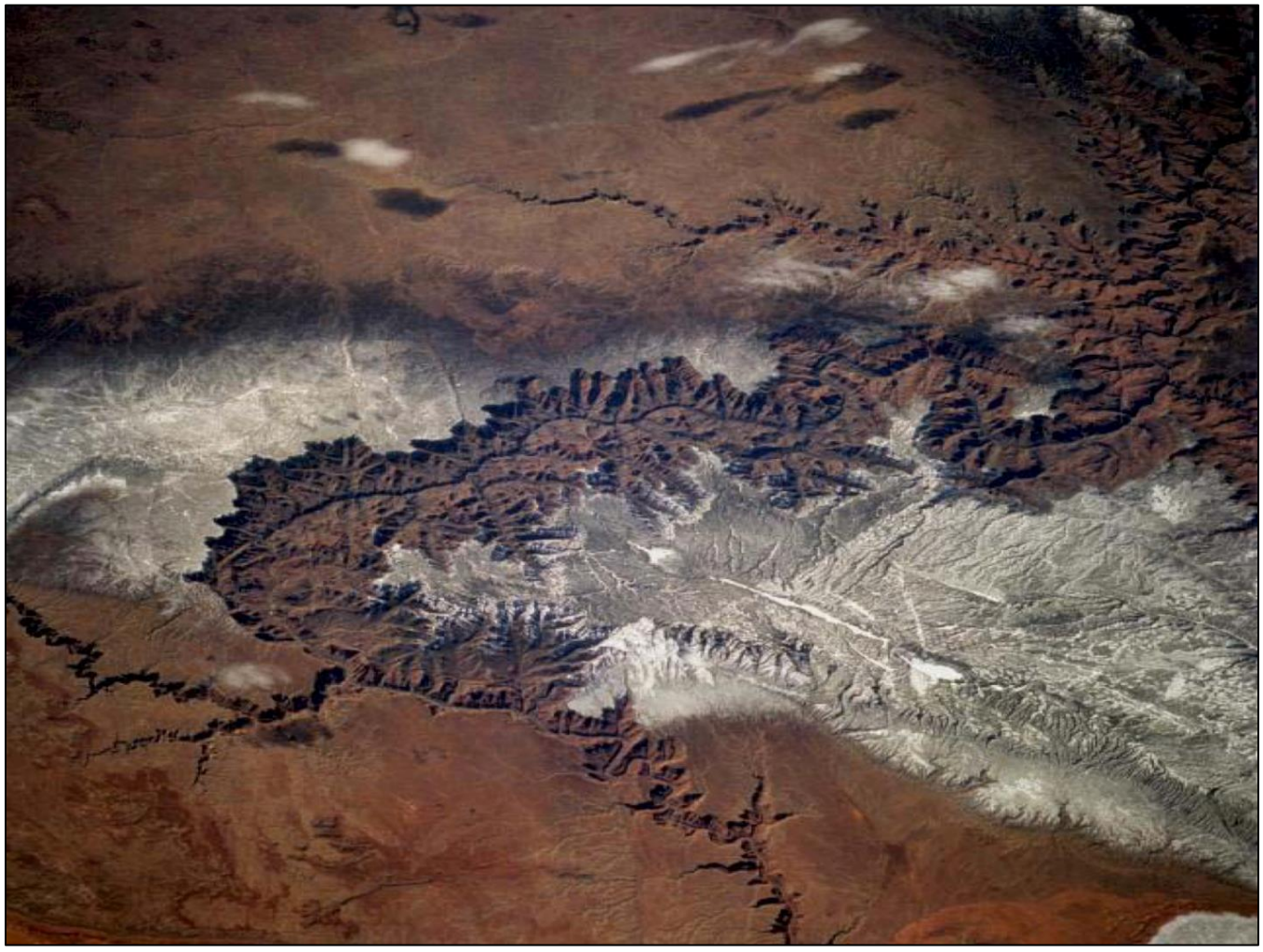
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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Greater Grand Canyon Landscape Assessment

Natural Resource Report NPS/GRCA/NRR—2018/1645





ON THIS PAGE
Grand Canyon National Park: Mather Point
Photograph by W. Tyson Joye, National Park Service

ON THE COVER
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Natural Resource Condition Assessment

Greater Grand Canyon Landscape Assessment

Natural Resource Report NPS/GRCA/NRR—2018/1645

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Executive Summary

The National Park Service (NPS) Natural Resource Condition Assessment (NRCA) program was designed to assist park managers by providing them with key information about the condition of park natural resources, the factors influencing these resources, and the areas where critical data and knowledge gaps exist. The Grand Canyon is an area of high biological diversity and astounding natural beauty, as well as a region of great cultural significance. When Grand Canyon National Park (NP) began planning for its NRCA, park management realized that expanding upon a standard NPS NRCA would be necessary to guide the management and protection of the significant resources within the park, due to the multi-jurisdictional management needs of many resources and the origination of many stressors outside the park.

This expanded Resource Condition Assessment (RCA) was christened the Greater Grand Canyon Landscape Assessment (GGCLA). The GGCLA used a trans-boundary, collaborative, and spatial approach to assess resources across an analysis area determined by watersheds rather than administrative boundaries. Given the importance of both natural and cultural resources in the region, and the common stressors they often face, the GGCLA included both in an integrated assessment, which included an extensive tribal outreach and engagement effort, and addressed the ethnographic importance of natural resources. The project emphasized the use of spatial data, conducted new analyses drawing on existing information, and produced new models and maps to address priority data needs.

Outcomes of the GGCLA included the spatial prioritization of areas in the region for management attention (Ch. 4) based on participatory analysis and stakeholder engagement, the assessment of condition and trend of twenty-five focal resources and nine stressors influencing them (Ch. 5), and recommendations for research and management moving forward (Ch. 6). The GGCLA also identifies key data gaps and needs, focusing on the increasing need for actionable, management-relevant science to meet the challenges of adapting to the ongoing effects of climate change, increasing human visitation, and competing demands for the region's limited water and other resources (Ch. 5, Appendix C).

The GGCLA encompasses a 5.2 million-acre analysis area surrounding Grand Canyon National Park, defined by the intersection of all Watershed Boundary Dataset hydrologic unit code (HUC) 10 watersheds that intersect the park boundary, in addition to HUC 10 watersheds that intersect the Grand Canyon Physiographic Rim (Billingsley and Hampton 1999, Seaber et al. 1987). This area, managed by numerous state, federal and tribal entities, as well as private landowners, was the subject of a watershed-based approach to assessing resource conditions in the region. Due to the transboundary nature of the analysis area and the significance of the canyon to so many, a collaborative process was sustained throughout the life of the project. Representatives of over 35 organizations participated in workshops, open houses, and technical work groups. Over 80 individuals contributed data, expert opinions or writing to the final report. Representatives of Grand Canyon NP, other land managers, and interested stakeholders selected resources and indicators for

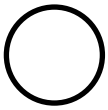
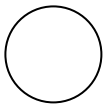
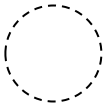
analysis, contributed data and expert knowledge to assessments, and interacted with spatial data in order to identify priority areas for future management attention.

The results of the GGCLA included a collaborative prioritization of areas according to the need for management attention for the region. Using spatial data reflecting resource values and selected stressors, a diverse group collaborated in the prioritization effort, which identified the Kaibab Plateau, South Rim, Shivwits Plateau, and the upper reaches of numerous watersheds draining into Grand Canyon as areas where focused attention from resource managers might have the greatest positive impact on future resource conditions. This prioritization, described in detail in Chapter 4, also provides managers with a tool for exploring the reasons that specific locations ranked high or low in priority, and for considering multiple resources and stressors simultaneously when planning or carrying out management activities. The prioritization, combined with the assessment of condition and trends for focal resources, will allow planners and managers in Grand Canyon NP and adjoining lands to capture efficiencies when implementing management projects, and it will help managers avoid unanticipated consequences when carrying out resource-specific management activities across the region.

The prioritization demonstrated that while many unique and high-value resources occur throughout the inner canyon, many of the perceived stressors that put them at risk are strongest above the rim. As the landscape perspective highlights the connectivity of the entire area of analysis, the upper reaches of the GGCLA watersheds, many outside the park boundary, emerge as high priorities, due to the potential for fire, water extraction, mining and development to degrade below-the-rim resources in the intricate, remote, and seemingly well protected canyons downstream. Also apparent from the GGCLA prioritization effort is the fact that particular side canyons rise in priority rank because of the co-occurrence of valued resources. While many efforts to prioritize involve drawing lines on maps and highlighting favorite places, water sources, or areas of high biodiversity, the spatial mapping and overlay process, informed by resource attributes and the stressors that put them at risk, highlights areas in need of management attention. It is a shift in understanding to recognize that the most treasured places or highest valued resources might not be the central focus of management if stressors can be better controlled or mitigated in upstream locations.

The results of the GGCLA also include an assessment of condition and trend for key resources, as determined by the assessment of multiple indicators for each focal resource (Ch. 5). Key findings for each resource category are summarized below. Most indicators were identified as currently in good condition or warranting moderate concern (Table A). The condition of several endangered species, extent of human intrusion, and extent of riparian communities warrant significant concern. Condition and trend information is displayed by indicator in Table B. A more detailed discussion of these findings can be found in Ch. 6.

Table A. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low
No Color*	Current Condition is Unknown or Indeterminate	No Arrow	Trend in Condition is Unknown or Not Applicable	–	–

* An open (uncolored) circle indicates that current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment; this condition status is typically associated with unknown trend and low confidence.

Table B. Summary of the condition and trend of indicators associated with each resource assessed in the Resource Condition Assessment; Condition status is classified as warranting significant concern (red). Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), or deteriorating (downward arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

 **Resource Condition Warrants Significant Concern**		
Trend	**Resource**	**Indicator**
 Deteriorating	Ecological Integrity	Human intrusion
	Riparian Communities	Xero-riparian extent
	River Avifauna	Southwestern willow flycatcher
	River Avifauna	Aquatic inverts-Colorado River
 Unchanging	Native Fish Species	Endangered fish
 Improving	Northern Leopard Frog	Presence

Table B (continued). Summary of the condition and trend of indicators associated with each resource assessed in the Resource Condition Assessment; Condition status is classified as warranting significant concern (red). Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), or deteriorating (downward arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

Resource Condition Warrants Significant Concern		
Trend	**Resource**	**Indicator**
Unknown	Riparian Communities	Exotic species
	Riparian Communities	Native/exotic species
	Bighorn	Survival/mortality factors
	Bighorn	Disease

Table C. Summary of the condition and trend of indicators associated with each resource assessed in the Resource Condition Assessment; Condition status is classified as warranting moderate concern (yellow). Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), or deteriorating (downward arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

Resource Condition Warrants Moderate Concern		
Trend	**Resource**	**Indicator**
⇩ Deteriorating	Biorichness	Surface water
	Biorichness	Net primary productivity
	Ecological Integrity	Residential/commercial
	Fire	Fire severity (average)
	Bighorn	Connectivity
	Mule Deer	Habitat connectivity
	Condor	Population integrity
	Northern Goshawk	Demographics
	Caves	Hydrological resources
	Seeps and Springs	Discharge
	Archaeological Resources	Site condition
	Night Skies	ALR spatial model
	Recreational Resources	Recreational facilities
	Wilderness	Acoustic environment/night skies
⇔ Unchanging	Ecological Integrity	Energy/mining
	Ecological Integrity	Transportation/services
	Rare/Endemic Plants	Special status plants
	Mountain Lion	Survival/mortality factors

Table C (continued). Summary of the condition and trend of indicators associated with each resource assessed in the Resource Condition Assessment; Condition status is classified as warranting moderate concern (yellow). Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), or deteriorating (downward arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

Resource Condition Warrants Moderate Concern		
Trend	**Resource**	**Indicator**
⇔ Unchanging (continued)	Mountain Lion	Seasonal movement
	Bighorn	Movements
	Mule Deer	Condition
	Northern Goshawk	Habitat quality
	Northern Leopard Frog	Condition
	Native Fish Species	Native/nonnative fish
	Caves	Biological resources
	Ethnographic Resources	Cultural landscapes
	Ethnographic Resources	Traditional Cultural Properties
	Wilderness Character	Degree untrammeled
⇧ Improving	Fire	Fire return interval (average)
	Night Skies	Park light inventory
Unknown	Riparian Communities	Hydro-riparian extent
	Riparian Communities	Native species
	Bighorn	Genetic structure
	Bighorn	Forage
	Invertebrate	Aquatic inverts-tributaries
	Invertebrate	Aquatic inverts-springs
	Invertebrate	Cave invertebrate richness
	Seeps and Springs	Water Quality

Table D. Summary of the condition and trend of indicators associated with each resource assessed in the Resource Condition Assessment; Condition status is classified as in good condition (green). Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), or deteriorating (downward arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

Resource Is in Good Condition		
Trend	**Resource**	**Indicator**
⇩ Deteriorating	Mule Deer	Habitat quality
	Caves	Geological resources
	Daytime Viewshed	Unimpeded viewsheds
	Acoustic Environment	Natural sound levels
	Recreational Resources	Observation points
	Wilderness	Ecological integrity
⇔ Unchanging	Biorichness	Geophysical diversity
	Biorichness	Vegetation community diversity
	Night Skies	Bortle scale
	Night Skies	ZLM
	Night Skies	SQI
	Night Skies	ALR ground-based
	Ecological Integrity	Agricultural land cover
	Mountain Lion	Habitat quality
⇔ Unchanging (cont'd)	Mountain Lion	Diet/prey base
	Mountain Lion	Body condition
	Bighorn	Habitat quality
	Mule Deer	Presence
	Mexican Spotted Owl	Presence
	River Avifauna	Avifaunal richness
	Native Fish Species	Rare/nonnative fish
	Caves	Paleontological resources
	Seeps and Springs	Presence of springs
	Recreational Resources	Trail segments
	Recreational Resources	Recreational opportunity spectrum
	Recreational Resources	Campsite density
	Wilderness Character	Biorichness potential
⇧ Improving	Native Fish species	Catch-per-unit-effort, large-bodied fishes
Unknown	Fire	Re-burns (average)
	Mountain Lion	Abundance
	Invertebrates	Terrestrial invertebrate richness

Table E. Summary of the condition and trend of indicators associated with each resource assessed in the Resource Condition Assessment; Condition status is classified as in currently unknown condition (white). Trend in condition is classified as condition improving (upward arrow), unchanging (two headed arrow), or deteriorating (downward arrow). Chapter 5 provides more details on resource condition and trend, including confidence level and reference conditions associated with each indicator.

 **Current Condition of Resource Is Unknown or Indeterminate**		
Trend	**Resource**	**Indicator**
 Deteriorating	–	–
 Unchanging	–	–
 Improving	–	–
Unknown	Bighorn	Population

Landscape

Focal resources under the Landscape category included biorichness, ecosystem integrity, and fire. For these resources, indicators relevant to water availability (e.g., net primary productivity for biorichness) suggest vigilance and protection of surface waters and restoration of seeps and springs wherever possible due to ongoing and predicted worsening of drought events associated with climate change. Sensitivity to disturbance indicators also indicate caution or significant concern due to increased human population and development in the region. For fire, departure from historic fire regime varies across the analysis area, with roughly a third of the region in poor condition, a third in fair condition, and a third in good condition.

Vegetation

Limited data on trends in plant community composition and structure preclude a comprehensive assessment of trends in vegetation resources throughout the analysis area, so the assessment effort focused on unique species and assemblages. Focal resources in the Vegetation category include rare and endemic plant species and riparian vegetation communities. For these resources, occurrence of rare and endemic plant species warrants particular caution because a variety of stressors, including groundwater withdrawal, uranium extraction, commercial and residential development, user impacts, and climate change, may impact such plants. Due to altered river flow regimes as a result of the construction and operation of Glen Canyon Dam, xero-riparian communities are in decline. Additionally, increased occurrence of exotic plant species, in riparian communities in particular, is cause for concern.

Wildlife

Focal resources in the Wildlife category included bighorn sheep, mountain lion, mule deer, northern leopard frog, California condor, eagles, Mexican spotted owl, Northern goshawk, the avifauna of the river corridor, Northern Leopard frog, and invertebrates. Condition of indicators relevant to connectivity and movement for wildlife warrant caution due to future increases in human disturbance, transportation infrastructure, and development. Condition of indicators relevant to climate change, such as future availability of water and some forage types, also warrant caution, due to the likelihood of decreased precipitation and altered temperatures in the region, affecting wildlife food, water, and habitat. Resources subject to unique stressors include California condors, whose reintroduced population is dependent on intensive active management, due to poisoning from lead and other environmental contaminants; bighorn sheep, for which disease transmitted from domestic livestock is a source of significant concern; sensitive avifauna along the Colorado River (particularly the Southwestern willow flycatcher), for which habitat has declined due to drought and loss of riparian vegetation; Northern Leopard frog; and aquatic invertebrate taxa, which experience novel competition and predation regimes as a result of dam-driven environmental changes.

Fisheries

The construction of Glen Canyon Dam resulted in the extirpation of three endangered fish species, while the remaining species have experienced considerable declines. Distribution and abundance of remaining populations of at-risk species, however, generally demonstrate stable or increasing populations at this time. Native fish populations have been sampled in most major creeks and rivers, but are little known in other parts of the analysis area. Continued monitoring of well-studied populations, and expansion of these efforts to geographically dispersed populations would enhance understanding of population trends by geography and sensitivity to regional stressors.

Physical Resources

Focal physical resources include caves and seeps and springs. For caves, hydrological and biological resources both warrant greater inventory and monitoring efforts. Climate warming is likely to reduce water resources in the future, while the possibility of increased groundwater withdrawal could impact cave hydrology. For springs, only a few individual springs have received the repeated surveys necessary in order to evaluate trends in flow and quality. Those few, however, have generally exhibited declines in flow over the past few years, and this trend is consistent with regional drought and climate change predictions.

Visitor Experience

Visitor experience resources include night skies, daytime viewsheds, recreational resources, the natural acoustic environment, and wilderness character. Current artificial light levels are low in the analysis area, and management efforts to bolster dark night skies are actively being implemented. The daytime viewshed is a crucial value for many visitors to the region. While air quality has improved or stabilized in recent years, projected future decreases in air quality due to increased development across the Southwest could impact this resource. Most recreational resources are carefully managed and maintained, although some sites and buildings face disrepair and a backlog of scheduled maintenance due to budget shortfalls. The acoustic environment is most impacted on

private and state lands, and over large areas of the park, as a result of aircraft overflights. Increasing demand for flight-seeing could increase the already significant impacts on this resource in the future. Wilderness character is currently most impacted by dispersed recreation and management activities across the region. Increased motorized use outside the park may require more management intervention, while management of ever-increasing numbers of visitors jeopardizes the visitor experience within the park.

Based on the findings of Ch. 4 and Ch. 5, several recommendations and lessons learned were identified regarding future research and management across the region. These include: focus future management where it is needed most; maintain and build partnerships; prioritize research needs and incentivize research that links science with management and informs landscape-scale management; target research and monitoring to answer specific management questions using statistically rigorous methods; address emerging landscape-scale stressors; and integrate the outcomes of the GGCLA into future planning processes. These recommendations are discussed in greater detail in Ch. 6.

It is our hope that results from the GGCLA can and will be used to guide management and research decisions across organizations, well into the future. For example, GGCLA outcomes can help direct future planning and management efforts, such as Grand Canyon NP's Resource Stewardship Strategy. The data needs identified by managers can be used to direct and incentivize future research efforts throughout the analysis area, better linking science with management. Maps of priority areas can be used as decision tools for targeting scarce resources on the places and challenges where management is most needed. Beyond the specific scientific and management outcomes, however, the partnership and inclusivity that grounded this effort can provide a foundation for future conversations, analyses and planning efforts. GGCLA offers a rich and transparent forum for stimulating and sustaining the critical collaborative relationships that will be necessary to safeguard the Grand Canyon region for future generations, as environmental change generates complex management challenges in the coming century.

Contributors

The Greater Grand Canyon Landscape Assessment was grounded in collaboration, and the report benefited from a large group of contributors whose technical expertise, subject matter knowledge, generosity with data, and willingness to write made this project possible. The GGCLA was coordinated through a core team, including Tom Sisk, Sasha Stortz, Clare Aslan, and Jill Rundall of the Landscape Conservation Initiative at Northern Arizona University, and Todd Chaudhry, Ronda Newton, Santiago Garcia, Mark Nebel and Jean Palumbo of the National Park Service. These individuals authored large portions of the report, managed and developed spatial data, or coordinated the development of data and report sections provided by other contributors. Conservation Science Partners, particularly Brett Dickson and Luke Zachmann, was an essential partner on the project, contributing new spatial analyses for resource condition assessments and spatial prioritization. Science and Resource Management staff in the Grand Canyon National Park Division of Resource Management provided their expertise as section authors, supporting contributors, or reviewers. Jean Palumbo and Louella Holter edited and formatted the document. The draft document was sent for review to stakeholder participants and report contributors, many of whom responded with important revisions and comments. Sallie Hejl, Desert Southwest Cooperative Ecosystems Studies Unit Research Coordinator also provided NPS peer review.

