significant bias, since most temperate forestland-, shrubland-, and grassland-dominated ecosystem types are offered little protection. Nevertheless, our assessment indicated that the GGCHNM encompasses a relatively large amount of temperate forest and cool semi-desert scrub and grassland, which are currently underrepresented in the existing protected areas network (Fig. 2; Aycrigg et al. 2013). Perhaps one of the most extensive stands of old-growth ponderosa pine (*Pinus ponderosa*) forest remaining in the West is found on the Kaibab Plateau (Sesnie and Bailey 2003). This forest, which would define much of the core of the GGCHNM, is home to the endemic Kaibab squirrel (*Sciurus aberti kaibabensis*) and provides important foraging habitat for the globally significant Kaibab mule deer herd, among other species.

Around the West, significant biases also are evident with respect to the protection of major landform types. For example, cliffs and mountain tops have much more protection than basins, flats and valley bottoms (Fig. 3). However, the GGHCNM includes a diversity of landform types (Fig. 3) that together would serve to protect biodiversity under a changing climate (e.g., Lawler et al. 2015). These diverse terrain features also give rise to the collection of springs and seeps, riparian areas, meadows, and other wetland habitats that sustain the terrestrial and aquatic biota in the region. The presence of these features suggest that designation of the GGCHNM would protect the high elevation habitat features that could serve as refugia for species moving up in elevation due to climate change. The varied topography, geophysical diversity, and low climate velocity of the proposed GGCHNM would contribute substantially to a national portfolio of protected areas lacking resilience to a changing climate.

CONCLUSIONS

Our landscape-level assessment of the GGCHNM in a West-wide context highlighted the intrinsic value of the area with respect to multiple indicators of conservation value, namely resilience to climate change, ecological connectivity and intactness, and biodiversity. Considering also the results of Dickson et al. (2014, in press), protective designation of the proposed GGCHNM would substantially enhance the existing network of protected areas in the face of climate change, while supporting fundamental ecological processes, such as habitat connectivity. The value of this area in sustaining the ecological function and large, contiguous landscapes that also support high levels of biodiversity should not be underestimated.

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Table 1. *Nine indicators used to assess ecological and conservation values within the proposed 1.78-million acre Greater Grand Canyon Heritage National Monument.*

Indicator	Primary source	Description
Climate resilience	Hamann et al. (2014)	We used a published model of multivariate climate velocity (Hamann et al. 2014) 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 Representative Concentration Pathway (RCP) 8.5 scenario (IPCC 2014), and included 11 biologically-relevant climate metrics related to changes in both temperature and precipitation between 1995 and 2055. Climate velocity represents the velocity (speed and direction) a species must migrate to persist in an area with the same climatic conditions, given projected changes in climate. Low velocities (high climate resilience) indicate that the same climate conditions the species currently occurs within are nearby, whereas high velocities (low climate resilience) indicate a species will have to migrate longer distances to keep up with changing climate.
Geophysical diversity	Theobald et al. (2015)	Geophysical diversity is a fundamental driver of both ecological and evolutionary processes that generate species diversity and foster landscape resilience to climate change (Lawler et al. 2015). To characterize geophysical diversity we used a model of physiographic diversity (Theobald et al. 2015) that characterizes unique geophysical units based on an overlay of landforms and surficial lithology. In this model, diversity is calculated using the Shannon-Weaver Equitability Index (described in Magurran 1988) and at multiple spatial scales, equivalent to average sizes (1.2 – 115.8 km radii) of HUC 4-16 watersheds.
Ecological flow	Dickson et al. (in press)	We derived a model and 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. 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 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.
Ecological integrity	Theobald (2013)	We used an updated version (Theobald et al. 2016) of a model of human modification (Theobald 2013), which characterizes the intensity and footprint of human modification across the West, based on 12 types of human activities.
Proximity to protected areas	USGS (2012)	Distance to nearest protected area as defined by the Protected Areas Database of the United States (PAD-US version 1.3). Protected areas were identified as IUCN categories I-IV and category V Bureau of Land Management National Conservation Lands for this analysis.
Vegetation diversity	USGS Gap Ecological Systems Type (USGS 2011)	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 USGS Gap Ecological System Land Units (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.
Rarity-weighted species richness	NatureServe (2013)	We used NatureServe's rarity-weighted richness index data layer (NatureServe 2008; refreshed in 2013) as an indicator of species rarity and irreplaceability (see Chaplin et al. (2000) for references and description of methods). This index identifies sites that contain critically-imperiled or imperiled species with restricted distributions (i.e., G1-G2 – ranked species).
Geophysical rarity	Theobald et al. (2015)	To characterize geophysical rarity, we calculated the areal extent of each of 188 unique geophysical unit types based on an overlay of landforms and surficial lithology (Theobald et al. 2015) across the western US, then normalized the values based on the maximum value so that they ranged from 0 (least rare) to 1 (most rare).
Night sky darkness	NOAA (2012)	We used an existing dataset of artificial nighttime lights observed via satellite (NOAA 2012).