The individuals listed below contributed directly to the GGCLA report by providing spatial data or other existing analyses, developing maps or models, sharing their subject matter knowledge, and writing report sections. Many more people provided their input and perspectives through GGCLA collaborative meetings, technical work groups, and open houses (accessible via Appendix A). We are grateful to all of you.

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Chapter 1. Background on the Greater Grand Canyon Landscape Assessment and the National Park Service Natural Resource Assessment Process

1.1 Development of the Greater Grand Canyon Landscape Assessment Concept

The National Park Service (NPS), steward of many of our nation's most important natural, physical, and cultural resources, is charged with protecting and preserving its resources so that they are unimpaired for current and future generations. To do this, national parks must manage their resources within the broader ecosystem context. The NPS Natural Resource Condition Assessment (NRCA) was designed to assist park managers with this task by providing them with key information about the condition of park natural resources, the factors influencing these resources, and the areas where critical data and knowledge gaps exist. NRCAs are in progress or have been completed for more than 160 national parks with significant natural resources, and NRCAs for 110 additional parks are planned in the next few years.

The Grand Canyon is an area of high biological diversity and astounding natural beauty, as well as a region of great cultural significance. When Grand Canyon NP began planning for its NRCA, park management realized that the standard NPS NRCA would not be sufficient to guide them in the management and protection of all the significant resources within the park. The scope of the project was eventually expanded in several ways to accommodate the unique resources within and around the park. This expanded NRCA was christened the Greater Grand Canyon Landscape Assessment (GGCLA).

First, the standard NPS NRCA addresses natural, but not cultural resources. In a region that has experienced human habitation since the end of the Pleistocene Era, more than 10,000 years ago, and where archeologists have found evidence of prehistoric human use in more than 4,300 places, cultural resources are critically important. They document the history and represent the culture of many of the 11 traditionally associated tribes of Grand Canyon. For this reason, the management of Grand Canyon NP decided to expand the NRCA to include cultural resources.

In addition to the traditionally associated tribes, a great number of other people also highly value the Grand Canyon region. Future planning for the park would greatly benefit from the support of these stakeholders and their knowledge of the area. Park management thus adopted a collaborative approach that included stakeholders in the resource assessment process. They also conducted additional outreach to the traditionally associated tribes.

Grand Canyon NP is not an island. Processes and activities that occur inside the park affect the surrounding areas, and processes and activities that occur outside of the park affect conditions within

the park. Therefore, park management incorporated the surrounding areas into the assessment area, and considered stakeholder input when determining the extent of the analysis area.

Finally, the NRCA process mandates that existing data about parks be used to inform resource condition assessments. However, to prioritize areas in need of management attention, it was necessary to weigh all of the often competing priorities, such as resource value or level of stress faced by a resource, and then represent these data spatially, rating them in terms of relative importance. This spatial representation of resources, as a fourth refinement of the NRCA process, is discussed further in Chapter 4. Stakeholder engagement is discussed in Chapter 3, and focal resource condition assessments are presented in Chapter 5.

1.2 The Natural Resource Condition Assessment

Natural Resource Condition Assessments (NRCAs), which is the backbone of the GGCLA, evaluates current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue-and threat-based resource assessments. All NRCAs have the following distinguishing characteristics:

- They are multi-disciplinary in scope.[1]
- They employ hierarchical indicator frameworks.[2]
- They identify or develop reference conditions/values for comparison against current conditions.[3]
- They emphasize spatial evaluation of conditions and Geographic Information System (GIS) products.[4]

[1] The breadth of natural resources and number/type of indicators evaluated will vary by park

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

- They summarize key findings by park areas.[5]
- They follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for understanding current conditions, and/or present-day stressors that are best interpreted at park, watershed, or landscape scales (although NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used, which are designed to be appropriate for the stated purpose of the project, as well as adequate documentation. For each study indicator for which current condition or trend is reported, we identified critical data gaps and described the level of confidence in at least qualitative terms. Involvement of park staff and NPS subject matter experts at critical points during the project timeline was also important. These consultants assisted with the selection of study indicators; they recommended data sets, methods, and reference conditions and values; and they helped to ensure a multi-disciplinary review of study findings and products.

NRCAs can yield new insights into current park resource conditions but in many cases their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers credible science-based information that has practical uses for a variety of park decision-making, planning, and partnership activities.

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

targets. In the near term, NRCA findings will assist strategic park resource planning and help parks to report on government accountability measures. In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program. For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital sign monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

Chapter 2. Resource Setting, Stewardship, and the Greater Grand Canyon Landscape Assessment Approach

2.1. Introduction

One of the unique features of the Greater Grand Canyon Landscape Assessment (GGCLA) is that, in contrast to other NPS Natural Resource Condition Assessments, it encompasses and considers an area far larger (5.2 million acres) than Grand Canyon NP (1.2 million acres). Lands in the analysis area are under the jurisdiction of numerous entities, including the National Park Service (NPS), Bureau of Land Management (BLM), U.S. Forest Service (USFS), State of Arizona, and Hualapai, Havasupai, Kaibab Paiute, and Navajo Indian reservations. Some private lands are also included in the project areas. Obtaining specific information about resources outside of Grand Canyon NP from land owners and managers has proven to be challenging, and much of that information is not readily available. This chapter provides information about the resource setting (Figure 1) and the stewardship of resources principally for Grand Canyon NP, for which this information was more readily available.

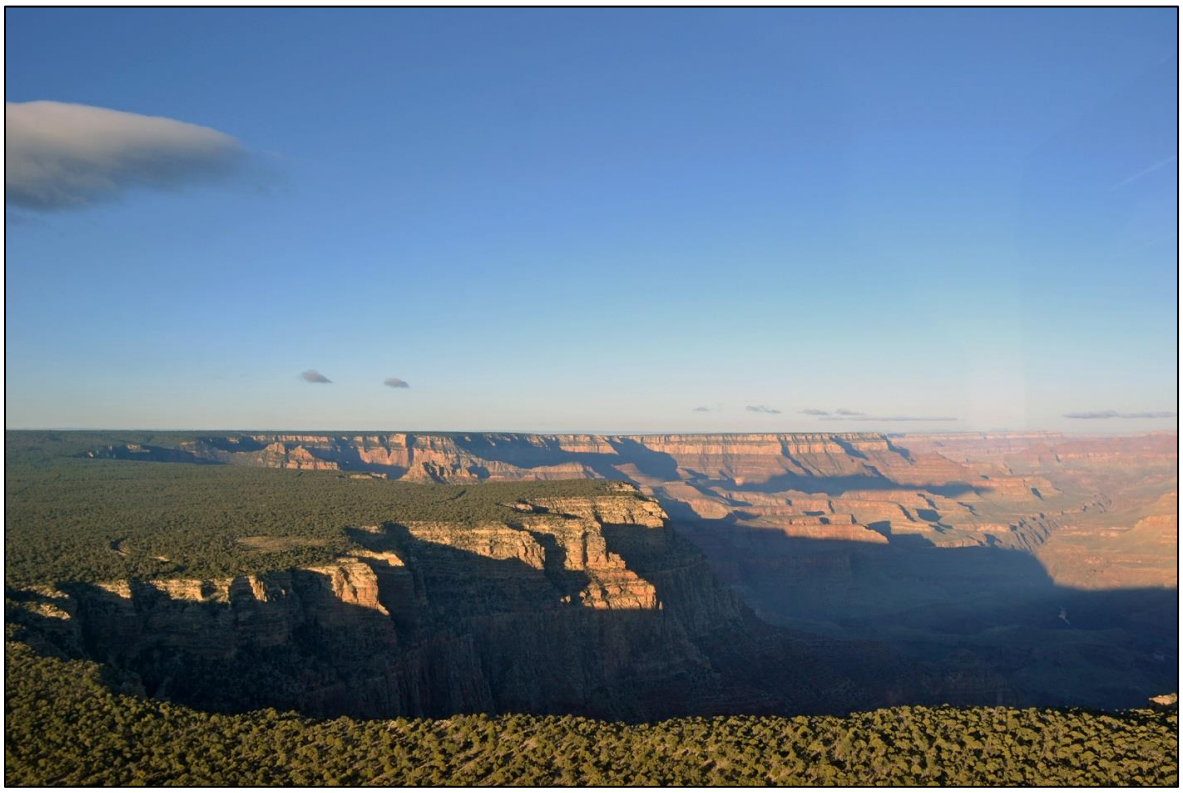


Figure 1. Aerial view of the South Rim of Grand Canyon National Park (NPS photo).

2.1.1. Enabling Legislation

Grand Canyon NP was first set aside as a park "for the benefit and enjoyment of the people" on February 26, 1919 (40 Stat 1175, Grand Canyon National Park Establishment Act). Major changes were made in the park boundary in 1975 by Public Law 93-620, the Grand Canyon Enlargement Act, which states that Grand Canyon NP is a "natural feature of national and international significance." It established Grand Canyon NP from a mixture of state and federal lands, which included the former national park, Grand Canyon and Marble Canyon National Monuments, portions of Lake Mead National Recreation Area, and USFS, BLM, and tribal lands.

2.1.2. Geographic Setting

The GGCLA area encompasses the park and the surrounding watersheds, including the lower sections of the Little Colorado River, Havasu Creek, Kanab Creek, and the Paria River watersheds. Grand Canyon NP is situated in one of the largest undeveloped areas in the United States. To the south of the park entrance is the town of Tusayan, with a land area of 144 acres. Tusayan was incorporated in 2010 but was a census designate population of 558 at the time of the 2010 census (U.S. Census Bureau 2010).

Size

Grand Canyon NP comprises 1,217,403 acres; or 487,350 hectares; or 1,904 square miles. The GGCLA analysis area comprises 5 million acres; or 2,023,428 hectares; or 7,812 square miles.

Location

Grand Canyon NP is situated within the Greater GGCLA area, which is located in northwestern Arizona.

Physiographic setting

The GGCLA area is located in the Colorado Plateau Physiographic Province. The park encompasses the canyon and portions of the plateaus to the north and south along 277 miles of the Colorado River, starting at the confluence of the Colorado and Paria Rivers near Lees Ferry in northern Arizona and ending at the boundary with Lake Mead National Recreation Area.

2.1.3. Visitation Statistics

Grand Canyon NP, which is the number-one tourist attraction in Arizona, generates significant economic activity for the region. Visitors to the park (Table 1, Figure 2) are estimated to bring in more than $420 million to local economies, supporting at least 10,000 jobs (National Park Service 2010).

Table 1. Grand Canyon National Park visitation statistics for 2015; total visitation was 5,520,736 in 2015 (NPS 2014).

Category	Subcategory	Number
Backcountry user nights	Corridor	55,302
	Other backcountry trails	39,703
Colorado River user days (Lees Ferry to Diamond Creek)	Commercial	112,973
	Noncommercial	102,912
Mule trip riders – Xanterra, South Rim	Phantom Ranch (1 night)	2,436
	1-hour rim ride	305
	Canyon Vistas	10,223
Mule trip trail rides- North Rim	1-hour rim ride	3,415
	Half day inner canyon ride	4,810
	Half day rim ride	1,024
Train passengers[A]	–	153,613
Commercial air tour flights[B]	–	55,215

[A] North-bound boardings

[B] 2012 numbers by FAA



Figure 2. Visitors enjoying sunset at Yavapai Point. In 2013, 4,564,840 people visited Grand Canyon National Park (NPS photo).

2.2. GGCLA Approach

The purpose of a Natural Resource Condition Assessment is to assess the condition and trends of key natural resources in national parks through a synthesis of the existing data. The GGCLA effort follows this approach, while expanding the scope in several ways. These include: 1) grounding the assessment in a multi-stakeholder collaborative process, 2) integrating natural and cultural resources, 3) leveraging spatially explicit analyses, and 4) covering an expanded analysis area that encompasses important watershed areas beyond park boundaries. The GGCLA project was managed and implemented through a core team of Grand Canyon NP staff and Northern Arizona University (NAU) employees, and was funded by Grand Canyon NP and the National Park Service Natural Resource Condition Assessment program, with additional support from NAU's Landscape Conservation Initiative.

To meet the standardized requirements of the NRCA, and to address the complexities of the additional components, the GGCLA project included two interconnected analytical efforts. One, the resource condition assessment (RCA), focused on assessing conditions of individual focal resources through an analysis of status and trends based on indicators and stressors. The second, a collaborative group process, focused on the development of spatial data layers directed by stakeholder interests for use in a participatory spatial prioritization process. Both efforts are served by stakeholder engagement, as described in Chapter 3. Stakeholder input was solicited to identify valued landscape attributes and associated stressors to the landscape. This analysis was used to select areas of high value, high vulnerability, and high interest to stakeholders as future targets for management and conservation priority, and it also offered a forum to discuss resource issues in the GGCLA area across jurisdictional boundaries and outside regulatory processes such as NEPA (Chapter 4).

Stakeholder feedback was instrumental in identifying the expanded analysis area for the assessment. Stakeholders felt that a larger study area, encompassing the full extent of the Grand Canyon and its associated ecosystems, was necessary for a landscape approach. In response to this feedback, park staff developed a primary analysis area for the GGCLA that extended beyond park boundaries to encompass regions of neighboring land ownership, focusing on a 5-million-acre area of interest. The analysis area included all Watershed Boundary Dataset hydrologic unit code (HUC) 10 watersheds that intersect the park boundary, in addition to HUC 10 watersheds that intersect the Grand Canyon Physiographic Rim (Billingsley and Hampton 1999, Seaber et al. 1987). It also included the Little Colorado River, Havasu Creek, Kanab Creek, and the Lower Paria River HUC 10 Watersheds.

The analysis area encompassed lands managed by numerous jurisdictions, including lands of American Indian tribes, the USFS and the BLM, and private and state land (Figure 3). The park and the stakeholders acknowledged that although this was the primary analysis area, the scale of analysis would vary for different resources depending on several factors. For example, availability of data might reduce the area analyzed. Conversely, when considering a resource such as groundwater, the scale might be much larger than the analysis area in order to address the entire area of an aquifer.

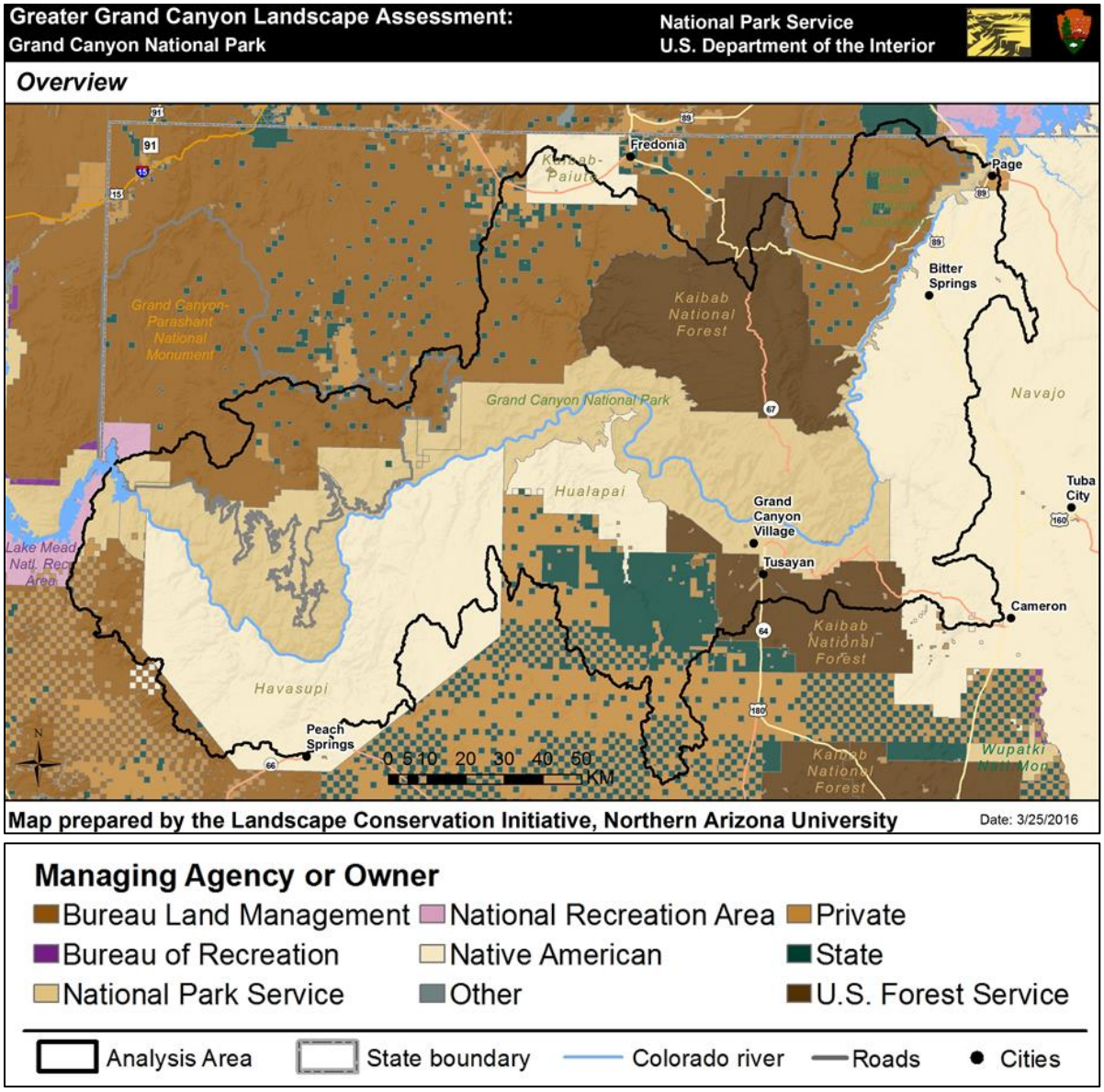


Figure 3. The GGCLA project area encompasses 5.2 million acres in Grand Canyon NP and surrounding watersheds, including the lower sections of the Little Colorado River, Havasu Creek, Kanab Creek, and the Paria River watershed. The analysis area includes tribal, federal, state, local, and private lands (Landscape Conservation Initiative).

2.3. Natural and Cultural Resources and Descriptions

Extensive descriptions of natural and cultural resources in Grand Canyon NP are provided in the latest Backcountry Management Plan Draft Environmental Impact Statement, which served as the source of information for this section (Grand Canyon National Park 2014).

2.3.1. Ecological Units

Grand Canyon NP encompasses more than 1.2 million acres along 277 miles (446 kilometers) of the Colorado River. Designated park lands include the canyon itself, which ranges in a straight-line rim-to-rim distance from 590 feet (180 meters) to nearly 18 miles (29 kilometers), as well as portions of the plateaus beyond each rim.

Geographically, the park can be divided into eight soil-based land resource units (Figure 4), defined by combined soil, elevation, temperature, and precipitation characteristics. These characteristics, in turn, influence the vegetation types in the analysis area. Major vegetation types in Grand Canyon NP and surrounding landscapes range from hot, low-elevation desert to cool, high-elevation spruce-fir forest (Figure 5). These vegetation types include nearly all the North American life zones, due in large part to the dramatic topographic zonation of the canyon itself, which spans an average of 5249 vertical feet (1600 meters) from the Colorado River to the rims. The topographic diversity creates high habitat and species diversity, making the GGCLA a microcosm of North American biorichness; indeed, comparable diversity is encountered across the Grand Canyon altitudinal gradient as exists along the latitudinal gradient from Mexico to Canada.

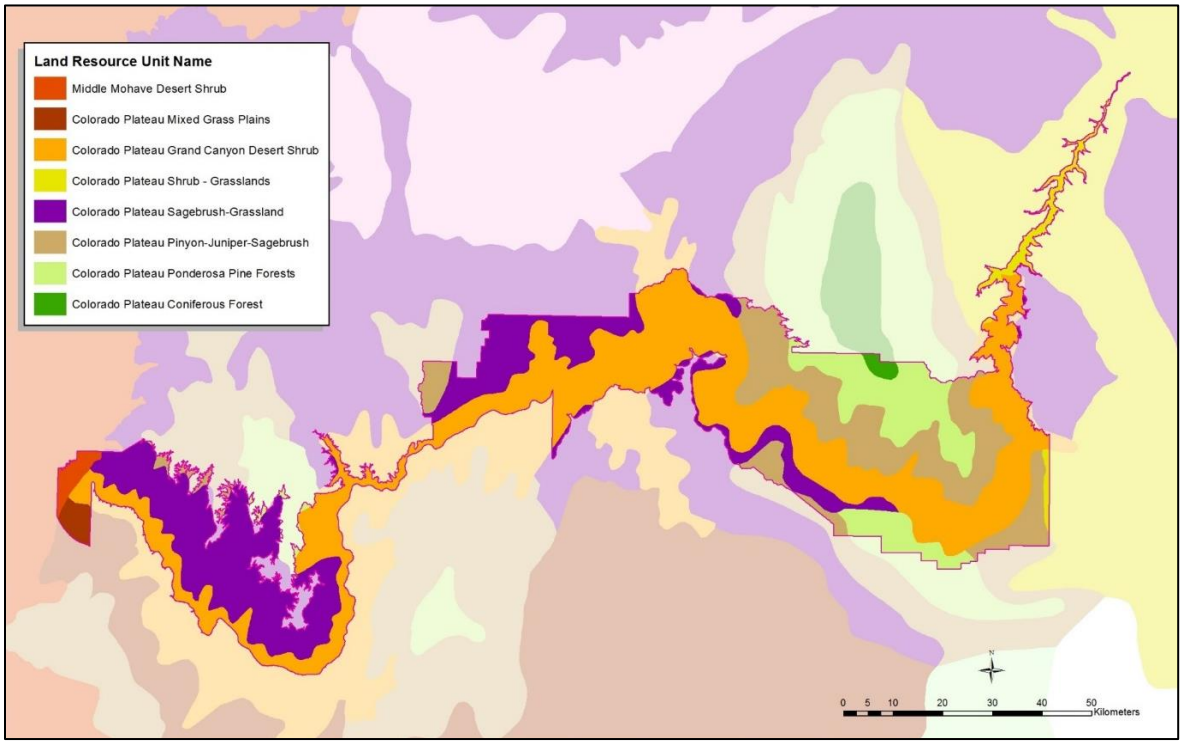


Figure 4. Land resource units for Grand Canyon National Park are defined by combined soil, elevation, temperature, and precipitation characteristics.

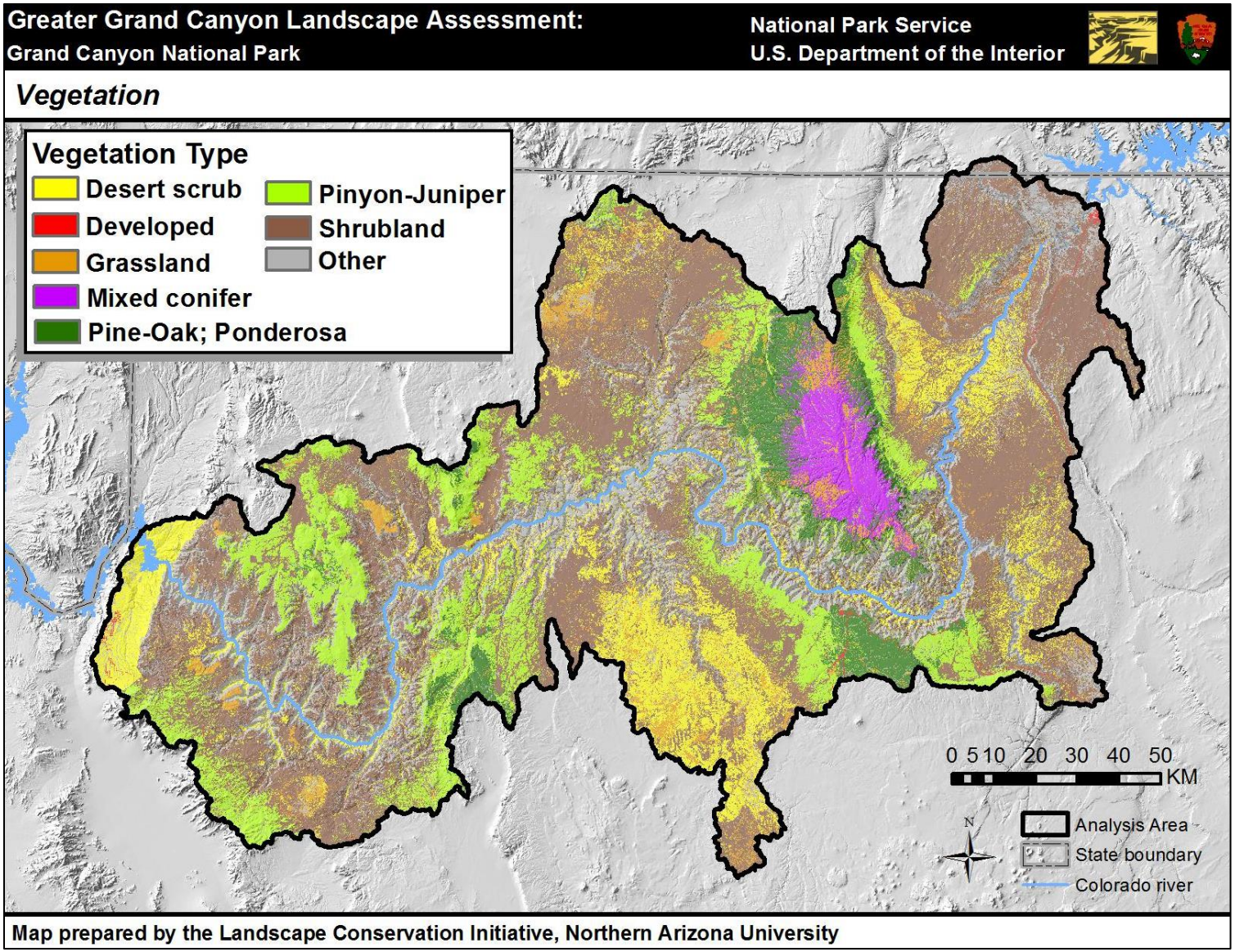


Figure 5. Major vegetation types in the Greater Grand Canyon Landscape area (NPS).

With this elevational diversity comes extensive climatic diversity. Temperatures at the canyon bottom can range from highs above 90 ºF in summer to lows in the 30s in winter. At the North Rim, which is 300 meters higher in elevation than the South Rim, temperatures can range from highs in the 70s in summer to sub-zero lows in winter. The North Rim's spruce-fir boreal forests receive on average 2.1 inches of precipitation per month, whereas an average of only 0.71 inches per month reaches the inner canyon. The region is generally arid, with most moisture arriving in the form of dramatic summer thunderstorms and winter snowfall. Variability is therefore high across both season and location, leading to notably diverse microclimates and subhabitats.

The land resource units provide an indication of geologic diversity at a rough scale. Along the canyon's mile-high walls the Colorado River has exposed a cross-section of the earth's crust that represents about 2 billion years of geologic history (Figure 6; NPS 2015). More than 40 exposed layers have been identified. Immediately above the Colorado River are Precambrian rocks, and directly above these sit Cambrian Tapeats Sandstone, Bright Angel Shale, and Muav Limestone. The wide and striking Redwall Limestone and Supai Group form sharp bands near the summits of many of the canyon's formations. More recent sandstone and limestone layers form the upper reaches of the canyon walls to meet the North and South Rims.

Major vegetation types of the Grand Canyon region, along with their dominant species and life zone characteristics, are described as follows.

Spruce-fir Forest

The spruce-fir boreal forest, dominated by Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), and blue spruce (*Picea pungens*), occurs above about 8,200 feet in elevation and covers a little more than 1% of Grand Canyon NP. This habitat type is cool and moist, with dense tree cover, high plant diversity, and infrequent fires. Grazing and exotic plants are both rare in the spruce-fir forest due to high amounts of shade. No endemic plant species are known to occur in the spruce-fir forest within Grand Canyon NP. Rare wildlife found in this vegetation zone includes the tiger salamander (*Ambystoma tigrinum*) and little brown bat (*Myotis lucifugus*).

Mixed Conifer Forest

Mixed conifer forest (Figure 7), which occurs between 7,200 and 8,500 feet in elevation, is dominated by Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and ponderosa pine (*Pinus ponderosa*). This forest type covers about 3% of the park. These forests are characterized by a mixed-severity fire regime, with normal fire return intervals of 10–20 years. High moisture availability and warm daytime temperatures create high productivity and high tree density in this forest type. Grazing and exotic species are rare in this habitat. Representative wildlife in the mixed conifer forest comprises generalist and widespread species, including birds such as the hermit thrush (*Catharus guttatus*), Clark's nutcracker (*Nucifraga columbiana*), and Stellar's jay (*Cyanocitta stelleri*), and mammals such as the porcupine (*Erethizon dorsatum*), long-tailed vole (*Microtus longicaudus*), and mule deer (*Odocoileus hemionus*). There are no known endemic plant species in the mixed conifer forest of the park.

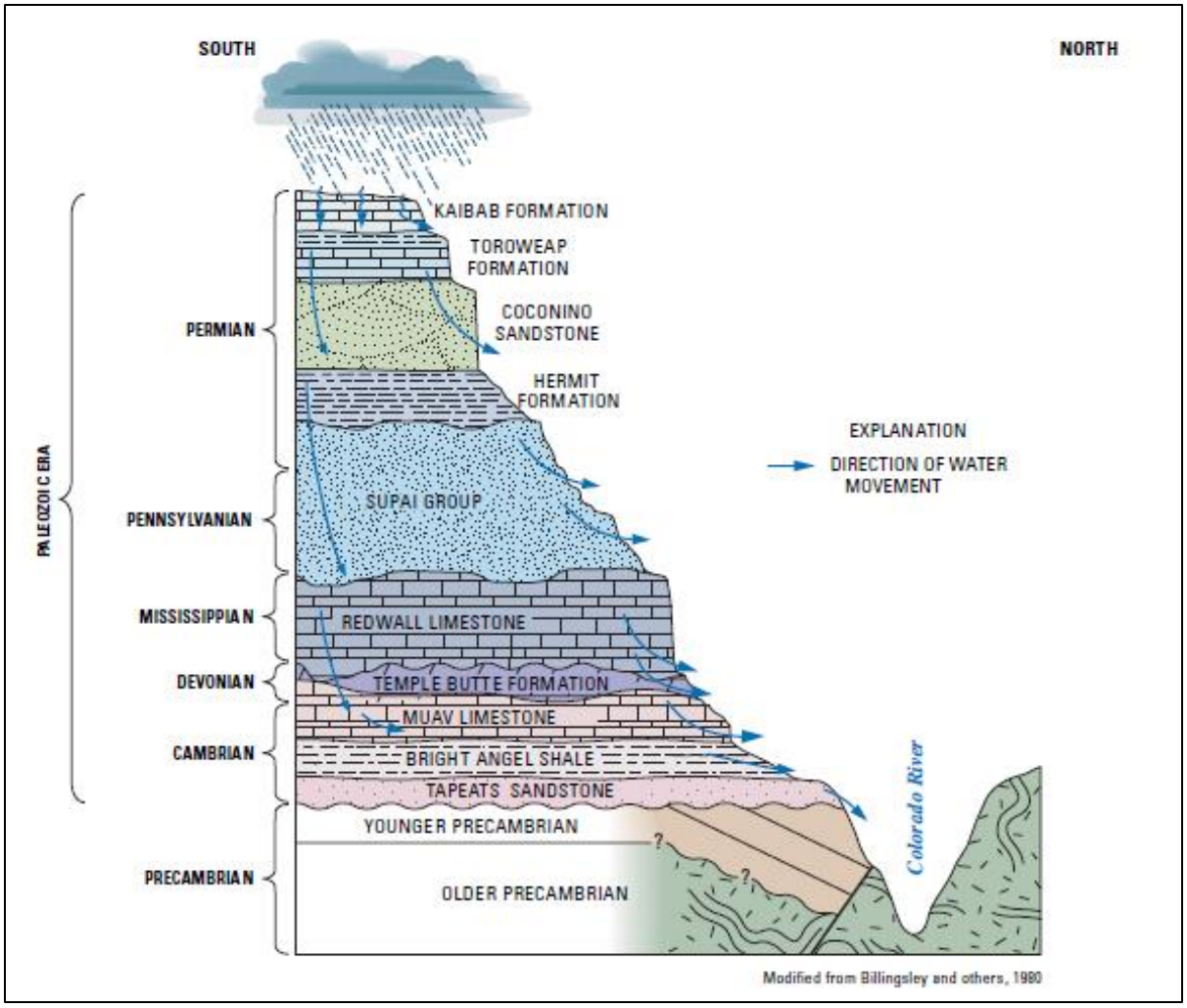


Figure 6. Stratigraphic section depicting water flow through the geologic strata of the Grand Canyon's South Rim (modified from Billingsley et al. 1980).

Montane-subalpine Grassland

Montane-subalpine grasslands, or meadows, are small areas dominated by herbaceous plants, forbs, and grasses, covering about 3,000–5,000 acres on the North Rim. Cool temperatures and high soil moisture exclude woody species from meadows, which are critical habitat for some species. Species richness is moderate, with exotics representing less than 10% of species. This vegetation type is rare in the southwestern United States, and in the GGCLA it has recently suffered from increasingly intense bison grazing. No endemic plant species are known to occur in the park's montane-subalpine grassland. Representative wildlife in the zone include habitat-generalist birds such as the broad-tailed hummingbird (*Selasphorus platycerus*), brown creeper (*Certhia americana*), and evening grosbeak (*Coccothraustes vespertinus*).



Figure 7. Mixed conifer forest in Grand Canyon National Park (NPS photo).

Ponderosa Pine Forest

Ponderosa pine forest comprises woodlands, forests, and savannahs, encompassing about 5% of Grand Canyon NP (Figure 8) and occupying elevations between 6,500 and 7,500 feet. The understory is characterized by shrubs, white fir, and Douglas fir. Low-severity fires are common and exotic species are rare. In contrast to much of the Southwest's ponderosa pine forest, neither logging nor fire suppression were major historical factors in Grand Canyon ponderosa pine forests, so vegetation composition patterns today are largely the result of site-specific fire history. The Grand Canyon goldenbush (*Ericameria arizonica*) is endemic to the park's ponderosa pine forest. A diversity of wildlife, including widespread birds, mammals, and reptiles, inhabits this forest type. A few examples of representative species are the mountain chickadee (*Parus gambeli*), northern flicker (*Colaptes auratus*), Western bluebird (*Sialia mexicana*), Abert squirrel (*Sciurus aberti*), coyote (*Canis latrans*), elk (*Cervus canadensis*), Great Basin gopher snake (*Pituophis melanoleucus*), and mountain short-horned lizard (*Phrynosoma douglassi*).



Figure 8. Ponderosa pine forest in Grand Canyon National Park (NPS photo).

Pinyon-juniper Woodland

About a quarter of the park falls within the pinyon-juniper life zone (Figure 9), including both woodlands and savannahs below about 6,560 feet in elevation. This vegetation type is dominated by single-needle pinyon (*Pinus monophylla*) and two-needle pinyon (*Pinus edulis*) as well as juniper (*Juniperus* spp.). Pinyon-juniper woodlands are characterized by multi-aged stands that vary widely in stem density, forming a mosaic influenced by drought, insects, and disease. Fire are infrequent in this vegetation type. Special status plants in the pinyon-juniper zone include the Grand Canyon goldenbush and straightbranched catchfly (*Silene rectiramea*). In addition, the sentry milk-vetch (*Astragalus cremnophylax* var. *cremnophylax*) is a federally listed endangered species. The diversity of common vertebrates in this life zone includes the common raven (*Corvus corax*), pinyon jay (*Gymnorhynus cyanocephalus*), Say's phoebe (*Sayornis saya*), desert cottontail (S*ylvilagus audubonii*), gray fox (*Urocyon cinereoargenteus*), plateau lizard (*Sceloporus undulatus*), and Sonoran gopher snake (*Pituophis melanoleucus*).



Figure 9. Pinyon-juniper woodland, South Rim, Grand Canyon National Park (NPS photo).

Shrub-steppe

The shrub-steppe community, covering less than 5% of the park just above the rims, is dominated by big sagebrush (*Artemisia tridentata*) and Bigelow sagebrush (*Artemisia bigelovii*). Soil depth, temperature, and occasional fires dictate relative species occurrence within this community. The endemic Grand Canyon goldenbush is the only special status plant occurring in the shrub-steppe zone. Representative vertebrates include many wide-ranging, habitat-generalist species, similar to those found in the pinyon-juniper and montane shrublands.

Montane Shrubland and Interior Chaparral

Montane shrubland and interior chaparral is one of the primary vegetation types in the Grand Canyon, occupying nearly 25% of the park's area. Dominant plants include scrub oak (*Quercus turbinella*) and manzanita (*Arctostaphylos pungens*) in the warmer chaparral regions and Gambel oak (*Quercus gambelii*), three-leaf sumac (*Rhus trilobata*), snowberry (*Symphoricarpos oreophilus*), and mountain mahogany (*Cercocarpus ledifolius*) in the cooler montane shrubland. Fires are infrequent but key to regeneration and plant cover patterns. This habitat zone contains known populations of both the endemic Grand Canyon goldenbush and the Roaring Springs prickle poppy (*Argemone arizonica*). In addition to many of the same vertebrates found in the pinyon-juniper, this zone also includes lower-elevation species such as the mourning dove (*Zenaida macroura*), plain titmouse (*Parus inornatus*), desert cottontail (*Sylvilagus audubonii*), desert woodrat (*Neotoma lepida*), white-tailed antelope squirrel (*Ammospermophi leucurus*), Great Basin gopher snake (*Pituophis melanoleucus*), and desert striped whipsnake (*Masticophis faeniatus*).

Desert Scrub

Desert scrub vegetation (Figure 10), occurring throughout a wide band between 1,200 and 6,000 feet in elevation, is the most widespread community in the Grand Canyon, occupying more than 500,000 acres. Plants derive from all four major North American deserts: the Mojave, Sonoran, Chihuahuan, and cold Great Basin. A principal characteristic of desert scrub is the presence of young, undeveloped soils in dry environments. Dominant plants in warmer zones include creosote (*Larrea tridentata*), bursage (*Ambrosia dumosa*), honey mesquite (*Prosopis glandulosa*), cholla (*Cylindropuntia* spp.), and ocotillo (*Fouqueria spendens*). In the cooler desert scrub, blackbrush (*Coleogyne ramosissima*), shadscale (*Atriplex* spp.), and Mormon tea (*Ephedra* spp.) dominate. Endemic plants of the desert scrub include the Roaring Springs prickle poppy, McDougall's yellowtops (*Flaveria macdougallii*), and Mentzelia to-be-named (*Mentzelia canyonensis*). Common vertebrates include many of those found in the montane shrublands and interior chaparral.



Figure 10. Desert scrub in House Rock Valley (Landscape Conservation Initiative photo).

Desert Grasslands

Desert grasslands, which are not common in Grand Canyon NP, result from disturbance to desert shrublands. They can occur on flats or gentle slopes at 3,500–5,500 feet in elevation. These habitats contain both warm and cool desert species. No endemic plants are known from the desert grasslands. Vertebrates ranging into this zone are common and widespread species known from other habitats, including many warm, lower-elevation species.

Riparian Habitats

Although they occupy only 1.4% of the total area of the Grand Canyon, riparian habitats are extremely important centers of species diversity as well as resources for wildlife species that use all other habitat types (Figure 11). In the Greater Grand Canyon Landscape, riparian areas include

hydro-riparian areas with year-round access to water, and xero-riparian habitats where water presence is intermittent. In spite of their rarity, riparian areas support about 29% of the park's rare and endemic species, as well as up to 10 times more birds than are found in surrounding desert habitats. A volatile water table and high potential for pollution threaten riparian areas and the diversity of species dependent upon them. In addition, riparian areas are subject to nonnative species invasion, including abundant tamarisk (*Tamarix ramosissima*) in the Colorado River corridor itself and Russian thistle (*Salsola tragus*) and annual bromes (*Bromus rubens, B. diandrus, B. tectorum*) in ephemeral xero-riparian sites.



Figure 11. Bright Angel Creek, Grand Canyon National Park (NPS photo).

The riparian zone, so important to the overall diversity of the region, includes populations of three endemic plant species: the Kaibab suncup (C*hylismia confertiflora*, syn. *Camissonia confertiflora*), McDougall's yellowtops, and Mentzelia to-be-named. Special status wildlife in the Colorado River corridor includes the humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), flannelmouth sucker (*Catostomus latipinnis*), and Kanab and Niobrara ambersnails (*Oxyloma haydeni kanabensis* and *Oxyloma haydeni*). Many more widespread species inhabit riparian areas in the park, including species common in other habitats and riparian specialists such as the common merganser (*Mergus merganser*), great blue heron (*Ardea herodias*), canyon wren (*Catherpes mexicanus*), ringtail (*Bassariscus astutus*), beaver (*Castor canadensis*), and canyon tree frog (*Hyla arenicolor*).