Table 2. *Datasets used to calculate the degree to which the proposed 1.78-million acre Greater Grand Canyon Heritage National Monument (GGCHNM) diversifies the existing protected areas network by increasing representation of different ecosystem components, specifically major vegetation types and landforms.*

Dataset	Source	Applied to representation analysis
Major vegetation types in western U.S.	Gap vegetation classes (USGS 2011)	Used to assess the degree to which the proposed GGCHNM diversifies the existing protected areas network by increasing representation of different vegetation classifications.
Landform types in the western U.S.	Theobald et al. (2015)	Used to assess the degree to which the proposed GGCHNM diversifies the existing protected areas network by increasing representation of different landform types.
Protected areas network	PAD-US v1.3 (USGS 2012)	We included lands managed specifically for conservation of species, IUCN categories I-IV IUCN (2008), and category V within the Bureau of Land Management National Conservation Lands (NCL) system.

Table 3. *Climate change adaptation strategies identified in Climate Smart Conservation – putting adaptation principles into practice (adapted from Table 8.1 of Stein et al. [2014]). These guidelines were developed by a 23-member expert workgroup led by the National Wildlife Federation, and included membership from seven federal natural resource management agencies.*

Adaptation strategy	Definition
Reduce non-climate stresses	Minimize localized human stressors (e.g., pollution) that hinder the ability of species or ecosystems to withstand or adjust to climatic events
Protect key ecosystem features	Focus management on structural characteristics (e.g., geophysical stage), organisms, or areas (e.g., spawning sites) that represent important "underpinnings" or "keystones" of the current or future system of interest
Ensure connectivity	Protect, restore, and create landscape features (e.g., land corridors, stream connections) that facilitate movement of water, energy, nutrients, and organisms among resource patches
Restore structure and function	Rebuild, modify, or transform ecosystems that have been lost or compromised, in order to restore desired structures (e.g., habitat complexity) and functions (e.g., nutrient cycling)
Support evolutionary potential	Protect a variety of species, populations, and ecosystems in multiple places to bet-hedge against losses from climate disturbances, and where possible manage these systems to assist positive evolutionary change
Protect refugia	Protect areas less affected by climate change, as sources of "seed" for recovery (in the present) or as destinations for climate-sensitive migrants (in the future)
Relocate organisms	Engage in human-facilitated transplanting of organisms from one location to another in order to bypass a barrier (e.g., urban area)

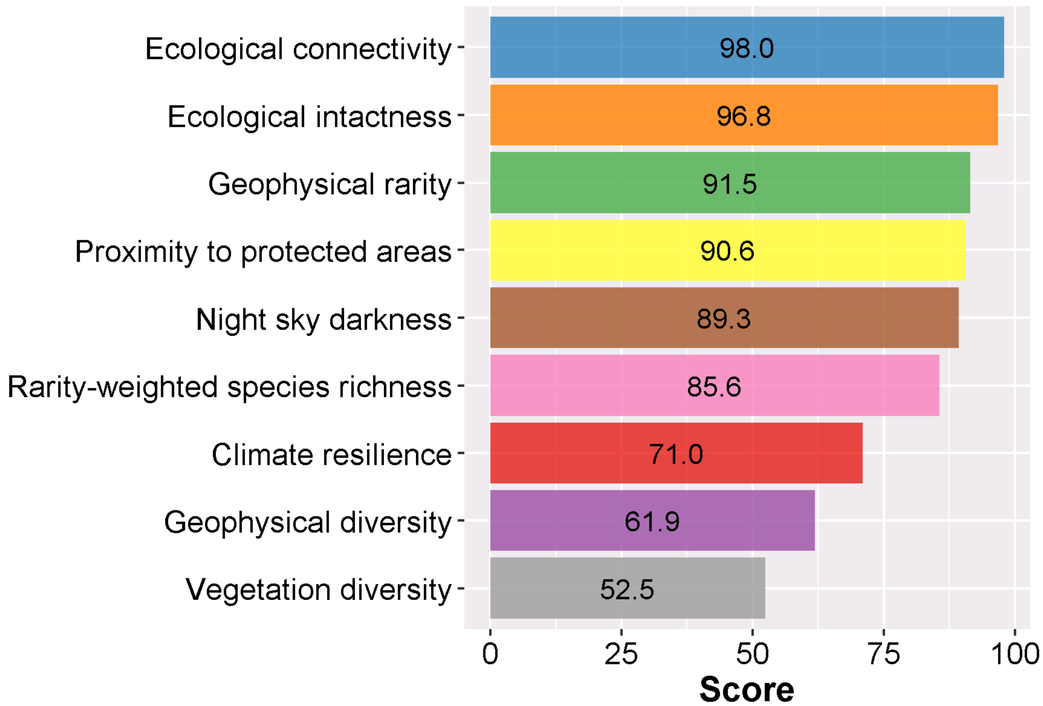


Figure 1. *Scores received by the proposed 1.78-million acre Greater Grand Canyon Heritage National Monument (GGCHNM) for each of nine indicators by comparing them to a random set of equivalently sized areas located across the entire western U.S. Potential scores range from 0-100 (100 being highest). A score of 98 for a given indicator indicates that the mean value of that indicator in the GGCHNM was greater than or equal to the mean value in 98% of equivalently-sized random samples. Scores of 50 or higher generally suggest a relatively important indicator.*

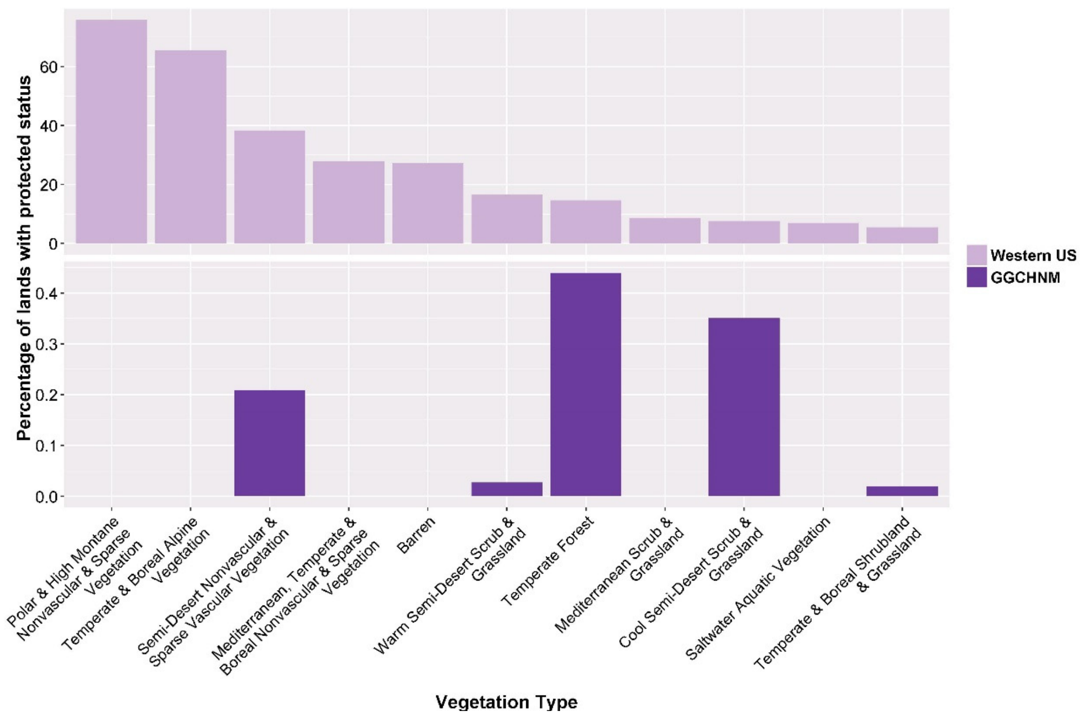


Figure 2. *Percentage of lands within different major vegetation types in the western U.S. that have protected status (IUCN categories I-IV and NCL lands in IUCN V; upper panel) and percentage of additional lands that would be protected with designation of the proposed 1.78-million acre Greater Grand Canyon Heritage National Monument (GGCHNM; lower panel). The area would serve to enhance and diversify the existing protected areas network by increasing the representation of key vegetation types, namely temperate forests and cool semi-desert scrub and grasslands, which currently have low representation within the current network.*