2.3.2. Watersheds

Springs are the main source of perennial water in the GGCLA. The 33 HUC 10 subwatersheds in the GGCLA represent surface water drainage features, corresponding to creeks, gulches, and washes that drain into the Colorado River (Amesbury et al. 2010; Figure 12). These water channeling features

influence local biorichness, the distributions of sensitive and invasive species, the occurrence of culturally and historically important features, and the viewshed. The watersheds extend in many cases well beyond the borders of the national park, comprising BLM, USFS, military, tribal, regional park, state trust, and private lands (Amesbury et al. 2010). As a whole, the region contains 1,928 miles (3,103 kilometers) of major streams, varying from perennial to intermittent to ephemeral. Besides the Colorado River, major streams include the Little Colorado River, Bright Angel Creek, Tapeats Creek, Shinumo Creek, Detrital Wash, Grand Wash, Havasu Creek, Hualapai Wash, Hurricane Wash, Kanab Creek, Virgin River, Halfway Wash, Toquop Wash, Beaver Dam Wash, Cottonwood Creek, Johnson Creek, Last Chance Creek, Paria River, and Wahweap Creek (Amesbury et al. 2010). Each of these is divided into subwatersheds feeding smaller washes and creeks.

Although the area within current streams and washes accounts for less than 2% of the overall area of the Grand Canyon, these features are critically important to species diversity, runoff filtration and moderation, and aquifer recharge. Maintenance of water quality and quantity throughout the landscape is therefore essential. Grazing, wallowing, and introduced species can disturb or modify riparian communities, particularly in the lands outside Grand Canyon NP. Water quality in Grand Canyon watersheds can be affected by pollutants from agricultural, mining, and construction activities, as well as from human and livestock waste, which can move through both surface and groundwater pathways. In the long term, water quantity may be heavily influenced by climate change and is dependent on aquifer recharge areas, which depends upon the relationship between precipitation, runoff, and evapotranspiration in the recharge area, mostly above the rim.

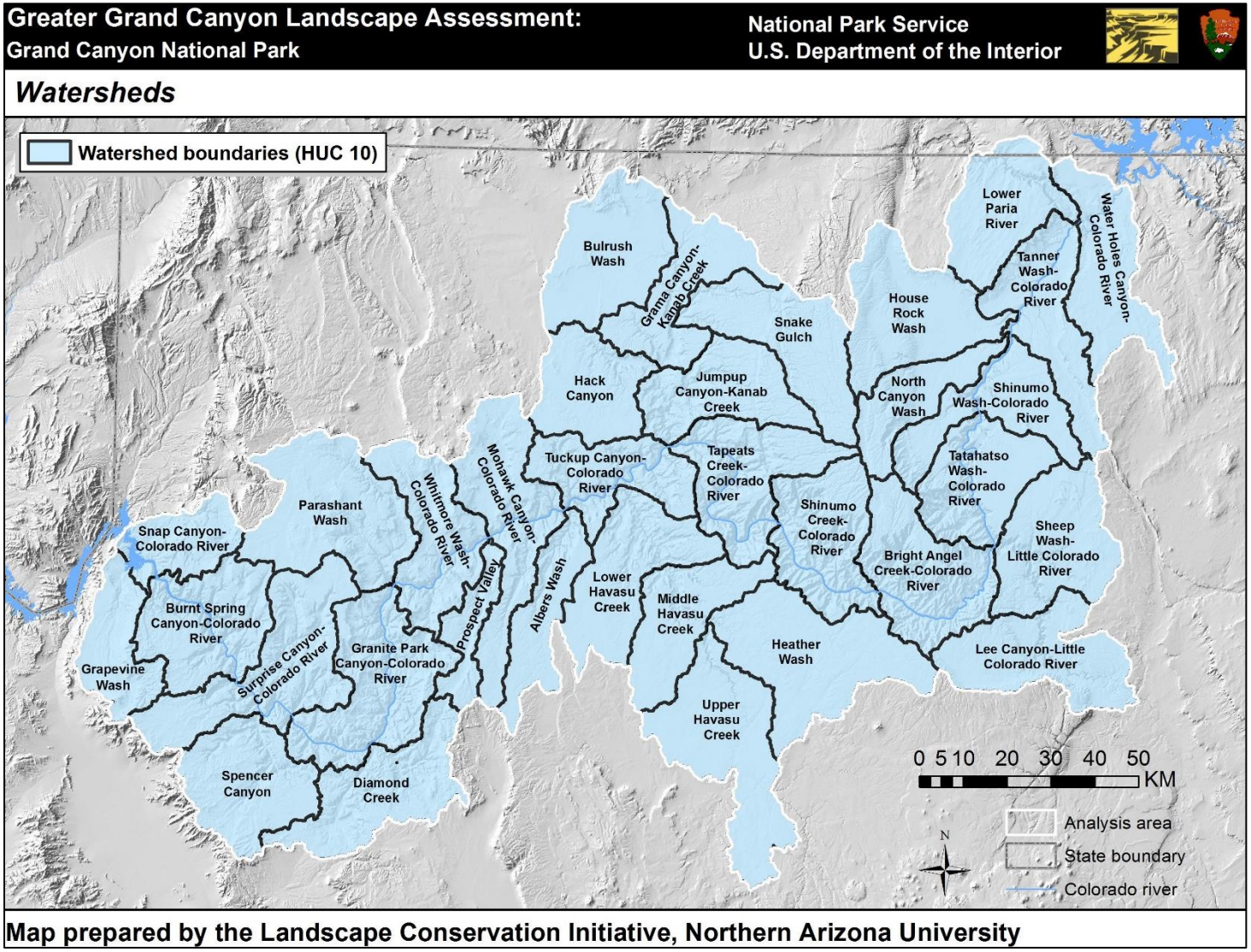


Figure 12. Greater Grand Canyon Landscape HUC 10 watersheds (Landscape Conservation Initiative).

2.3.3. Additional Landscape-scale or Regional Natural Resource Information

The vegetation communities, watershed, and geologic zonation described above account for the diverse habitats and species assemblages found in the GGCLA area. At the same time, the dramatic topographic relief compresses this diversity of life zones into a relatively small area, with the result that area land managers must work across life zones and make decisions at broader landscape scales. Therefore, during the GGCLA's participatory spatial prioritization process (described in Chapter 4), stakeholders were asked to separately consider conservation values and stressors for three regions: above the rim, below the rim, and within the Colorado River corridor. The resulting prioritizations would therefore be useful for managers operating at those broader, more relevant scales.

Because we performed a landscape assessment that extends beyond the borders of Grand Canyon NP, our analysis area also included other protected areas (see Table 2 in Section 2.4). One example is the Kaibab Squirrel National Natural Landmark, comprising 220,000 acres of ponderosa pine ecozone on the Kaibab Plateau (NPS 2010). The NNL—which protects both a prime example of a flagship habitat type (a climax ponderosa pine forest) and an endemic subspecies, the Kaibab squirrel (*Sciurus aberti kaibabensis*)—overlaps with Grand Canyon NP by about 10% of its land area; the remainder is Kaibab National Forest land. Management activities on the NNL are at the discretion of individual landholding entities, but jurisdictions are expected to consider the impact of their decisions on the regional ecological integrity. The presence of multiple protected areas in the analysis region introduces additional management objectives and emphasizes the importance of condition assessments to a broader number of stakeholders.

2.3.4. Resource Descriptions

Throughout this document, the indicators, reference conditions, and stressors relevant to key landscape resources are identified and examined using a combination of expert assessment, spatial analysis, literature review, and compiled field data. Natural resources and species of significance are identified here to portray the diversity of resources under consideration (Grand Canyon National Park 2014).

The Grand Canyon has been named an Important Bird Area by the Audubon Society, with more than 360 documented bird species. Regional biorichness is high for other species groups, as well: 61 herpetofaunal species, 92 mammal species, and 8,480 invertebrate species, including both native and non-native species, have been documented in the national park. Many of these are widespread habitat-generalists, able to occupy part or all of the topographically complex Grand Canyon region. Other important park resources are habitat-specialists or rare species, several of which are species of special concern, which are evaluated in this condition assessment.

Five bird species occurring in the Grand Canyon have been listed as threatened or endangered, or are proposed for listing under the Endangered Species Act. The California condor (*Gymnopgyps californianus*), a federally listed endangered species, is managed as an experimental, reintroduced population in the Grand Canyon region, and as endangered within the park. Other federally listed endangered birds in the Grand Canyon include the Southwestern willow flycatcher (*Empidonax trailli extimus,* Figure 13) and the Yuma clapper rail (*Rallus longirostris yumanensis*). The Mexican

spotted owl (*Strix occidentalis lucida*) and the Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) are listed as threatened.



Figure 13. The southwestern willow flycatcher *(Empidonax trailli extimus)* is a federally listed endangered species (USFWS photo by Jim Rorabaugh).

Non-federally listed species in Grand Canyon NP may nevertheless be listed as species of concern by the State of Arizona or the Navajo Nation. Federally delisted birds in the Grand Canyon that retain Special Concern status in Arizona include the American peregrine falcon (*Falco peregrinus anatum*) and the bald eagle (*Haliaeetus leucocephalus*). The golden eagle (*Aquila chrysaetos*) is considered likely to decline in the foreseeable future by the Navajo Nation, which gives it a threat rating of G3–Vulnerable (http://www.natureserve.org/conservation-tools/conservation-status-assessment). The same rating has been applied to the desert bighorn sheep (*Ovis canadensis nelsoni*). The State of Arizona has designated the Mexican long-tongued bat (*Choeronycteris maxicana*), spotted bat (*Euderma maculatum*), and Western red bat (*Lasiurus blossevillii*) as Wildlife of Special Concern. Species of concern include Allen's lappet-browed bat (*Idionycteris phyllotis*), the greater western mastiff bat (*Eumops perotis californicus*), the long-legged myotis bat (*Myotis volans*), the pale Townsend's big-eared bat (*Choeronycteris mexicana*), the pocketed free-tailed bat (*Nyctinomops femerosacca*), and the southwestern myotis bat (*Myotis auriculus*).

Besides sensitive species, a number of other important natural resources in the Greater Grand Canyon Landscape were identified by stakeholders in our assessment process. Overall biorichness is promoted by the high topographic relief and diversity of habitat types. Ecological integrity and connectivity of habitats are promoted by the ruggedness of the landscape, which results in large swaths of continuous natural area. Seeps, springs, and riparian areas are centers of diversity as well

as essential habitat components for many taxa. Also, natural sounds, uninterrupted vistas, and night skies are essential aesthetic resources that are central to visitor experiences in the region.

2.3.5. Resource Issues Overview

Past Activities or Conditions that Influence Current Park Conditions

An assessment of current resource conditions requires that we consider past activities that have left their mark in the Grand Canyon and on the Greater Grand Canyon Landscape. Grazing, mining, water development, and the construction of Glen Canyon Dam are all past pressures whose effects can still be felt in the canyon (National Parks Conservation Association 2010). Resource extraction, development, and grazing all continue above the rim, and their effects can be felt on both sides of the park boundary.

Mining was a primary driver of early settlement by Europeans in the Grand Canyon and vicinity. The region is dotted with old mines established for extraction of asbestos, uranium, bat guano, lead, zinc, copper, and other materials. The mines are historical sites but they also represent sources of erosion and potential pollution runoff, including, in some cases, radioactive material. For example, the Orphan Mine on the South Rim is an EPA superfund site. There are also older mines with ethnographic value, such as the Salt and Hematite Mines, both of which hold high spiritual and cultural value for American Indian tribes for whom traditional cultural landscapes encompass the entire Grand Canyon region (National Parks Conservation Association 2010).

Current mining concerns near the park are focused on uranium extraction. To date, hundreds of uranium mining claims have been established on BLM and NFS lands adjoining Grand Canyon NP. The claims are located within watersheds that drain into the canyon and therefore hold the potential to pollute scarce water resources throughout the park and region. Wildlife species dependent on these resources, as well as the canyon's natural acoustic environment and visitor experience, are likely to be impacted by this mining activity. In 2009, the NPS imposed a moratorium on the filing of new uranium claims, pending study of the likely impact of uranium mining on park resources (National Parks Conservation Association 2010). The debate, fueled by economic, cultural, and environmental concerns, continues.

Additional factors that influence current park conditions include nonnative species and recreational use, which can include high-impact disturbance of fragile resources (National Parks Conservation Association 2010).

Introduction to Resource Condition Stressors

Related to the above factors, a number of stressors are currently considered "of concern" in terms of potential harm to valued park resources. Chapter 5 presents a detailed examination of the following stressors: exotic plants, introduced animals, climate change, development, resource extraction, user impacts, groundwater withdrawal, altered hydrological regime, and overflights. For each of these, we examine the known status of and contributors to the stressor, assess the adequacy of current knowledge related to the stressor, and identify critical information gaps where additional data are necessary in order to permit adequate management decision-making.

2.4. Resource Stewardship

2.4.1. Fundamental Resources of Grand Canyon National Park

The Grand Canyon NP Foundation Statement (2010) identifies six fundamental resources and values that are integral to achieving the park's purpose and to maintaining its significance, along with desired conditions and management targets for those resources. The best representative qualities that embody Grand Canyon NP include geologic features and processes, biorichness and natural processes, visitor experiences, water resources, human history, and opportunities for learning and understanding. The following information was compiled from the Grand Canyon NP Foundation Statement (NPS 2010) and Grand Canyon NP's draft Desired Conditions document (2012a).

Geologic Features and Processes

The Grand Canyon is one of the planet's most iconic geologic landscapes. Ninety-seven percent of the park is considered a karst landscape. Its wide-ranging geologic features include diverse paleontological resources, a complex neotectonic and erosional history, and Pliocene to Holocene volcanic deposits (Figure 14). Besides its value as an important scientific chronicle, this geologic record is also largely responsible for the park's inspirational scenery.



Figure 14. Grand Canyon Supergroup – Hakatai Shale reveals mudcracks that formed as a shallow sea transitioned to coastal mudflats about 1,180 million years ago (NPS photo).

Geologic Features

Grand Canyon NP is known worldwide for its outstanding exposures of stratified rock, creating some of the world's best-known scenic vistas and geologic (stratigraphic) columns. Exposed rocks range from 1,840 to 270 million years in age, providing a record of more than a third of Earth's history. The park contains the most continuous section of Paleozoic sedimentary rocks in North America (if not the world). It also protects the most karst terrain of any national park in western North America.

Geologic Processes

The Colorado River, which established its course through Grand Canyon within the last 6 million years, likely evolved from pre-existing drainages into its current course. Geologic processes

including erosion on hill slopes and in tributaries and active tectonism continue to shape the canyon today.

Paleontological Resources

The Grand Canyon's fossil record is incredibly diverse, ranging from Precambrian stromatolites to exceedingly well-preserved Pleistocene vertebrate fossils. Rich deposits of well-preserved Quaternary fossils in dry caves provide a record of climate change since the late Pleistocene, and also contain by far the most important Quaternary fossil record on the Colorado Plateau.

Cave Resources

Grand Canyon NP has 300 known caves and probably hundreds more yet to be documented. These caves include unique formations and mineral deposits, significant archaeological remains, and unique biological systems including bat habitat. The cave and karst features, especially in the Kaibab, Redwall, and Muav Limestones, are an important part of the regional R aquifer hydrological system.

Biorichness and natural processes

Grand Canyon NP possesses outstanding biological diversity, containing five of Merriam's seven life zones: from rim to river, the Lower Sonoran, Upper Sonoran, Transition, Canadian, and Hudsonian zones.

Natural processes such as drought, floods, landslides, and fire influence the park's biota. Natural fires were eliminated for most of the twentieth century, but fire is currently allowed in some park areas under restricted conditions and in accordance with NPS's 2012 Fire Management Plan (NPS 2012b).

Diverse ecological communities

The wide range of elevation and topography found in the park contributes to a wide range of habitats and diversity of species.

Undeveloped landscape

Over 90% of Grand Canyon NP is managed as wilderness. In 1980, Grand Canyon NP submitted a proposal to designate 980,088 acres (80% of the park's total acreage) as wilderness, and an additional 131,814 acres (11% of the park) as potential wilderness. In addition, seven Research Natural Areas (RNAs) have been designated within the park. These RNAs are part of a national network of sites designed to facilitate research and preserve natural features. They are usually established in a typical example of an ecological community type, preferably one having been little disturbed in the past and where natural processes are not unduly impeded. These designations seek to keep undeveloped landscapes in a natural state.

Connectivity to Other Natural Areas

The park is connected to a series of other significant natural areas including national monuments, recreation areas, wilderness areas, national forests, and BLM areas, which allow some ecological processes to operate relatively unimpeded (Table 2). The park, combined with adjacent public and tribal lands, comprises one of the largest undeveloped area in the contiguous United States.

Table 2. List of public land natural areas contiguous with or near to Grand Canyon National Park. Taken together, these areas comprise one of the largest undeveloped areas in the United States.

Natural Area	Management	Size (acres)
Kaibab Squirrel National Natural Landmark	GRCA/NPS, KNF/USFS	220,000
7 Research Natural Areas	GRCA/NPS	9,943
Paiute Wilderness	BLM	87,900
Grand Wash Cliffs Wilderness	BLM	37,030
Mount Logan Wilderness	BLM	14,650
Paria Canyon-Vermillion Cliffs Wilderness	BLM	112,500
Kanab Creek Wilderness	BLM, KNF/USFS	75,300
Cottonwood Point Wilderness	BLM	6,860
Saddle Mountain Wilderness	KNF/USFS	41,140
House Rock Wildlife Area	AZGFD	60,000
Kaibab National Forest	KNF/USFS	642,474
Grand Canyon-Parashant NM	NPS/BLM	1,048,221

Visitor Experiences in a Unique Natural Landscape

In 2015, nearly 5.5 million visitors experienced firsthand the Grand Canyon's environmental interrelationships and resources. The majority of park visitors experience the park's scenic grandeur from developed South and North Rim areas. Relatively few visitors venture into the inner canyon for backcountry and river-based recreation opportunities, and to experience solitude, natural sounds, clean air, and night skies.

Wide Range of Recreational Opportunities

A range of recreational opportunities are available for visitors to the Grand Canyon, including both self-guided and commercial opportunities. These include hiking, rafting, backpacking, mule and horseback rides, camping, and scenic air tours. Park rangers offer interpretive programs and the Grand Canyon Field Institute offers educational tours and classes.

Natural Acoustic Environment

Visitors have opportunities throughout Grand Canyon NP to experience natural sounds. The sounds of civilization are generally confined to developed areas. The noise from air tours and commercial flights is most intense beneath stipulated flight corridors, but maybe be noticeable to each side of the corridor. Natural acoustics also allow tribal songscapes to persist.

Wilderness Character

Grand Canyon NP's proposed wilderness areas retain their wilderness characteristics and values, so that visitors find ample opportunities for primitive recreation and for solitude. Wilderness areas are affected primarily by the forces of nature, with minimal signs or sounds of people.

Scenic Vistas at a Vast Landscape Scale

A key element of the visitor experience at Grand Canyon NP is its completely natural, landscape-scale scenic views, which remain largely unimpaired by human activities.

Night Skies

The park maintains visibility conditions that are as close as possible to natural.

Air Quality

Air quality in the park is evaluated against national ambient air quality standards for criteria pollutants in order to protect air quality-sensitive resources and to enhance the overall visitor experience.

Water Resources

The best-known water source in Grand Canyon NP is the 277-mile (446 kilometer) stretch of the Colorado River that flows through it, but the park also contains many other important native waters. Most of these emerge from large spring systems on the canyon's north and south sides, and many surface in the inner canyon. Important tributary flows influencing water level and quality for the Colorado River include the Paria River, Little Colorado River, Kanab Creek, Bright Angel Creek, Tapeats Creek, Shinumo Creek, and Havasu Creek. Several Grand Canyon tributary flows are potentially eligible to be designated Wild and Scenic River and/or Outstanding Natural Resource Waters.

Grand Canyon tributary flows, seeps, and springs represent some of the least altered water resources in the Southwest, and they nurture a high percentage of the park's ecological diversity. They are also important to humans—many have cultural significance for tribes traditionally associated with the Grand Canyon. They are important for visitor safety and comfort, and they provide the highly prized activity of whitewater rafting.

In addition, the Glen Canyon Dam Adaptive Management Work Group, a federal advisory group formed to oversee the process of identifying and assessing downstream effects of the dam, has adopted "a set of Desired Future Conditions to help guide future experimentation, research, and monitoring" (Glen Canyon Dam Adaptive Management Work Group 2012).

Grand Canyon as a Steward of American Indian Culture and Heritage

The Grand Canyon region has witnessed thousands of years of human use and occupation, as documented in the archaeological record (Figure 15). The park is known to preserve thousands of archaeological sites, but to date only about 6% of park lands have been inventoried and many more sites remain unrecorded. Eleven American Indian tribes retain important connections to the canyon, with some considering it to be their original homeland and place of origin. These federally recognized, traditionally associated tribes include the Havasupai Tribe, Hopi Tribe, Hualapai Tribe,

Kaibab Band of Paiute Indians, Las Vegas Band of Paiute Indians, Moapa Band of Paiute Indians, Navajo Nation, Paiute Indian Tribe of Utah, San Juan Southern Paiute Tribe, Yavapai-Apache Nation, and Zuni Tribe.



Figure 15. Lino gray bowl from the Basketmaker III period, 500–800 A.D. Grand Canyon National Park Museum Collection (NPS photo).