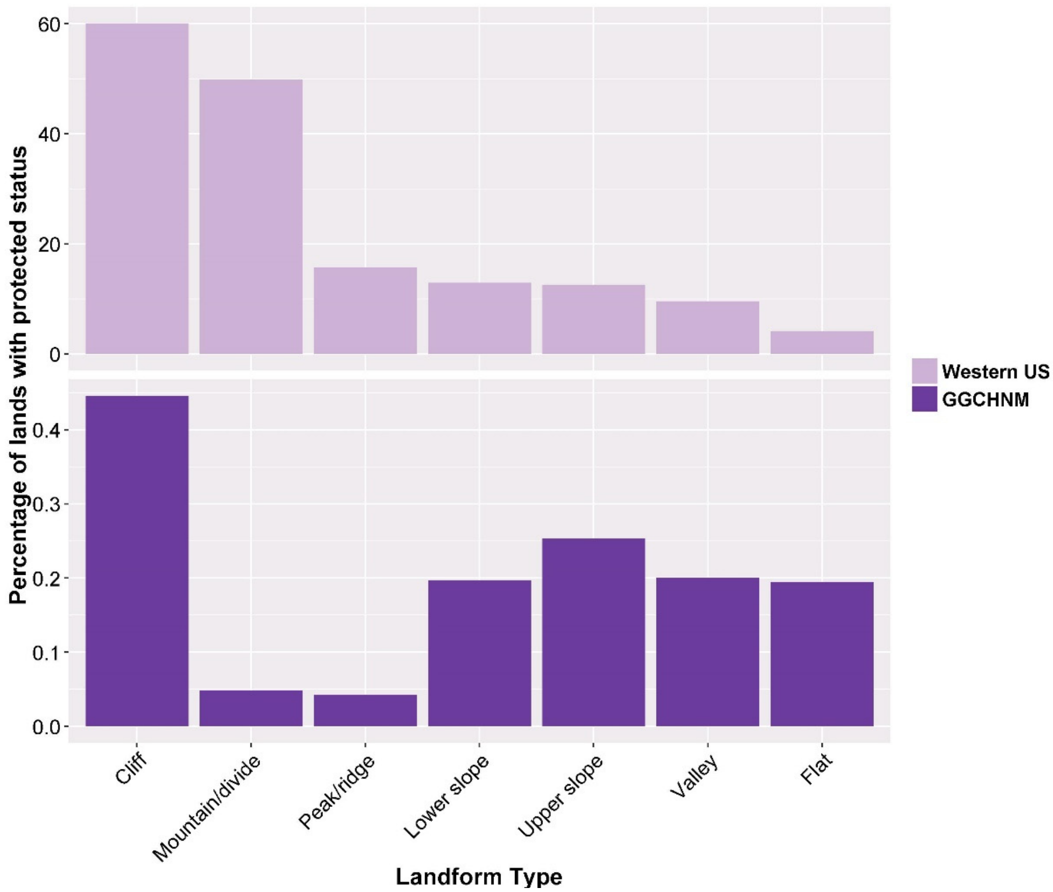
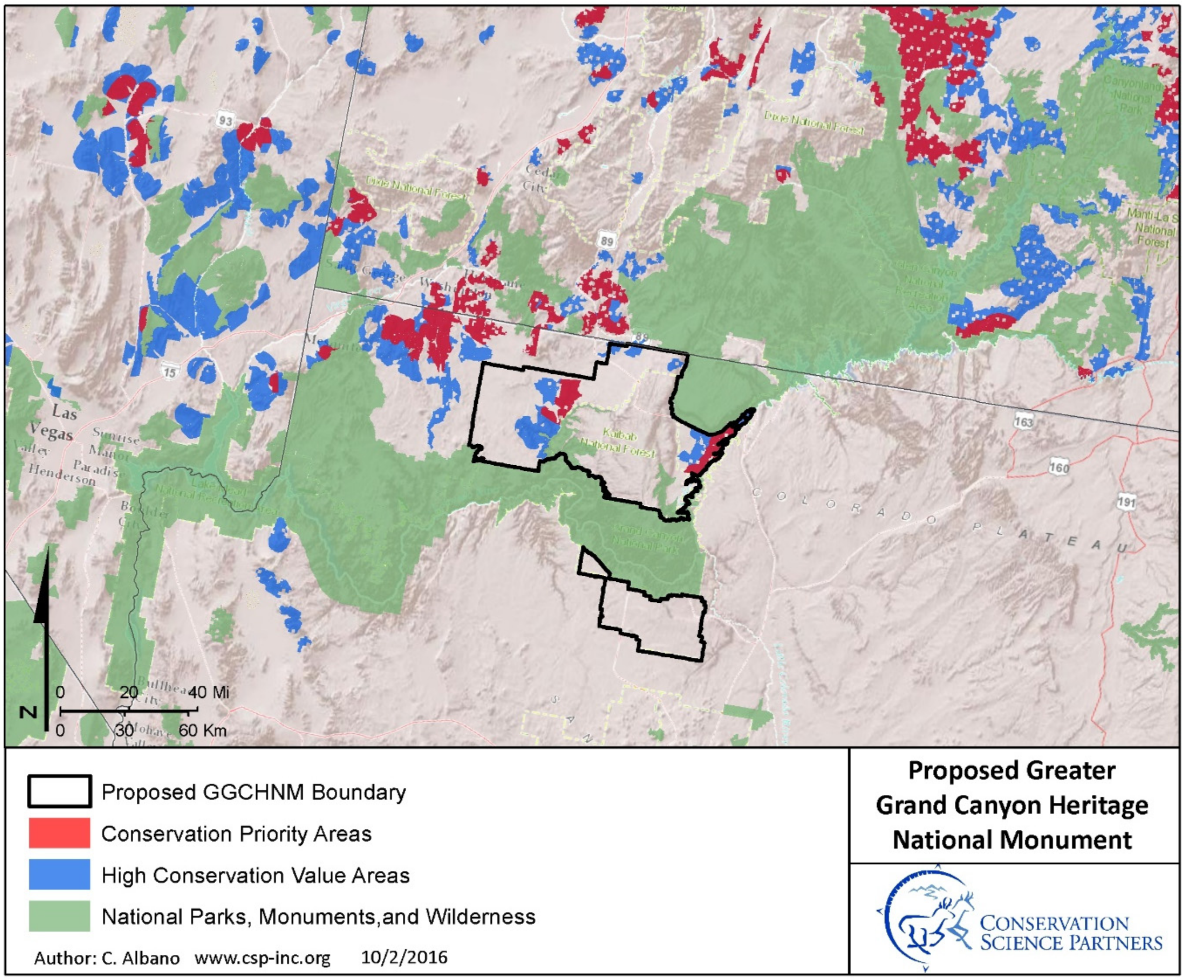
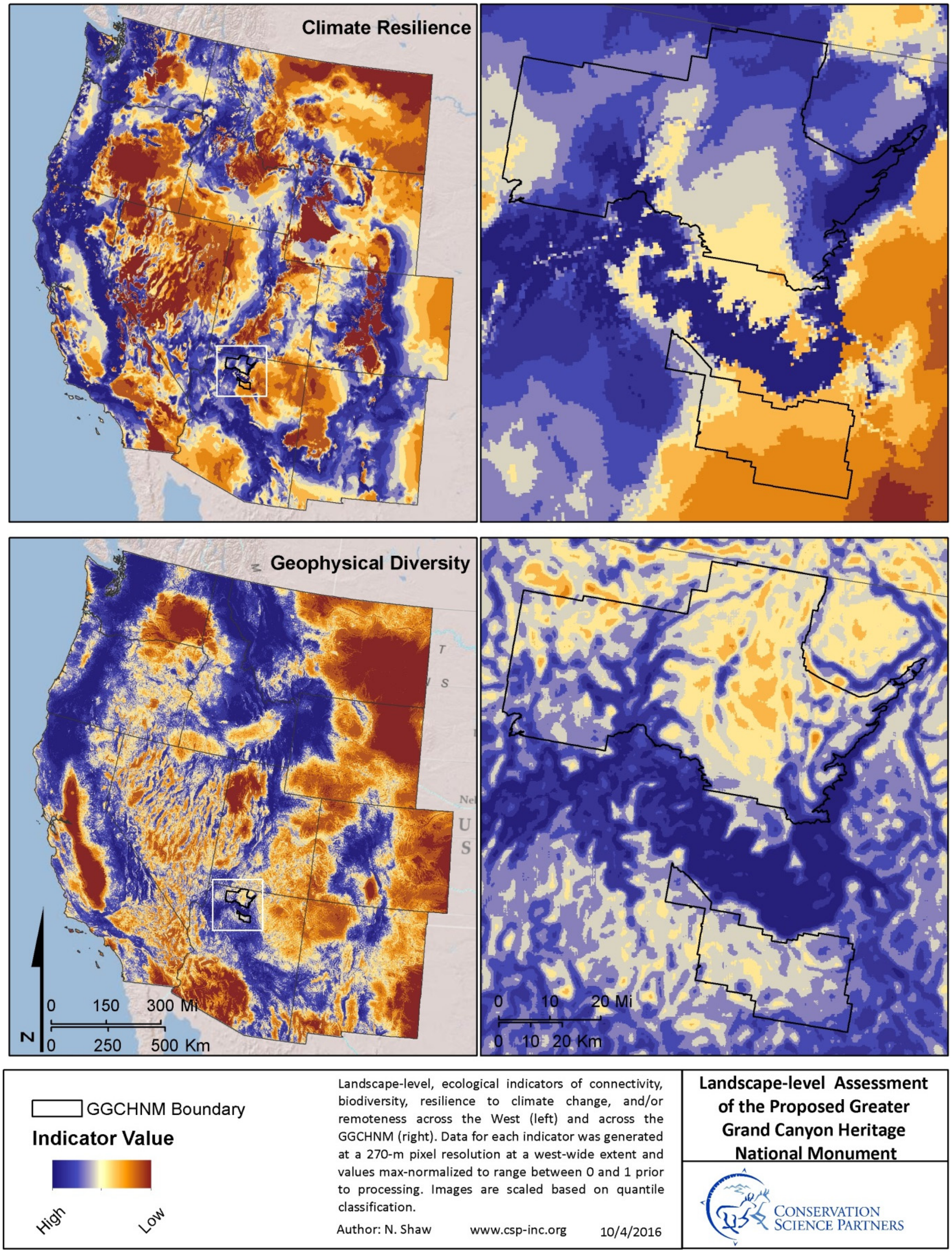


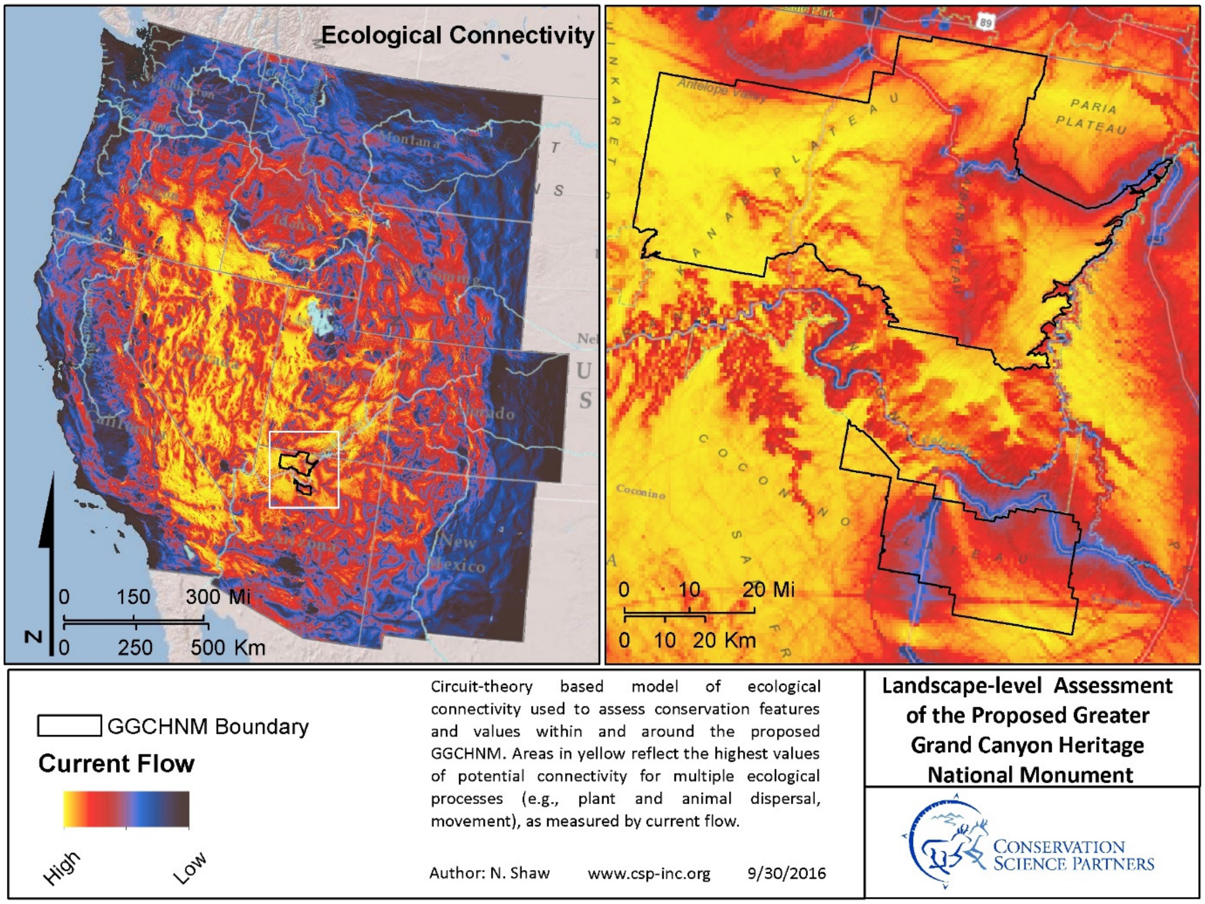
Figure 3. *Percentage of lands within different landform types in the western U.S. that have protected status (IUCN categories I-IV and NCL lands in IUCN V; upper panel) and percentage of additional lands that would be protected, with designation of the proposed 1.78-million acre Greater Grand Canyon Heritage National Monument (lower panel). The area has a disproportionately higher diversity of landform types than is found across the existing protected areas network. The area would serve to enhance and diversify the existing protected areas network by increasing the representation of most landform types, including valley bottoms and the terrain features that promote biodiversity and connectivity.*