The great significance of Grand Canyon NP's cultural heritage lies in the richness and diversity of the cultural groups found here and the varied lifeways people pursued to adapt to what many regard as a severe climatic and physiographic environment. Unique cultural adaptations made by diverse cultural groups over millennia —such as establishing travel routes from river to rim, farming at 8,000 feet, and using varied microenvironments seasonally across the region—served to nurture life in the rugged, remote Grand Canyon, and these same adaptive strategies are found in neighboring tribes' historic and present-day land use.

Grand Canyon as a Historic Resource

Grand Canyon NP hosts more than 800 properties listed in or eligible for the National Register of Historic Places. The most well-known and visible of these significant historic resources are the Mary Elizabeth Jane Colter National Landmark District buildings (Figure 16). These buildings, which include Hopi House, Lookout Studio, Hermits Rest, and Desert View Watchtower, illustrate the park's rustic architecture and NPS style. Significant landscape architecture and park planning are visible in the Grand Canyon Village National Historic Landmark District and the Grand Canyon Lodge National Historic Landmark District. These resources, along with many others, attest to the Grand Canyon's early development as a destination national park.



Figure 16. Victor Hall, 1936. The Fred Harvey Company's men's dormitory in Grand Canyon Village, designed by architect Mary Colter (NPS photo).

Indigenous Peoples and Links to the Canyon

Grand Canyon NP engages in meaningful government-to-government consultation and relationships with traditionally associated tribes, and park managers strive to respect tribal sovereignty. They recognize that tribes have strong historic, cultural, and spiritual connections to the Grand Canyon region and that tribal members have integral knowledge about the lands now managed by the National Park Service. Park planning documents reflect a shared interest by the park and the tribes in maintaining healthy ecosystems and in preserving and protecting cultural and natural resources.

Archaeological Sites (Paleoindian to Historic)

A total of 5,187 archaeological sites have been documented in Grand Canyon NP. The current condition of each site is evaluated according to the following designations:

- Good – The site shows no evidence of noticeable deterioration by natural forces and/or human activities. The site is considered currently stable and its present archaeological values are not threatened. The aspects of integrity that make the site significant have not been diminished. No adjustments to the currently prescribed site treatments are required in the near future to maintain the site's present condition.
- Fair – The site shows evidence of deterioration by natural forces and/or human activities. The aspects of integrity that make the site significant are diminishing. If the identified impacts continue without the appropriate corrective treatment (mitigation), the site will degrade to a poor condition and the site's National Register eligibility may be threatened.
- Poor – The site shows evidence of severe deterioration by natural forces and/or human activities. The aspects of integrity that make the site significant are diminished. If the identified impacts continue without the appropriate corrective treatment (mitigation), the site is likely to undergo further degradation and the site's National Register eligibility will be threatened. Data potential for historical or scientific research will be lost.

- Destroyed – The site's formal condition assessment resulted in a professional determination that the site was destroyed or so severely damaged that it is no longer eligible for the National Register of Historic Places; that eligibility testing may be required to determine whether subsurface deposits are present before making a final determination regarding site eligibility. The data potential/scientific research value is deemed insufficient to warrant further archaeological monitoring or investigation (Grand Canyon NP Monitoring Protocols, 2012, as amended, 2014).

Historic Built Environment

The condition of historic and prehistoric structures is also evaluated (NPS 2006), according to the following categories:

- Good – Historic structures listed on or eligible for listing on the National Register of Historic Places are in good condition when the structure possesses integrity of location, design, setting, materials, workmanship, feeling, and association to the historically significant period(s) based on the National Register Criteria for Evaluation (36 CFR 60.4), and the structure and important features are intact, structurally sound, and performing their intended purposes.
- Fair – The structure is in fair condition if either of the following condition is present: (a) There are early signs of wear, failure, or deterioration although the structure and its features are generally structurally sound and performing their intended purpose; or (b) there is failure of a significant feature of the structure.
- Poor – The structure is in poor condition if any of the following conditions is present: (a) The significant features are no longer performing their intended purpose; (b) significant features are missing; (c) deterioration or damage affects more than 25% of the structure; or (d) the structure or significant features show signs of imminent failure or breakdown).

<u>Opportunities for Learning and Understanding</u>

Grand Canyon NP's interpretive and resource education program is focused on instilling a sense of resource stewardship in visitors for the park via a multi-leveled approach of formal and informal interpretive contacts. The park provides person-to-person contact with visitors as well as non-personal interpretation using a variety of media. Visitor contacts include visitor center activities; casual trail interactions; structured, well-researched programs; educational outreach to school children through on- and off-site visits; print publications (including quarterly guides and site bulletins); a variety of Internet-based operations (including recorded ranger minute programs, an extensive Internet-based information system, and interactive programs); audio programs (such as podcasts and cell phone tours); and high-quality exhibits and waysides.

Interpretation and Resource-Based Education

Research-based interpretive and educational programs and information connect visitors to Grand Canyon resources and National Park Service ideals, aiming to instill a sense of stewardship for the canyon, other national park areas, and resources in their own backyards.

Research and Science Activities

Grand Canyon NP has long been an important setting for research on archaeology, geology, geography, ecology, geomorphology, recreation and visitor experience, natural acoustics, air quality, hydrology, and others. A high-quality park research program is critical for meeting park goals and objectives. It ensures systematic, current, and fully adequate park information; provides a sound basis for policy, guidelines, and management actions; helps management develop effective strategies, methods, and technologies to restore disturbed resources; and predicts, avoids, or minimizes adverse impacts on natural and cultural resources and visitor-related activities. In total, 717 research studies were conducted in Grand Canyon NP from 1960 to 2010 (Newton 2012). The majority of the research (29%) focused on physical science, covering such topics as air quality, geology, soils, and paleontology, followed by vegetation (17%) and wildlife (16%) studies. Research in Grand Canyon NP is conducted by multiple entities, including independent contractors, other governmental agencies, academic researchers, and the USGS Grand Canyon Monitoring and Research Center (GCMRC), established in 1996 to study the downstream effects of Glen Canyon Dam in Grand Canyon NP and the Lake Mead National Recreation area. The number of research projects conducted in the park each year has risen steadily since 1960.

Museum Collection

The museum collection storage facility (a 6,000-square-foot, climate-controlled facility completed in 1999) houses more than a million items from eight disciplines: archaeology, art, ethnology, biology, paleontology, geology, archival items, and history. The staff receives more than 2,000 research requests each year. The museum collection's present and future holdings contribute directly to understanding the park's purpose, themes, and resources, as well as housing objects that include objects the National Park Service is legally mandated to preserve. Natural and cultural materials and associated records provide baseline data that reflect the scientific and historical documentation of the park's resources and purpose.

2.4.2 Status of Supporting Science

The NPS has implemented a Vital Signs Monitoring program in parks with significant natural resources in order to improve its science information base. Long-term monitoring will provide parks with the resource information that is needed for effective decision-making, enabling the NPS to manage park resources "unimpaired for the enjoyment of future generations." Approximately 270 NPS units have been grouped into 32 NPS inventory and monitoring networks linked by geography and natural resource characteristics. With shared funding, parks in each network collaborated with each other and the professional staff of the network to design and implement long-term monitoring of key vital signs.

The Southern Colorado Plateau Network (SCPN) staff worked with representatives from Grand Canyon NP and other network parks to identify and evaluate vital signs for long-term monitoring. Table 3 lists the vital signs chosen for SCPN parks, including Grand Canyon NP (Thomas et al. 2006). In Grand Canyon NP, SCPN currently conducts long-term aquatic macroinvertebrate and physical habitat monitoring for Hermit Creek, Garden Creek, and Bright Angel Creek (Stumpf and Monroe 2011, 2012, 2014a, 2014b); bird community monitoring in mixed conifer forest and pinyon-juniper habitat (Holmes and Johnson 2010, 2013a, 2013b); and integrated upland vegetation and soils

monitoring (DeCoster and Swan 2011a, 2011b, 2013a, 2013b, 2014). Water quality monitoring in Grand Canyon NP began in 2012 and is currently ongoing.

Table 3. Vital signs for long-term monitoring in Southern Colorado Network Parks, and associated protocols.

Protocol	Vital Signs
Aquatic macroinvertebrates	Aquatic macroinvertebrates
	Habitat metrics
Integrated upland vegetation and soils	Vegetation composition and structure
	Soil stability and upland hydrologic function
Bird communities (in review)	Upland and riparian bird communities
	Habitat metrics
Water quality (in review)	Stream water quality
	Spring water quality
Integrated riparian, hydrology and geomorphology (in review)	Channel morphology
	Streamflow and depth to groundwater
	Riparian vegetation composition and structure
Spring ecosystems (in development)	Spring flow
	Wetted extent
	Wetland vegetation
Land surface phenology (in development)	Start of season
	End of season
	Spring peak greenness
	Monsoon peak greenness
	Season-long productivity
	Snow cover extent and duration

Chapter 3. Study Scope and Design

3.1. Introduction and Overview

The Greater Grand Canyon Landscape Assessment (GGCLA) was an iterative process consisting of the following phases: 1) development of the project's scope and outreach to collaborators; 2) data inventory and assessment; 3) data development, compilation, and processing; 4) spatial analyses, along with stakeholder participatory analysis; and 5) review and reporting. A brief overview of each project phase is provided below. A key design principle in our approach was flexibility in matching specific methods to the needs of Grand Canyon NP managers and stakeholders, as well as the availability of information for a specific resource. This meant that reporting areas varied by resource, as did the method of conducting the assessment of a given resource. Figure 17 describes the GGCLA process.

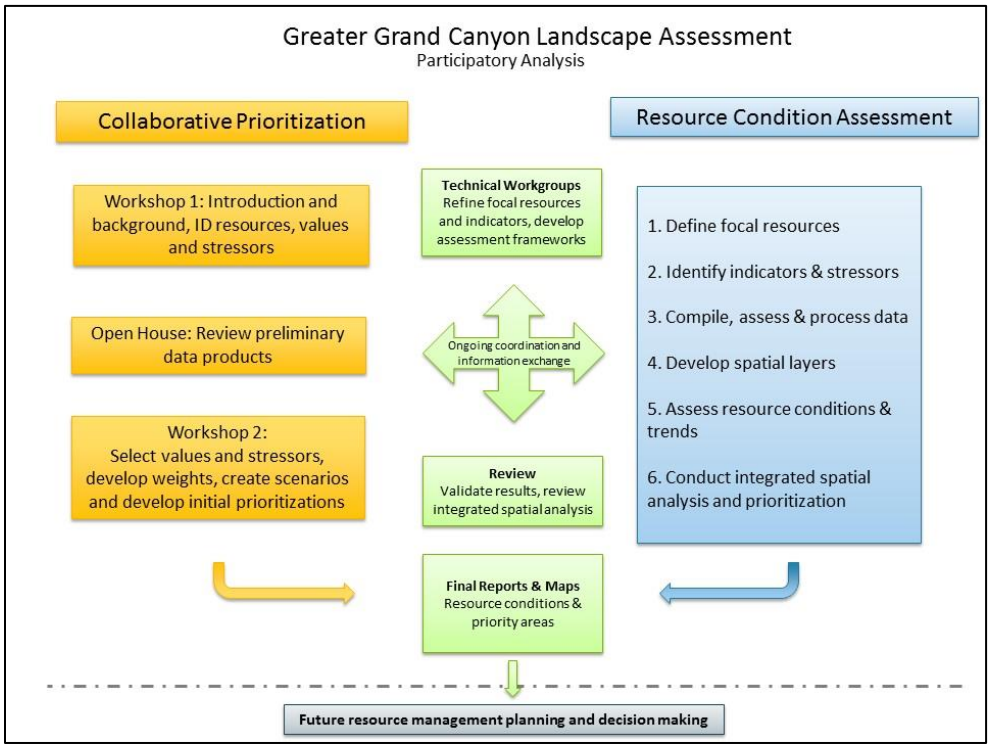


Figure 17. The GGCLA takes a two-pronged approach to landscape assessment. The blue boxes on the right outline the Natural Resource Condition Assessment process that is common throughout the National Park Service. The yellow boxes on the left illustrate the collaborative process that engages stakeholders and neighboring landowners. The green boxes and arrows describe the ways that technical consultation with subject matter experts both advance the process and keep them connected. Ultimately, the two come together to inform multiple land and resource management planning and decision processes involving Grand Canyon National Park.

3.1.1. Project Scope and Outreach

The broad scope of the GGCLA was defined in part by Grand Canyon NP's desired conditions (in draft form) and the vital signs and measures developed in collaboration with the Southern Colorado Plateau Network. These also directed an initial inventory of information sources, including spatial and tabular data, and published and gray literature. These sources were assessed for their suitability for subsequent analyses. Due to the collaborative nature of the assessment, outreach and scoping were a major focus of the project and included an interdisciplinary workshop. Outreach and stakeholder engagement identified a diverse group of stakeholders from neighboring lands and jurisdictions, and from the community of interest that is tightly linked to the Grand Canyon, along with potential scientific collaborators.

3.1.2. Data Inventory and Needs Assessment

A series of in-depth technical work group (TWG) meetings with interested stakeholder and subject matter experts, focused on specific resources, were held to compile and more rigorously assess existing data sources, identify indicators of resource condition, and guide methods for analysis.

3.1.3. Data Development, Compilation, and Processing

Although NRCAs are intended to draw from existing data resources, the GGCLA project, with additional funding, was able to develop some new maps and conduct limited analyses. In addition to new data products, we compiled disparate datasets into single, resource-specific datasets, and georeferenced and mapped non-spatial datasets.

3.1.4. Condition and Trend Analysis/Relative Condition

For each indicator of each resource, condition and trend were determined based on available current condition information and reference condition information. Availability of information varied enormously among indicators and among resources (described in depth in Chapter 5). Where possible, quantitative and spatial data were used to assess current and reference condition.

Where data gaps made a quantitative or spatial assessment of current and reference conditions impossible, current understanding and data needs were described, and condition was assessed qualitatively relative to historical information or reference data available in published literature. For a small minority of resources, no historical or reference data existed and a condition assessment was impossible. In these cases, we simply identified data needs. Across resources, a comprehensive list of the data needs was identified and shared with Grand Canyon NP resource staff. They refined the list to further focus on manager's science needs. This list is accessible via Appendix C as a resource to guide future monitoring and research efforts.

In each Resource Condition Assessment, current condition was rated according to categories consistent with NPS guidance (Table 4 and Table 5).

Table 4. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

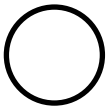
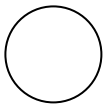
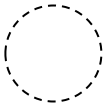
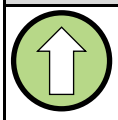
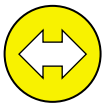
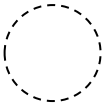
Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low
No Color	Current Condition is Unknown or Indeterminate	No Arrow	Trend in Condition is Unknown or Not Applicable	–	–

Table 5. Example indicator symbols with verbal descriptions.

Symbol Example	Verbal Description
	Resource is in good condition; its condition is improving; high confidence in the assessment.
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.
	Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

Summary tables presenting condition and trend for each indicator are provided in the assessment of each resource in Chapter 5.

3.1.5. Spatial Analysis

An interactive spatial analysis approach was employed in order to prioritize landscapes based on management needs and stakeholder interests across the landscape. A series of maps was produced to depict both individual resource conditions and integrated spatial analysis for landscape

prioritizations. Many of these maps were developed in collaboration with land managers and data managers across the project areas in order to create datasets that went beyond jurisdictional boundaries. Stakeholders reviewed and interacted with these maps in an open house, and in a second interdisciplinary workshop they reviewed and integrated the products.

3.1.6. Review and Reporting

Subject matter experts reviewed specific focal resource assessments. The report products were reviewed and finalized for submittal in accordance with NPS guidance, and distributed to stakeholder participants. As depicted in Figure 17, the GGCLA included a large collaborative component to direct the project's scoping and to prioritize the landscape based on stakeholder-identified values and stressors.

3.2. Stakeholder Engagement

Preliminary scoping of the GGCLA began with a meeting of Grand Canyon NP resource managers and Northern Arizona University staff in 2012. The goal was to identify specific qualities of the landscape assessment and discuss how the assessment could add value to their work. Following Grand Canyon NP's agreement to move forward with a landscape-scale approach, a number of stakeholder engagement events, including workshops and technical work groups, were held to structure scoping, determine appropriate analytical techniques, share and compile existing data, and explore spatial data to develop landscape prioritizations. Agendas, meeting summaries, attendee lists, and background documents for each event are provided (accessible via Appendix A). A complete list of outreach activities is given in Table 6.

Table 6. GGCLA stakeholder outreach. List of outreach events, including workshops, technical work group meetings, and presentations (does not include correspondence or working meetings).

Event	Date
Presentation: GRCA Conversations on the Edge Public Lecture Series*	May 3, 2012
Presentation: Grand Canyon Association Members' Gathering*	May 19, 2012
Stakeholder Workshop 1	October 11, 2012
Grand Canyon Trust Intertribal Gathering	November 15, 2012
Presentation: Tusayan Town Hall Meeting	January 9, 2013
Technical Work Group: Vegetation	March 26, 2013
Presentation: Grand Canyon River Guides Training Session*	March 30, 2013
Technical Work Group: Caves	April 2, 2013 (AM)
Technical Work Group: Springs	April 2, 2013 (PM)
Technical Work Group: Cultural Resources	April 23, 2013
Technical Work Group: Wildlife	May 9, 2013
Technical Work Group: Ecosystem Intactness and Biodiversity	June 12, 2013 (AM)
Technical Work Group: Fire	June 12, 2013 (PM)

*GGCLA was presented as part of a broader presentation on GRCA science and resource management

Table 6 (continued). GGCLA stakeholder outreach. List of outreach events, including workshops, technical work group meetings, and presentations (does not include correspondence or working meetings).

Event	Date
Open House for Hualapai Tribe	July 25, 2013
Open House for Biennial Conference of Research on the Colorado Plateau	September 16, 2013 (2 sessions)
Poster Presented to Biennial Conference of Research on the Colorado Plateau	September 17, 2013
Presentation to Biennial Conference of Research on the Colorado Plateau	September 18, 2013 (2 separate presentations)
Presentation to Tribal Council, Paiute Tribe of Utah	October 3, 2013
Presentation to Tribal Council, Kaibab Band of Paiute Indians	October 17, 2013
Presentation to Hopi Tribe, Cultural Preservation Department	October 23, 2013
Presentation to Hopi Tribe, Cultural Resources Advisory Team	November 21, 2013
Presentation to GRCA Park Leadership Team	January 7, 2014
Presentation to Hopi Tribe Land Team	February 18, 2014
Technical Work Group: Visitor Experience	March 5, 2014
Stakeholder Workshop 2	June 10-11, 2014

*GGCLA was presented as part of a broader presentation on GRCA science and resource management.

3.2.1. Stakeholder Identification

We defined stakeholders as those with a direct stake in managing, using, and studying Grand Canyon NP, including neighboring land managers. Contacts were identified through Grand Canyon NP's existing NEPA contact database, and through specific individuals suggested by park staff of several divisions. In addition, one-on-one discussions were conducted with a key group of invitees, and participants were asked who else should be contacted and included in the effort. More than 175 individuals, representing natural and cultural resource program managers from Grand Canyon NP and neighboring land management agencies, along with non-profit organizations, user groups, and researchers with a direct stake in managing, using and studying Grand Canyon NP and surrounding region were invited and kept informed about efforts. Representatives of more than 35 organizations participated in workshops, technical work groups, or both (listed below):

- Arizona Game and Fish Department
- Bureau of Land Management–Vermillion Cliffs National Monument
- Bureau of Reclamation
- Center for Biological Diversity
- Colorado Plateau Cooperative Ecosystems Studies Unit
- Desert Botanical Gardens
- Flagstaff Dark Skies Coalition

- Grand Canyon Association
- Grand Canyon Hikers and Backpackers Association
- Grand Canyon River Outfitters Association
- Grand Canyon Trust
- Hualapai Tribe, Department of Cultural Resources
- Kaibab Paiute Tribe–Southern Paiute Consortium
- Museum of Northern Arizona
- National Park Service–Cave and Karst Program
- National Park Service–Glen Canyon National Recreation Area
- National Park Service–Grand Canyon National Park
- National Park Service–Intermountain Region
- National Park Service–Lake Mead National Recreation Area
- National Park Service–Natural Resource Stewardship and Science Directorship
- National Park Service–Southern Colorado Plateau Network
- National Parks Conservation Association
- Navajo Nation–Historical Preservation Department
- Northern Arizona University–Ecological Restoration Institute
- Northern Arizona University–Geography, Planning and Recreation
- Northern Arizona University–School of Environmental Sciences and Sustainability
- Northern Arizona University–School of Forestry
- Prescott College–Adventure Education and Environmental Studies
- Sierra Club
- Springs Stewardship Institute
- The Nature Conservancy
- University of Arizona–Drachman Institute
- U.S. Fish and Wildlife Services
- U.S. Forest Service–Kaibab National Forest
- U.S. Geological Survey–Grand Canyon Monitoring and Research center
- Xanterra

3.2.2. Workshop 1

Workshop 1 was the first stakeholder workshop of the GGCLA, and a major scoping effort. It was convened in October 2012, with the following objectives:

- Share background on context and approach for the GGCLA.
- Discuss roles of Grand Canyon NP, Northern Arizona University, and participants.
- Develop shared understanding of project process, data availability, and analytical capabilities.
- Discuss which resources to include in the analyses, as well as landscape values and stressors.
- Identify the next steps, including participation in Technical Work Groups.