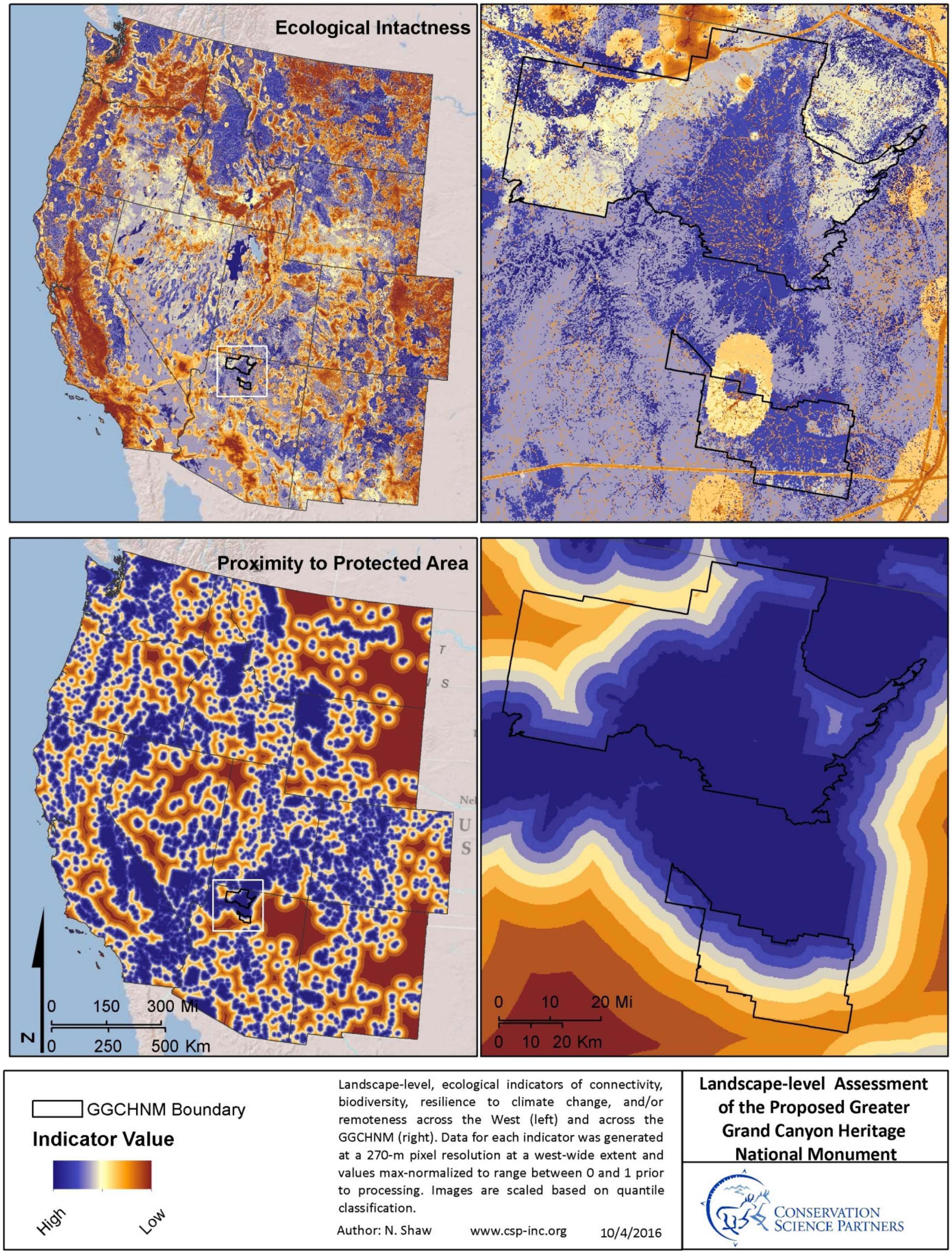
Map 1. *Proposed 1.78-million acre Greater Grand Canyon Heritage National Monument (GGCHNM). This map includes the conservation priority areas and other high conservation value areas identified on unprotected, roadless BLM lands derived by Dickson et al. (2014). Protection that includes these areas, in particular, would promote climate resilience and facilitate key ecological connections with protected areas immediately to the north and south of the GGCHNM boundary.*