The workshop was attended by about 60 people, representing more than 20 organizations, including Grand Canyon NP. Meeting attendees participated in facilitated discussions to identify valued landscape attributes (values) and stressors across the landscape. Discussions were distinguished according to geographic area. The attendees focused on three areas: the river corridor, the area below the canyon rim, and the area above the rim (Figure 18). Although some values and stressors are relevant across the entire landscape, these three physically different regions are characterized by differing ecosystems, patterns, processes, and management issues. Participants rotated so that each participant attended a session on each geographic area. After the rotations were complete, facilitators synthesized all identified values and stressors into a compiled list for each geographic region. Participants used dot voting to highlight their top six values and top six stressors across geographic areas (Figure 19). We categorized the values and stressors and prioritized moving forward with those values and stressors that received the most dots in each geographic region. Prioritized values and stressors identified by Grand Canyon NP and non-park participants did not differ markedly.

This prioritized list of values and stressors was used in two ways: first, they were grouped into categories of focal resources and indicators to address in the hierarchical resource condition assessment (Figure 17, Table 7). Second, they were used as guidance for developing spatial data layers to be used in spatial analysis exercises and prioritization in future workshops.

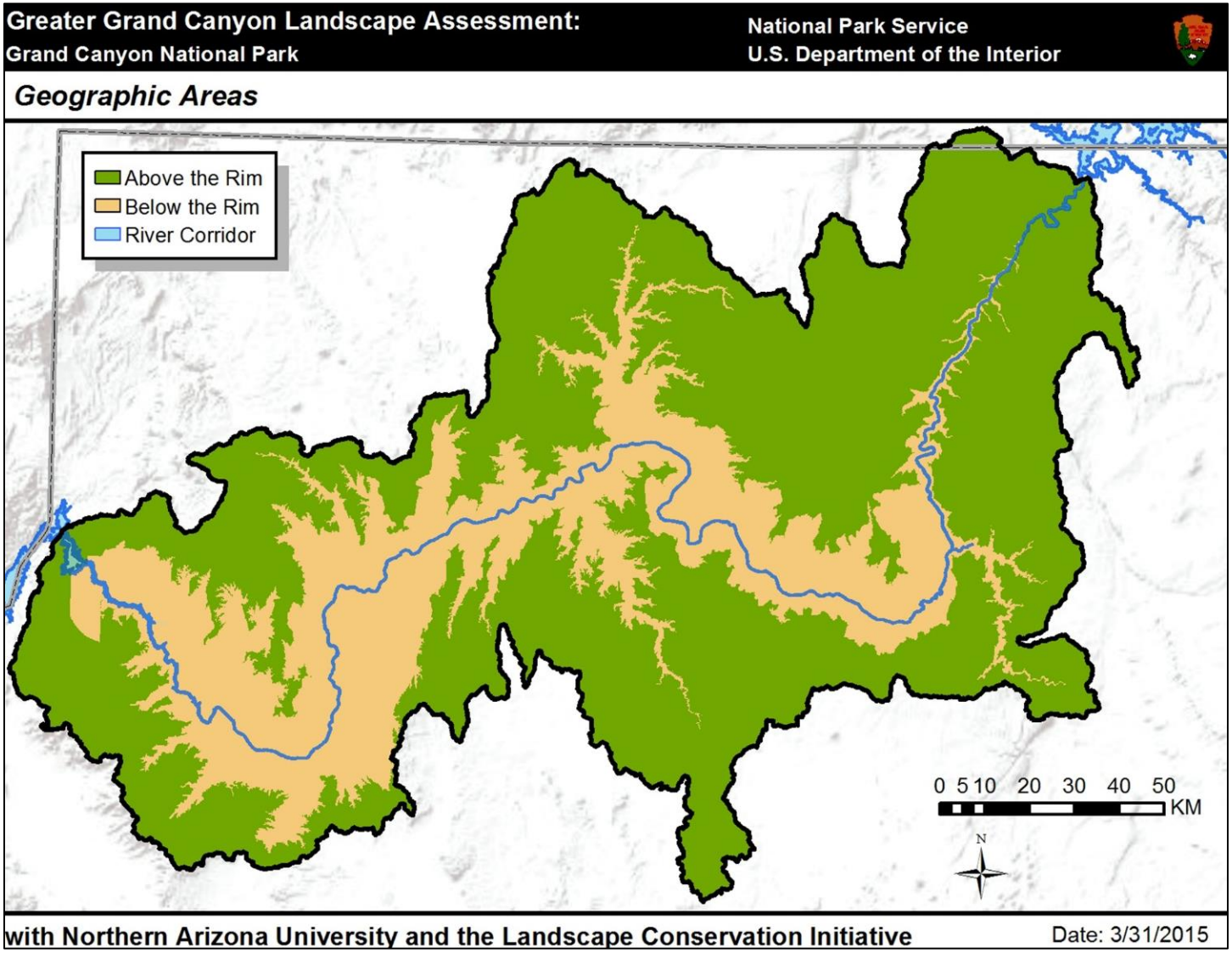


Figure 18. The Greater Grand Canyon Landscape Assessment project area was divided into three geographic areas: above the canyon rim, below the canyon rim, and in the river corridor (Landscape Conservation Initiative).



Figure 19. Participants in the October 2012 GGCLA workshop used dot voting to indicate their values and stressors across the study area (LCI photo).

Table 7. Resources and indicators of resource condition for the greater Grand Canyon landscape analysis.

Category	Resource	Indicator
Landscape	Biorichness	Geophysical diversity
		Surface water availability
		Vegetation community diversity
		Net primary productivity
	Ecological integrity	Residential and commercial land cover
		Agricultural land cover
		Energy production and mining
		Transportation and service corridors
		Human intrusion and disturbance
	Fire	Fire return interval
		Fire severity in ponderosa pine vegetation types
		Reburns in pinyon-juniper, desert shrublands, and desert scrub

Table 7 (continued). Resources and indicators of resource condition for the greater Grand Canyon landscape analysis.

Category	Resource	Indicator
Vegetation	Rare and endemic species	Occurrence of rare and endemic plants
	Riparian communities	Riparian community extent
		Native riparian species richness and composition
		Occurrence of exotic species
		Proportion of native and exotic species
Wildlife	Bighorn sheep	Habitat quality
		Habitat connectivity
		Movement
		Population estimate
		Survival and mortality factors
		Genetic structure
		Forage availability
		Disease factors
	California condor	Population integrity
	Eagle	Nest and eagle sightings
	Invertebrates	Aquatic invertebrate richness – Colorado River
		Aquatic invertebrate richness – tributary streams
		Aquatic invertebrate richness – springs ecosystems
		Cave invertebrate richness
		Terrestrial invertebrate richness
	Mexican spotted owl	Presence – protected activity center (PAC) occupancy
	Mountain lion	Habitat quality
		Abundance
		Survival and mortality factors
		Diet and prey base
		Seasonal movement
		Body condition
	Mule deer	Presence (deer distribution)
		Condition (population trends)

Table 7 (continued). Resources and indicators of resource condition for the greater Grand Canyon landscape analysis.

Category	Resource	Indicator
Wildlife (continued)	Mule deer (continued)	Habitat quality
		Habitat connectivity
	Northern goshawk	Habitat quality
		Demographics
	Northern leopard frog	Presence
		Population condition
	River avifauna	Avifaunal richness by reach
		Southwestern willow flycatcher habitat availability, presence,
		and nesting
Fisheries	Native fish	Relative abundance/dominance of native and nonnative fish
		Endangered fish abundance and distribution
		Rare/high-risk nonnative fish species captures
		Catch-per-unit -effort of large-bodied fish
Physical Resources	Caves	Geological resources
		Hydrological resources
		Biological resources
		Paleontological resources
	Seeps and Springs	Spring presence
		Spring discharge
		Water quality
Cultural Resources	Archaeological resources	Site condition
	Ethnographic resources	Traditional Cultural Properties
		Cultural landscapes
Visitor Experience	Night sky	Bortle scale
		Zenithal limiting magnitude
		Sky quality index
		All-sky light pollution ratio
		Local light – light shielding and diffusion fixtures

Table 7 (continued). Resources and indicators of resource condition for the greater Grand Canyon landscape analysis.

Category	Resource	Indicator
Visitor Experience (continued)	Daytime viewshed	Unimpeded and undisturbed viewsheds, lines of site from
	Recreational resources	Trail segments
		Recreational facilities
		Recreational opportunities
		Vista points
		Campsite density
	Natural acoustic environment	Differences between existing and natural ambient sound levels
	Wilderness	Biorichness potential
		Degree untrammeled
		Natural sound and dark night sky
		Ecological integrity
Stressors	Altered hydrologic regime	
	Climate change	
	Development	
	Ungulates: Introduced Species and Expanding Ranges	
	Exotic plants	
	Groundwater withdrawal	
	Overflights	
	Resource extraction	
	User impacts	

3.2.3. Technical Work Groups

Following the synthesis of information from Workshop 1, the core team convened a series of Technical Work Group (TWG) meetings, which occurred from March 2013 to March 2014. The purpose of these meetings was to further refine and scope the assessment by engaging park resource staff, subject matter experts, and interested stakeholders in a more specific dialog about focal resources, appropriate indicators of their condition, the relevant and available information to address resource condition, and the proper approaches for assessing their condition in aspatial and spatial contexts. In January 2013, invitations were sent to GGCLA stakeholders and subject matter experts. TWG meetings were convened for landscape, vegetation, wildlife, physical resources, cultural resources and visitor experience. Fisheries did not convene a TWG because other stakeholder meetings had recently occurred.

The objectives of each TWG meeting were as follows:

- Discuss the scope of and approach to assessing the focal resource(s).
- Determine indicators and criteria for assessing focal resource condition(s).
- Determine approach to spatially representing focal resource(s).
- Identify the information that is available or needed in order to complete the assessment.
- Discuss roles, responsibilities, timelines, and how to move forward working together.

In conjunction with the TWG meetings, one-on-one meetings with Grand Canyon NP resource program managers were held to discuss the feasibility of assessing specific resources, appropriate indicators, existing assessment frameworks, and available data.

3.2.4. Refined Focal Resources

The core team identified themes in the feedback from these meetings in order to refine the scope of the project, identify additional references or contacts for information regarding the resources, and select indicators for inclusion in the RCA using a hierarchical assessment framework. We synthesized feedback from the TWGs in order to define each focal resource, select final indicators for assessment, and identify spatial data layers needed to inform the assessment. In order to develop spatial data layers when possible, the list of desired data products identified from Workshop 1 and the TWGs was filtered into a smaller list based on feasibility. Feasibility was characterized by the availability and quality of data, the ability to represent concepts spatially, the ability to produce a defensible spatial data layer, and the time and cost required to produce.

3.2.5. Outreach to Traditionally Associated Tribes of the Grand Canyon Region

Given the tremendous historical, cultural, and spiritual importance of the Grand Canyon to 11 traditionally associated American Indian tribes, and the presence of tribal lands within the GGCLA study area, tribal engagement was an important component of the GGCLA, and an ongoing effort throughout the project. In August of 2012, Grand Canyon NP Superintendent David Uberuaga sent a letter to the leadership of the 11 traditionally associated American Indian tribes, explaining the project and inviting the tribes to participate in the project and to attend Workshop 1. The project engaged a Tribal Outreach coordinator who followed up the letters with phone calls and meetings and made presentations to interested tribal entities (Table 6). Tribes that chose to participate and provide input for the GGCLA included the Hualapai Tribe, the Hopi Tribe, the Kaibab Band of Paiute Indians, and the Navajo Tribe. Information about the ethnographic value of GGCLA focal resources was largely gathered from existing literature. Tribal representatives who chose to participate reviewed and provided feedback for the draft of the condition assessment for ethnographic resources and ethnographic value of all GGCLA focal resources, which were prepared by the tribal outreach coordinator. See Appendix B for more details on tribal outreach for the GGCLA.

3.2.6. Open House

In September 2013, two half-day open house sessions were hosted in Flagstaff in conjunction with the 12th Biennial Conference on Science and Management on the Colorado Plateau. This offered the core team an opportunity to provide stakeholders with an update on the project. Attendees had the

opportunity to view preliminary maps of a number of data products and provide feedback via written comments and in discussion with GGCLA core team members.

3.2.7. Workshop 2

In June of 2014, a second stakeholder workshop was held. The purpose of this workshop was to offer stakeholders the opportunity to interact with spatial data and develop landscape prioritizations based on identified values and stressors. This process and its outcomes are described in more detail in Chapter 4.

3.3. Study Design

To assess resource condition and trend, along with management priorities, we employed a hybrid approach, drawing on the Conservation Action Planning approach (The Nature Conservancy 2007) and on experiences from Participatory Landscape Assessment (Sisk et al. 2006) to identify values and stressors based on both stakeholder input and the availability of data. Discussion of values and stressors led to the selection of specific focal resources for analysis through the resource condition assessment. Indicators of resource condition, reference conditions and stressors were also identified through structured deliberation. Our approach included two distinct but interwoven efforts (Figure 6):

- A hierarchical framework that addresses current condition of focal resources through their indicators and trend of resource condition in relation to reference conditions. The outcome of this work was an understanding of status and trend of individual resources identified in the analysis area, primarily addressed in Chapter 5. Data used to assess resource condition were obtained from existing records from Grand Canyon NP and other stakeholders. Some new analysis was conducted using existing data sources.
- A spatial analytical framework that identified locations of high value and high risk across the landscape based on values and stressors (Figure 20) in the GGCLA region identified by stakeholders and Grand Canyon NP resource staff. The outcomes of this analysis are specific prioritized locations on the landscape, primarily addressed in Chapter 4. These areas may deserve further management attention, become focal points for coordination across management areas or boundaries, or enable boosted management efficiency due to the colocation of highly valued resources or stressors.

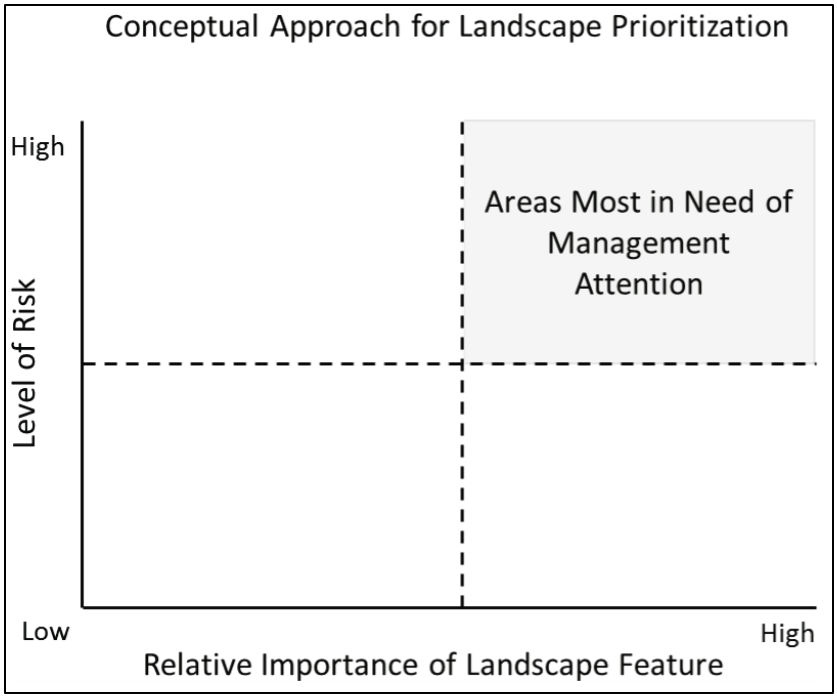


Figure 20. The spatial analytical framework of the Greater Grand Canyon Landscape Assessment project identifies areas of high value and high risk across the landscape. Where these values coincide are areas prioritized for management attention.

The dual approach was intended to assist Grand Canyon NP management as they work in the future to accomplish the following tasks:

- Implement an ecosystem-based approach for resource management that integrates different disciplines.
- Focus limited staff/resources on implementing strategic management actions for high-priority resources and subwatersheds.
- Develop and justify project proposals for internal/external funding sources.
- Develop the Resource Stewardship Strategy for Grand Canyon NP.
- Engage in watershed or landscape partnerships and education efforts.
- Provide a model to other park units and partners working on similarly complex resource management issues within the Colorado Plateau and other ecoregions.

3.3.1. Analytical Framework

GGCLA focal resources were identified through the methods discussed in Section 3.1 in coordination with park staff, subject matter experts, and interested stakeholders. These resources were grouped into broad categories. The categories were organized by themes focused around the existing Grand Canyon NP resource management organizational structure as much as possible in order to increase coordination with and relevance to park managers.

Indicators for each focal resource were also selected through deliberation with park staff, subject matter experts, and interested stakeholders during the first scoping workshop and subsequent TWG meetings. Indicators were selected based on scientific relevance and availability of existing data. Some ecologically important indicators were not addressed in the assessment due to lack of information; these are identified as data needs in each resource condition assessment. Reference frameworks were used to compare current resource condition to a reference point. When known, the reference framework was based on literature review, park desired conditions, or historical data, and provided primarily by Grand Canyon NP staff. Many reference conditions had been previously identified as part of an effort to develop desired conditions for park resources.

Hierarchical Framework

The NRCA process requires the design or selection of a framework for analysis of resource conditions. A framework is a hierarchical way of organizing key resources important for land management. The Nature Conservancy's Conservation Action Planning (CAP) process (2007), the Heinz Framework adapted from the Heinz Center's "The State of the Nation's Ecosystems 2008" report (Heinz 2009), and the Southern Colorado Plateau Network Vital Signs framework (Thomas et al. 2006) provided the starting point for developing the organization of the GGCLA framework. The framework consists of categories, resources, and indicators, as well as reference conditions and stressors for each resource, and provides the organizational structure used to address resource condition in Chapter 5.

Several approaches were used to address stressors. First, specific stressors were identified in relation to each resource and addressed in the status and trend of that resource. Second, landscape-level stressors that impacted many resources were identified through scoping and their current condition and trends are described at the landscape scale in Chapter 5. Finally, stressors were addressed in integrated spatial analysis. The focal resources, indicators, and broad organizational categories used are listed in Table 7.

Spatial Analytical Framework

Landscape-level prioritization for the GGCLA was developed through a participatory, spatial framework of valued landscape attributes and risks, or stressors, to the landscape (Sisk et al. 2006). Valued landscape attributes, or focal resources that can be spatially represented, were overlaid with spatial representations of landscape stressors. Areas with high value, or high risk, or where value and risk intersect were identified and discussed as potentially in need of management attention (Figure 20). Data layers were weighted to establish relative importance and confidence levels for the data. Stakeholders and managers selected which spatial data layers to include in the spatial analysis and the weights to give them in order to develop "scenarios" for prioritizing management. This framework was employed in Workshop 2, where stakeholders were able to view and interact with a subset of spatial data developed for the project. They selected spatial data layers and worked in groups to use them to address scenarios with the goal of prioritizing management across the landscape. The approach and results are described in further detail in Chapter 4.

3.3.2. General Approach and Methods

Design Principles

The GGCLA approach was collaborative, interdisciplinary, and ecosystem based, creating an assessment on a landscape scale that crossed boundaries and was spatially explicit. The project and products adhere to NRCA guidance on process, outline, content, format, and GIS/digital data standards (NPS 2009) while adding additional elements including integration of cultural and natural resources, addressing resource condition beyond the boundaries of Grand Canyon NP when possible, and developing a landscape prioritization. Our approach was also consistent with the Park Service's "Call to Action" in several ways: we designed an approach that encouraged "scaling-up" by promoting large landscape conservation to support healthy ecosystems and cultural resources, and "scholarly pursuits" by sponsoring excellence in science while gaining knowledge about park resources (NPS 2012). While adhering to NPS NRCA guidance and the Call to Action, we built upon these requirements with several key design principles in designing the GGCLA:

Apply a Modified Hierarchical Framework

We reviewed existing hierarchical frameworks and developed an approach that worked best for the data availability and information needs of this landscape. We focused on spatial analysis in determining resource condition to increase relevance and prioritize management.

Emphasize Spatial Analysis and Novel Spatial Prioritization Approaches

Whenever possible, we depicted resource condition spatially. We used methods grounded in our past work to map priorities across the region.