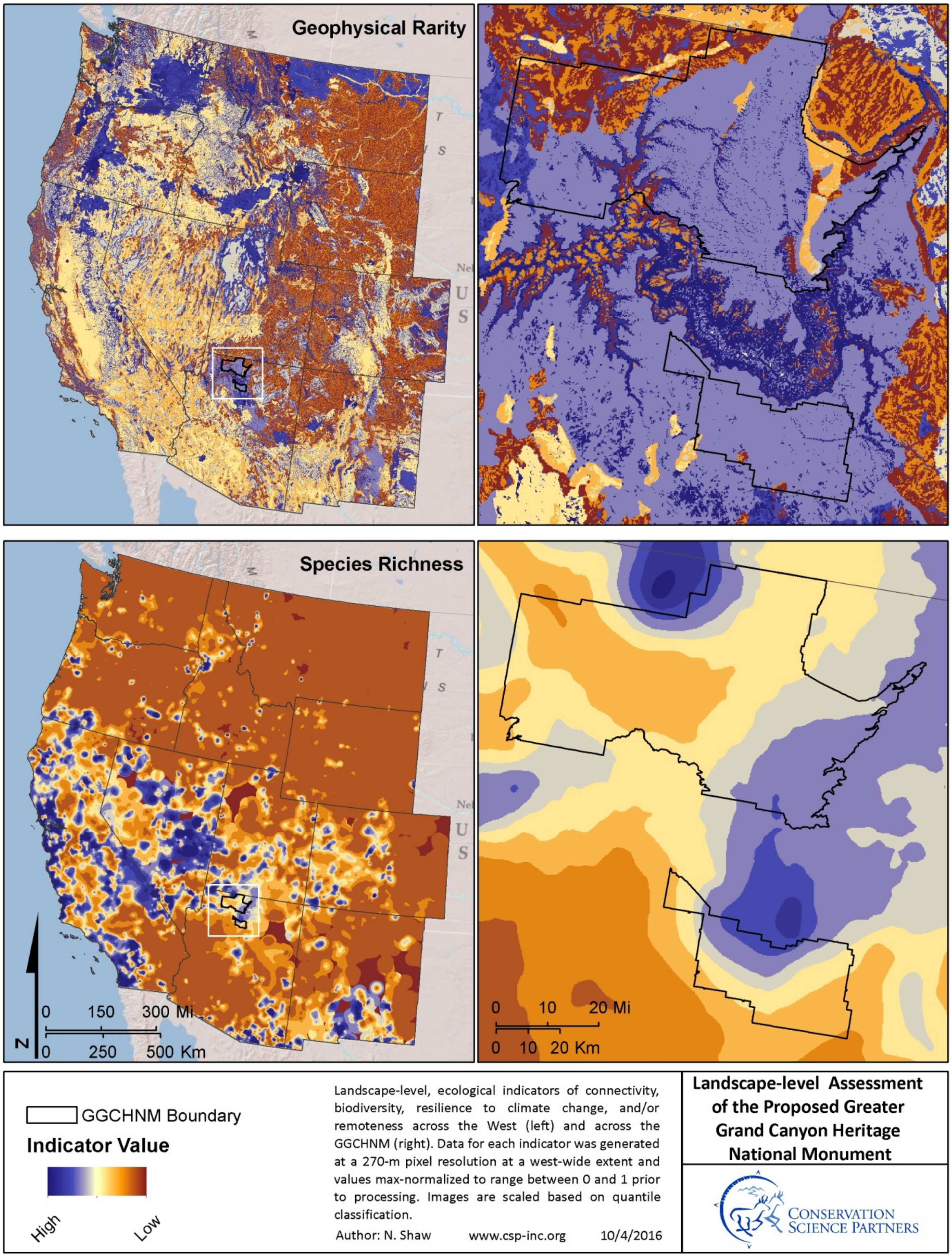
Map 2. *Landscape-level, ecological indicators of* ***climate resilience*** *(top) and* ***geophysical diversity*** *(bottom).*



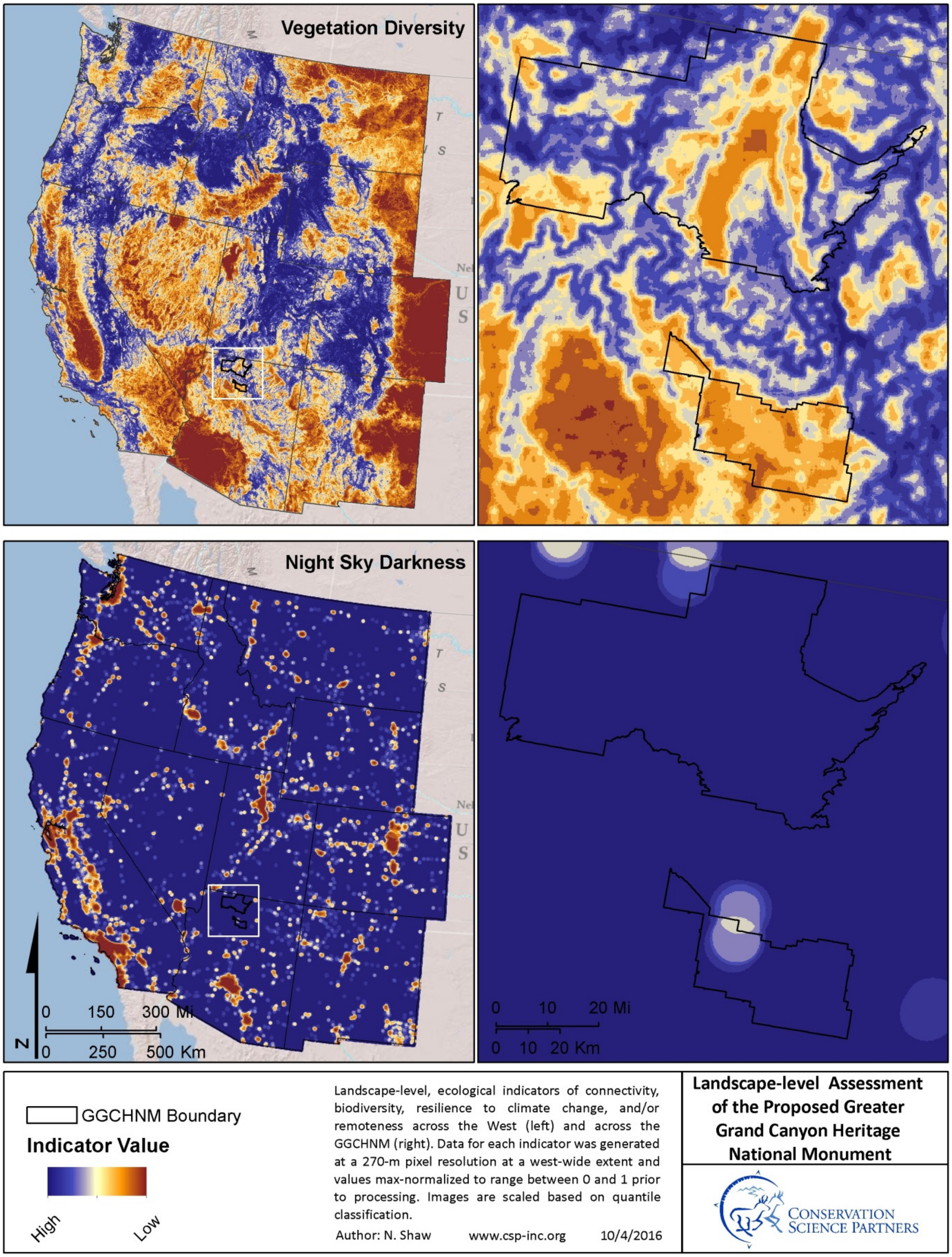
Map 3. *Circuit-theory based model of West-wide ecological connectivity used to assess conservation features and values within and around the proposed 1.78-million acre Greater Grand Canyon Heritage National Monument (GGCHNM). Model derived and described by Dickson et al. (in press).*



Map 4. *Landscape-level, ecological indicators of* ***ecological intactness*** *(top) and* ***proximity to protected area*** *(bottom).*



Map 5. *Landscape-level, ecological indicators of* ***geophysical rarity*** *(top) and* ***rarity-weighted species richness*** *(bottom).*



***Map 6.** Landscape-level, ecological indicators of **vegetation community diversity** (top) and **night sky darkness** (bottom).*