Integrate Cultural and Natural Resources

While often managed separately, natural and cultural resources are inherently linked. They experience many of the same stressors, and actions to manage one may affect another. Furthermore, the natural environment of the Grand Canyon is itself a cultural resource, and its condition is critical from both ecological and cultural perspectives. With that in mind, we assessed both natural and cultural resources in this effort and worked to acknowledge the cultural relevance of the natural resources we assessed. We also conducted extensive work with tribal partners to inform them of the effort, share data and relevant information, and receive feedback and review of our work.

Rely On Existing Data, but Develop Some New Analyses and Visualizations

The Natural Resource Condition Assessment framework calls for leveraging existing data to establish baseline condition and ongoing trend information, along with additional informational needs. While we relied on existing data in our analyses, we worked to combine datasets across jurisdictions and to visualize and analyze existing data in new ways, primarily spatial, in order to optimize the utility of this existing information.

Develop a Landscape-Scale, Trans-Boundary and Collaborative Process

Although Grand Canyon NP is an important management unit alone, it is also embedded in a larger landscape. Water, wildlife movement, fire, and many more issues are relevant beyond the borders of Grand Canyon NP. Furthermore, many stressors to Grand Canyon NP resources come from outside the park. Addressing the condition, trend, and priority of resources across this larger landscape offers

a forum for managers and stakeholders to identify common opportunities, discuss regional issues, and solve problems.

3.3.3. Reporting Areas

We used several types of reporting areas for the condition assessment. For the Resource Condition Assessments laid out in Ch. 5, the choice of reporting area had to do with the availability of data across the extent of the study area, as well as the scale of the resource assessed. Because resources have different meanings and different scales, and because the availability of data varied, the reporting area varied by resource. For example, River Avifauna data was collected and reported by river reach, a more intuitive delineation than watersheds for this particular resource.

The overarching consistent reporting areas were based on hydrologic units or HUCs. They were the natural choice for reporting on information available for the full extent of the analysis area. The analysis area for the GGCLA was determined based on the intersection of HUC 10 watersheds with the physiographic rim of the Grand Canyon because they provided natural boundaries and a standardized way to look across the study area. Therefore, HUCs provided a truly landscape-level way to report on resource condition regardless of management jurisdiction. However, HUC units do not provide a clean overlay with Grand Canyon NP boundaries. For this reason we also summarized resource condition by management jurisdiction when possible to provide management-specific context for our analyses. Together, these two methods of reporting resource condition expand the interpretability of these analyses, as well as their utility in future decision making (Figure 21). In addition, Grand Canyon NP uses backcountry management units to track, manage, and regulate backcountry use. Therefore, we reported on resources relevant to backcountry management, such as recreational resources and user impacts, by backcountry management units.

Resource managers often break up discussions of canyon management by above the canyon rim, below the rim in the inner canyon, and the river corridor. We expanded this conceptualization to the analysis area, and used it in our stakeholder meetings and prioritizations because it was a manageable way for stakeholders to focus discussions in what could otherwise be an overwhelmingly large and complex landscape. Originally, we identified three unique zones of the GGCLA area, based on manager's views that they differed in fundamental ways that would necessitate independent analytical efforts focusing on areas above the rim, below the rim, and the river corridor. While these delineations guided the selection of focal resources, the prioritization exercise laid out in Ch. 4 lead to a focus specifically on areas above and below the rim. After stakeholder workshops, it became obvious that considerable resources were already being focused on the River Corridor, and that the GGCLA effort would likely have little impact on management priorities or resource conditions there, given the complex jurisdictional relationships and a complex policy framework, with its own scientific and stakeholder structures in place. For these reasons, we eliminated the River Corridor as a separate area of attention in for prioritization, and focused that effort on the areas of the Greater Grand Canyon Landscape that was not directly impacted by the operations of Glen Canyon Dam.

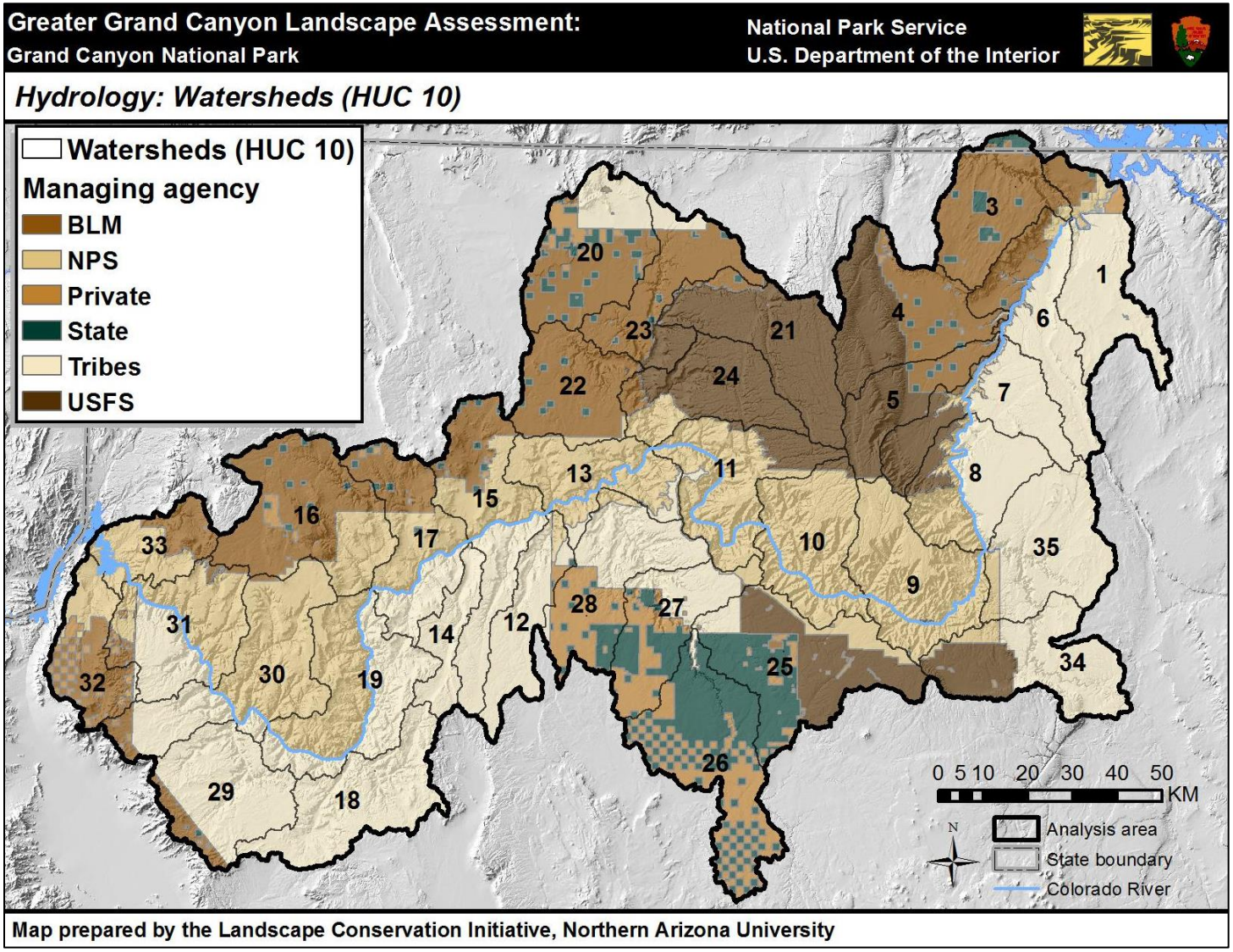


Figure 21. HUC 10 watersheds and land ownership of the Greater Grand Canyon Landscape Assessment project area (Landscape Conservation Initiative).



Chapter 4. Identifying Priorities for Landscape Conservation and Management

4.1. The Challenges of Scale and Complexity

At the center of the GGCLA project lies the shared recognition that the efforts of so many will prove much more valuable if the project results in new insights and actionable information to help successful management and conservation of Grand Canyon NP and the greater Grand Canyon region. Identification and implementation of the management actions needed to safeguard one of the world's great natural areas is an intellectual task of immense proportions. It requires both a wealth of detailed technical information, and the perspective to see emergent patterns and opportunities that rise above the innumerable needs and concerns that surface on a daily basis. Each are important in its own right, but insufficient to illuminate the appropriate path for meeting the goals and objectives shared by stakeholders across this large and varied landscape.

Every park comprises multiple ecosystems of great complexity, linking physical, biological, and cultural resources at multiple scales, from particular sites (springs, archaeological structures, or the location of sensitive species, for example) to entire watersheds, each one unique in its composition, structure, and function. These resources exhibit different attributes at different scales of observation, and their characteristics vary greatly across the landscape (Lindenmayer et al. 2008). Furthermore, wise management requires sensitivity to a multitude of human values and social dynamics that collectively define what actions are possible, practical, and effective in meeting management objectives (Muñoz-Erickson 2013). Considering the resource base from a scientifically informed position, while acknowledging and honoring the social dimensions of management, is a formidable task for park leaders and their staffs, especially during this period of climate change and the uncertainties introduced by social and financial constraints on public lands management. Extending consideration from the park itself to an even larger area, encompassing the interconnecting watersheds and biophysical processes that both affect and are affected by management decisions, expands this challenge manifold. Yet consideration of the larger landscape is essential to making informed decisions regarding the future of Grand Canyon NP (Holcomb et al. 2013). These realities of the twenty-first century place a premium on maintaining an informed "big-picture" perspective, while leveraging the expanding power of science and modern analytical techniques that connect landscape-level thinking with the detailed physical, biological, and social science that is needed to ensure that management decisions lead to informed action and desirable outcomes. The GGCLA does not provide specific management prescriptions, but rather provides the information required to do so in the future.

4.2. Participatory Analysis

Participatory analysis, the foundation upon which the GGCLA rests (see Figure 17 in Chapter 3), is employed with increasing frequency in efforts to address complex, landscape-level management issues (Luz 2000). Without a framework to address the social aspects of park management, the technical information in the park's Resource Condition Assessment would provide little guidance for action, and without science to inform actions, management would be unable to design sound strategies to meet emerging challenges. Thus, participatory analysis combines the scientific data and expert opinions assembled in the RCAs (Chapter 5) with a stakeholder-directed prioritization of areas in need of future management attention. The resulting map-based priorities are presented and interpreted here at multiple scales. Guidance is offered for examining the drivers that underlie priority areas and suggestions are given for carrying forward an iterative process for refining priorities and adjusting them amid new information and changing conditions. The enhanced level of engagement by a diverse body of stakeholders makes sound science and analytical tools available to all, supporting a deliberative process that provides participants with an avenue for constructive engagement with park managers on complex, shared challenges in land and resource management (Stortz 2014).

4.3. The Value of Landscape Prioritization

Without a clear context for accessing, integrating, and analyzing the individual resource assessments, the RCA effort for the Grand Canyon area might have provided a snapshot of the park in the early twenty-first century, but would have offered little actionable information or new insight into how managers might address the emerging challenges associated with increased human visitation, nearby development, a changing climate, and other forms of change that will profoundly affect the park and surrounding areas over the coming decades. Addressing complex challenges across a very large area requires setting priorities so that managers can choose wisely from among the multitude of possible actions, and decision makers can allocate resources in the most efficient way.

The GGCLA incorporates an analytical pathway that directly addresses the particular challenges of the Grand Canyon region by producing a landscape prioritization that identifies areas in greatest need of management attention. This approach draws upon scientific data, expert opinion, and stakeholder perspectives to solve an elusive management puzzle (Stortz 2014).

4.3.1. Setting Priorities

Proper allocation of limited time and resources largely determines the success or failure of management and conservation efforts. This allocation of effort must place resource conditions, expert knowledge, and stakeholder values and expectations above institutional culture and dynamics. Land and resource managers may feel pressure to opt for doing "more of the same," even when changing conditions call for the reassessment and reallocation of effort. The need to prioritize over the long term may be overlooked in the rush to address "brushfires" that, if addressed in isolation, can ultimately decrease efficiencies and undermine progress toward larger, longer-term objectives.

When conducted in a transparent manner, driven by sound data and incorporating appropriate physical, biological, and social considerations, landscape prioritization provides a broad-brush view of where limited resources can be best employed to achieve the greatest benefits. It also provides a

framework for examining why certain areas may deserve increased management attention. Across the greater Grand Canyon landscape, underappreciated areas may emerge as high priorities due to diminishing resource condition, the anticipated effects of known environmental stressors, the expression of elevated value on the part of stakeholders and the public or any combination of such factors.

Identification of areas as management priorities does not presuppose any particular action, but it does alert managers to the fact that strong factors are in play, and that the intersection of high value and perceived stress makes these areas worthy of careful analysis and consideration and, perhaps, timely management intervention (Sisk et al. 2006). Thorough planning should take into consideration that proposed management actions, undertaken for particular purposes in identified priority areas, might have the potential to benefit multiple resources simultaneously. For example, efforts to protect springs and seeps might also benefit endemic plants associated with perennial water as well as downstream populations of sensitive fish species. Studies of GGCLA priority areas might suggest how the mitigation of existing stressors, such as efforts to reduce fire hazard in forested watersheds with high fuel loads, could safeguard downstream resources by avoiding post-fire flooding and sedimentation or reducing their intensity when fires occur.

The identification of areas that are most in need of management attention may also help avoid conflicting management actions, where efforts to improve the condition of one resource might further degrade another. Such cases may occur where single-species management plans are implemented in isolation, or where sensitive species co-occur but their phenologies, habitat requirements, or particular sensitivities to disturbance may not align in ways that facilitate management. In these and similar cases, an examination of the multiple factors that led to an area's prioritization can enable managers to better identify effective approaches that capture efficiencies and avoid unwitting conflicts among multiple objectives pursued by different, often independently acting teams of resource specialists.

4.3.2. Landscape Perspective

Well-informed management incorporates a landscape perspective bounded by geomorphic and ecological processes that extend beyond administrative boundaries. The detailed study of individual resources in isolation of the watersheds or ecosystems where they occur may actually limit our understanding of the natural world, isolating it within disciplinary knowledge silos and focusing attention on specific features or species rather than on the broad patterns and integrated perspectives that guide successful policy and management actions.

The geomorphic and ecological processes that affect multiple physical, biological, and cultural resources in Grand Canyon NP often manifest at broad spatial scales. Fire, for example, may impact tens of thousands of acres in a single event that crosses multiple drainages and ecosystem types, with variable effects related to its changing intensity over time and space. Similarly, pulses of intense rain that sweep across broad plateaus and mesa tops generate concentrated flows of unimaginable power when constrained by narrow canyon walls; the warming climate, now obvious when measured at global scales but often obscured by extreme site-to-site and inter-annual variation in the arid West, nevertheless exacerbates the effects of periodic drought across the dissected Grand Canyon

landscape. In this dynamic and diverse region, management priorities should be based on broad patterns and long-term trends in the condition of multiple resources. During periods of rapid change, actions should be tied to the vulnerability of focal resources to identified stressors, themselves dynamic and varying across the variable landscape, depending on elevation, slope, exposure, and land cover.

Ecologists refer to the scale at which influential processes operate as the "minimum dynamic landscape"—the smallest area that can encompass the extent of disturbances that shape ecosystems and will determine their future (Pickett and White 1985). When prioritizing management actions based on changing conditions that respond to the influences of flood, fire, human development, and climate, the minimum dynamic unit in the Grand Canyon region extends well beyond the boundaries of Grand Canyon NP. The headwaters of the myriad side canyons, for example, may strongly affect downstream processes. The GGCLA therefore identified an "area of analysis" based on watershed boundaries that encompass an area several times the size of the park.

4.3.3. Public Engagement, Social Factors, and Management

Management priorities are not driven by natural science alone; people also influence management decisions, now more than ever before. Large and widely distributed neighboring communities are taking an increasingly active role in determining the future of the national parks, so that resource managers must incorporate scientific research with human values and perspectives in order to fully address the challenges faced by the park's decision makers. Failure to address both the resource conditions and the social dimensions of park management can lead to impasses that prevent the implementation of even the best informed and well-intended decisions (Sarewitz 2004). Across the nation, but perhaps particularly in areas of the West where the future of public lands is actively debated and often characterized by dispute, it is vital that management priorities reflect broadly held values and incorporate the shared perspectives, as well as the divergent views, of the nation's diverse populace in a manner that reflects and strengthens the democratic process. Social factors—human values, traditional knowledge, and multicultural perspectives—all deserve careful consideration and influence when developing priorities.

4.4. Data Integration and Participatory Analysis

Earlier chapters describe both the generalized process for RCAs in the NPS and the unique elements integrated into the assessment for Grand Canyon NP. Expansion of the analysis area beyond the park boundaries, incorporation of cultural resources into the assessment, and engagement of stakeholders in the prioritization process are important components of this effort. The GGCLA has adopted a process that engages stakeholders throughout, including identification of focal resources, sharing of relevant data, and design, parameterization, review, and interpretation of prioritization results (see Hampton et al. 2003).

4.4.1. Selection of Resources to Be Included In Spatial Analysis

In the first GGCLA Stakeholder Workshop, in October 2012, more than 60 participants representing more than 20 organizations worked together to identify the resources to be included in the RCA, as well as the multiple indicators to best reflect the condition and trend of each resource. The outcome of this process (see Table 7, Chapter 3) became the primary guidance for the GGCLA in seeking out

available information, evaluating data quality, and conducting new analyses and modeling efforts to maximize inferences about these resources. At the same time, the participants in Workshop 1 identified a set of values that they believed could be used to effectively map areas of high overlap of occurrence across the GGCLA area of analysis. Similarly, the group examined and discussed the numerous active factors that placed resources at risk. Stressors that could be mapped across the area of analysis were recommended for future use in the analysis of management priorities.

Following Workshop 1, we developed spatial representations of these values and stressors, to the degree that data availability allowed. In some cases, subject matter experts provided copious amounts of data and informed advice on generating comprehensive data layers. In other cases data were lacking and robust spatial analysis and mapping were impossible. In yet other cases, novel analyses and modeling of existing data sets provided new opportunities for representing important values and stressors in spatial form. Obtaining the cooperation of subject matter experts and access to the best available data was often challenging, and in some cases many months were required to clarify data quality and develop the strong collaborative relationships necessary for organizing and analyzing existing data in new ways, in order to make information more relevant to managers and to facilitate integrated analysis and modeling. The result of these efforts was the assembly of a rich data base, including spatial information for many physical, biological, and cultural resources, made available for the first time in a form that allowed the overlay of multiple values with multiple resources, in iterative analyses guided by the cooperation of experts, skilled analysts, experienced resource managers, and engaged stakeholders.

4.4.2. Identification of Key Values

The second GGCLA workshop, in June 2014, brought this data library back to the stakeholders and provided technical support to participants in the form of Geographic Information Systems and the analysts needed to explore, discuss, and analyze the data in real time. At Workshop 2, participants were able to inspect and explore the range of preliminary data products that had been thus far generated by the GGCLA in response to the needs assessment, discuss which desired data products were not available and why, and express their comfort or lack of comfort with each preliminary data layer. Here, the "wish lists" generated in project scoping and in Workshop 1 were informed by the reality of what information was and was not available for the GGCLA area of analysis. These interactions led to a refined list of key values and stressors to be incorporated into collaborative prioritization efforts, as well as an enhanced list of resources to be incorporated into the RCA. Taken as the final stakeholder input to guide data development, this feedback was subsequently reviewed by external subject matter experts, and final spatial data layers for each value were developed by the GGCLA team. Representative examples of the values that were subsequently used in prioritization are presented in Figure 22.

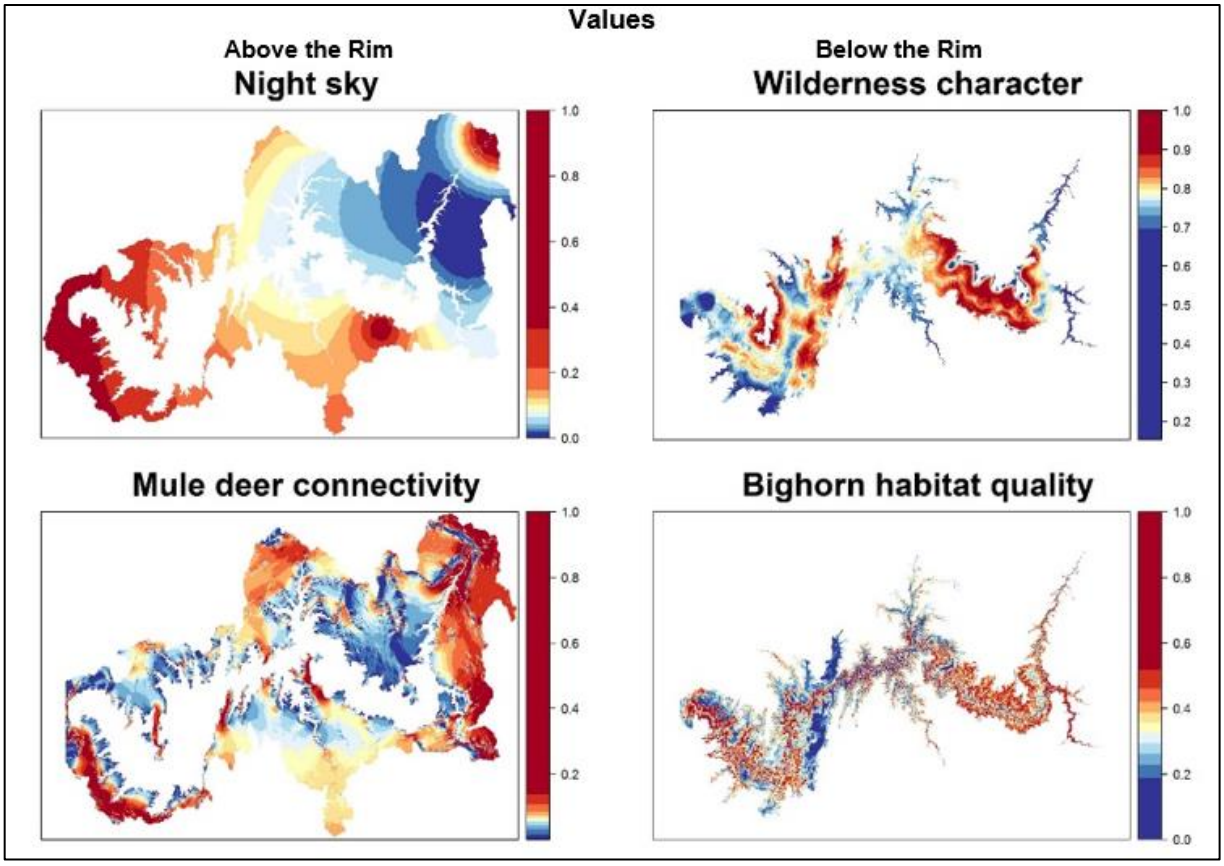


Figure 22. Four examples of landscape-level depictions of high-value resources identified by stakeholders through an iterative, participatory process. Spatial data layers that figured prominently in the prioritization process drew on a wide variety of data sources and employed advanced analytical approaches to create new spatial models capturing stakeholder-identified values. These included (top left) a night sky index, representing the relative isolation from human light sources and thus the potential to experience dark skies and (bottom left) areas likely to provide pathways for unimpeded movement to mule deer. Both were used in assessing priorities above the canyon rim. Wilderness character (top right), an index of relative solitude and removal from permanent human impacts, and (bottom right) habitat quality for bighorn sheep, a species of management interest, both factored into prioritization efforts for areas below the rim. Each was depicted on an index scaled for relevance to the individual layer, e.g. high (1) to low (0) habitat quality. These values are discussed in greater detail in Chapter 5.

4.4.3. Identification of Key Stressors

Similarly, stressors were examined and discussed in Workshop 2, with considerable focus on how existing data limitations could be addressed and overcome when representing the relative vulnerability of areas within the GGCLA area of analysis. In the same breakout groups and work sessions where stakeholders identified, reviewed, and refined resource-specific values, they also examined landscape-scale stressors. Outcomes from this work included a list of stressors to be included in the RCA and a shorter list to be incorporated into the prioritization effort, tailored to the unique conditions and vulnerabilities of resources above and below the canyon rim. This list was further vetted by subject matter experts, who identified additional data sources and commented on

data quality, prior to the finalization of each spatial data layer. Four examples of stressors used in the GGCLA prioritization effort are illustrated in Figure 23.

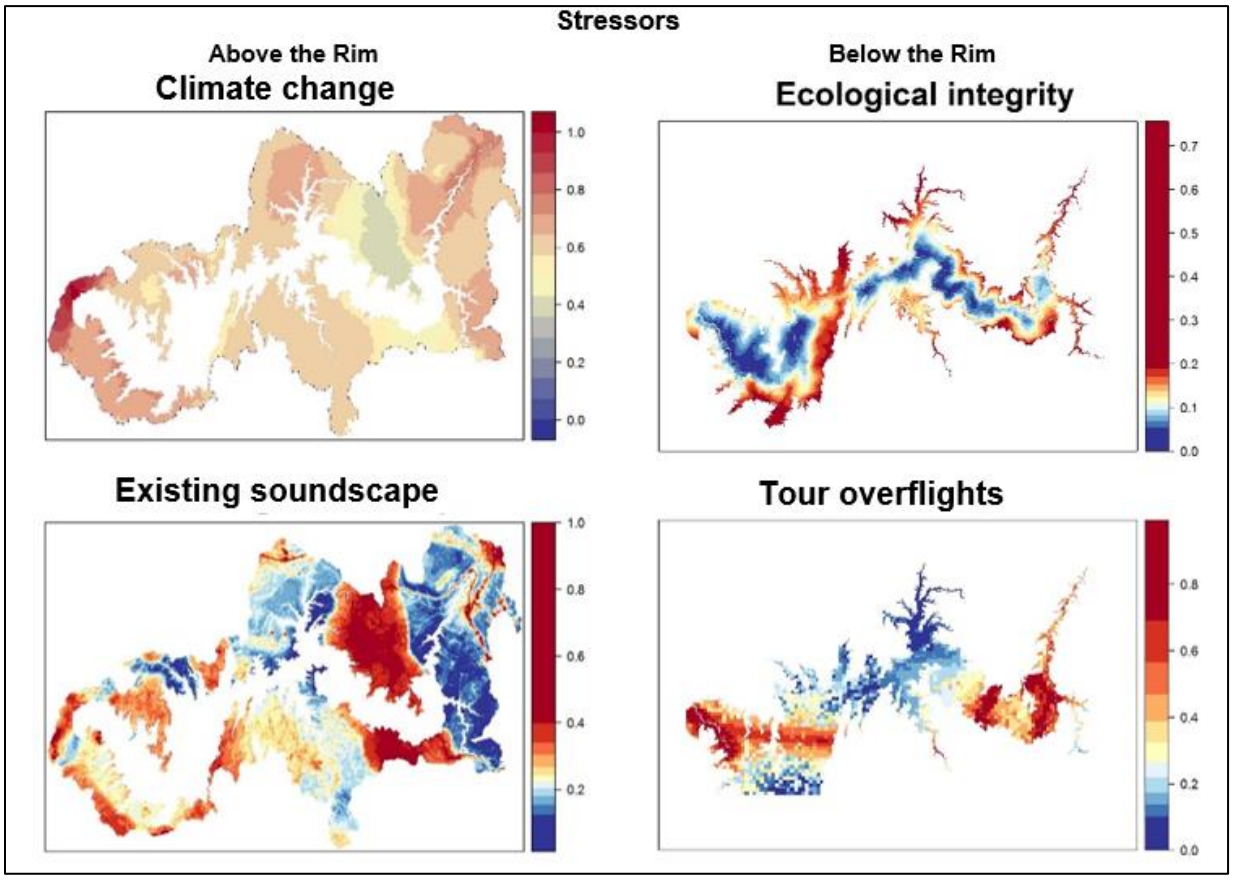


Figure 23. Four examples of stakeholder-identified stressors presumed to place resources at risk across the GGCLA area. Only a small subset of perceived stressors to the integrity of the Grand Canyon region could be mapped across large areas. Among those selected for use in prioritization were (top left) climate change, which illustrates the relative magnitude of ongoing and anticipated climate warming, and (bottom left) existing natural acoustic environment, drawing on a national dataset to illustrate locations where artificial noise impacts the acoustic environment for park visitors and wildlife. Both of these variables were used to assess stressors above the canyon rim. (top right) Ecological integrity, mapped here in inverse scale, identifies areas experiencing a greater degree of human modification, and (bottom right) tour overflights illustrates the intensive use of Grand Canyon airspace by air tours. These latter factors were identified as two of the predominant stressors to resources below the canyon rim. All stressors are described in detail in Chapter 5, Category 8.

4.4.4 Participatory Analysis and the Iterative Nature of Landscape Prioritization

In addition to reviewing the spatial data layers representing individual values and risks, and suggesting refinements to each preliminary product, the second GGCLA workshop undertook an initial prioritization exercise that involved assessing the importance of each data layer, and developing an approach for combining them. Working in four independent breakout groups, each supported by its own GIS analyst and facilitator from the GGCLA team, stakeholders developed

approaches for aggregating multiple values and stressors in a manner that best captured the consensus of the group, subject to the technical advice provided by analyst and facilitator.

Taking into account the diverse perspectives and multiple requests of each group, the technical team then took the stakeholder input into the computer lab to generate, overnight, the first-generation priority maps for each group. This preliminary analysis involved standardizing raster projections (UTM Zone 12N, NAD 83) at 30 meter resolution, and ensuring that map extents matched for each data layer, with appropriate cell alignments. All data were rescaled to values that ranged from 0 to 1, with scales inverted when necessary to ensure that desirable values were highest in all cases. Stakeholder-identified values and stressors were assessed independently for areas above and below the rim, using weighted linear combinations, calculated in the R statistical programming environment, such that

$$S_{ij} = \sum_{k=1}^{n} w_{jk} * c_{ik}$$

where S is the aggregated score for the stakeholder identified value (or stressor) of each pixel on the map, as represented by the weighted linear combination of each of n variables, k, included in the analysis, with each pixel, i, having a characteristic numerical value, c, for each variable identified for inclusion, which is multiplied by the relative importance of the variable, w, given the weighting factor j, applied across the area of analysis. Figure 24 illustrates one of the initial outputs from this process, including spatial representation of higher-scoring pixels.

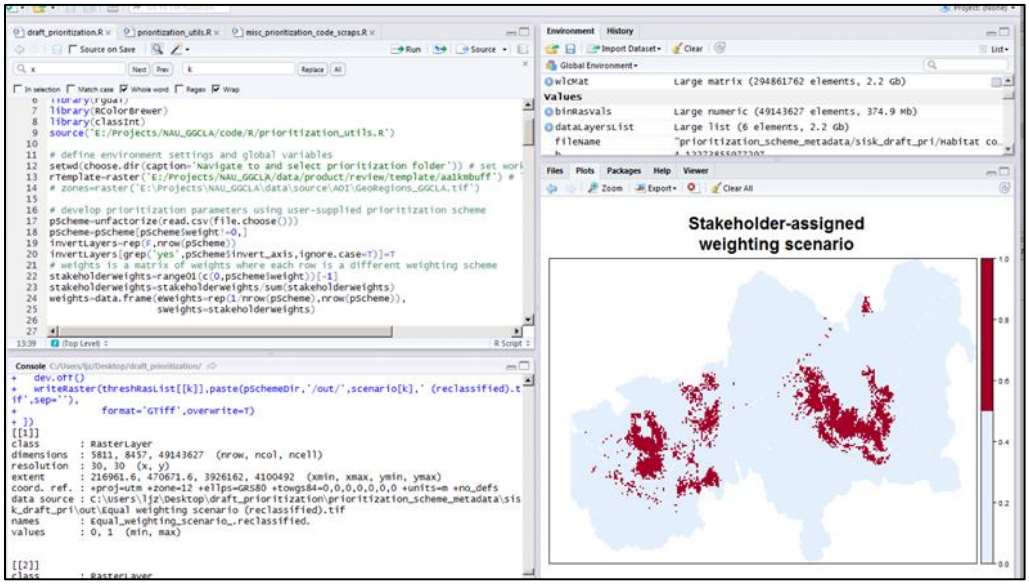


Figure 24. Example of initial overnight analysis of stakeholder prioritization efforts, conducted during the second GGCLA workshop (June 2014). The weighted analysis conducted in R (scripts shown in the left panel) resulted in the spatial representation of higher scoring pixels based on the stakeholder assigned weighting scenario (right).

This exercise in participatory setting of priorities provided the first "live" analytical experience for stakeholders. On the second day of the workshop, each breakout group was given results derived from their efforts of the previous afternoon. These served not as "answers" to be blindly accepted, but rather as preliminary results to be scrutinized and interpreted as participants refined methods and interpreted relationships among input data and outputs. The workshop's final agenda items had each breakout group present its preliminary results for values and stressors, after listing and explaining their selection of inputs and variable weights. Outputs from each group differed, in some cases markedly. Examples of preliminary outputs are presented in Figure 25, which can be constructively critiqued in light of the outcomes of final analyses, presented later in this chapter.

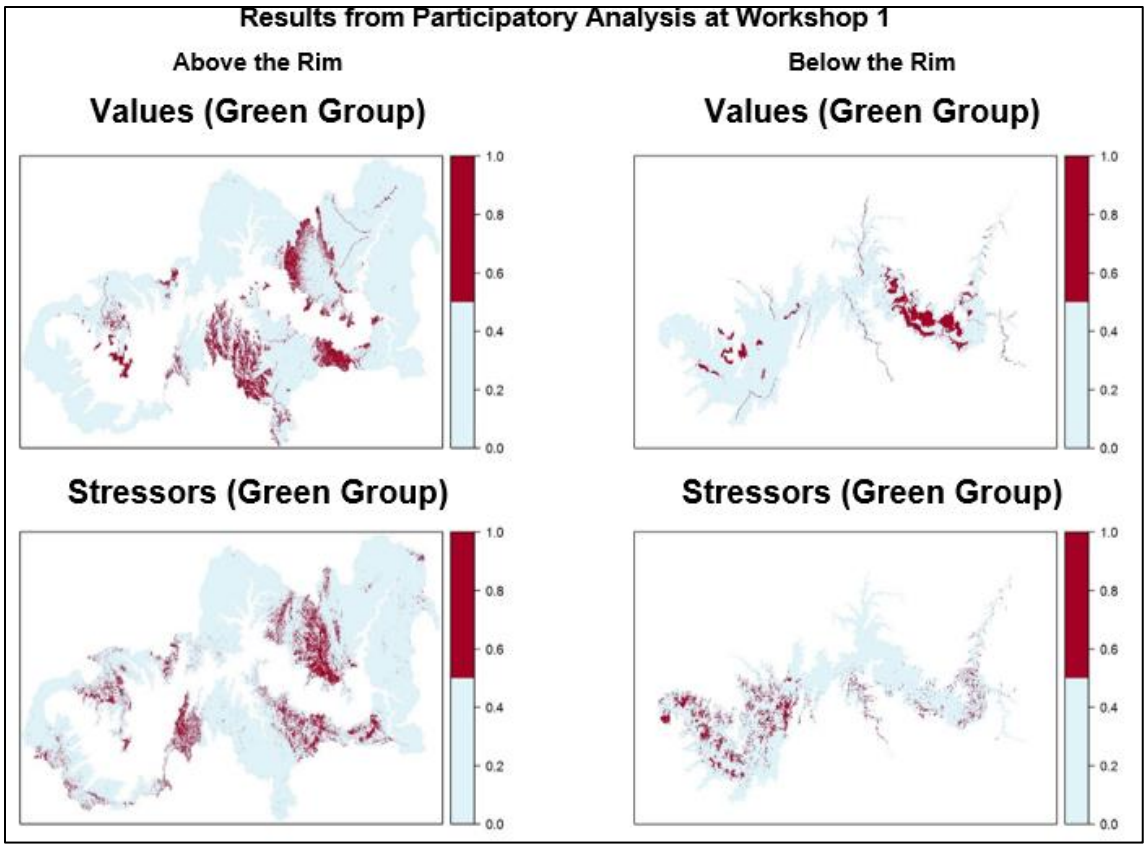


Figure 25. Preliminary results from a breakout group of the second GGCLA stakeholder workshop (June 2014). Participants explored spatial data developed in response to the previous needs assessment, then developed approaches for representing aggregated values and perceived stressors in three break out groups. These preliminary results illustrate the first efforts to synthesize the views of multiple stakeholders. Illustrated here are the outcomes of the green group. Each breakout group presented its results verbally, along with their rationale for inclusion of specific variables. Subsequent deliberation by the full workshop led to a refined approach that integrated strengths from each initial effort, identified areas where data refinements were needed, and produced specific guidelines for the final prioritization effort, conducted by the LCI following the workshop. See Figures 24, 25, 26, and 27.

In closing the workshop, participants examined the strengths and weaknesses of their approaches and discussed how improved prioritizations could be informed by these preliminary exercises. When

asked to either select one approach to be refined and formalized, or provide further analytical advice regarding how a different and improved GGCLA prioritization should be undertaken, participants selected the latter option and offered informed guidance for a final iteration of the prioritization effort, drawing on lessons learned in each of the rapid-fire efforts undertaken by the breakout groups. Further refinements of input data layers and some adjustment to variable weights were then carried over into efforts that culminated in the maps of Figures 26 and 27.

The iterative process of examining data, evaluating the strengths and limitations conducting initial analyses, and allowing these to inform subsequent refinement and improvement is an important aspect of participatory analysis. Landscape prioritization is important in guiding difficult decisions regarding the allocation of management effort, but it also serves the important purpose of engaging a diverse public—with its broad insight, experience, and expertise—in the shared mission of identifying those areas most in need of management attention. In so doing, not only will those areas be more accurately represented, but the support for taking the actions needed to protect values and minimize stressors in those areas will likely become stronger and more unified (Dryzak 1990).

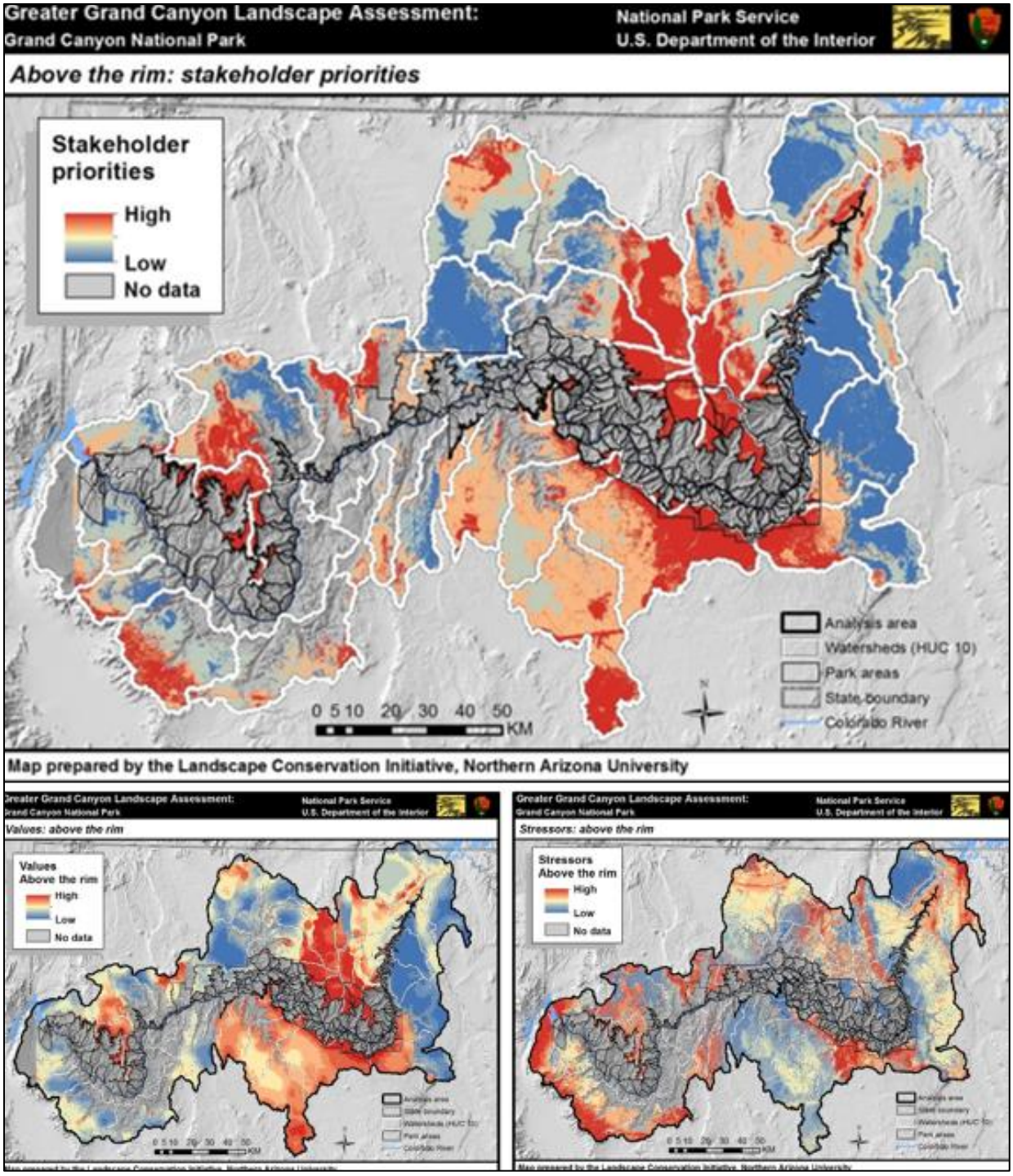


Figure 26. Values (bottom left) and stressors (bottom right) collaboratively selected through an iterative process were overlain to generate above-the-rim priorities (top) (Landscape Conservation Initiative).

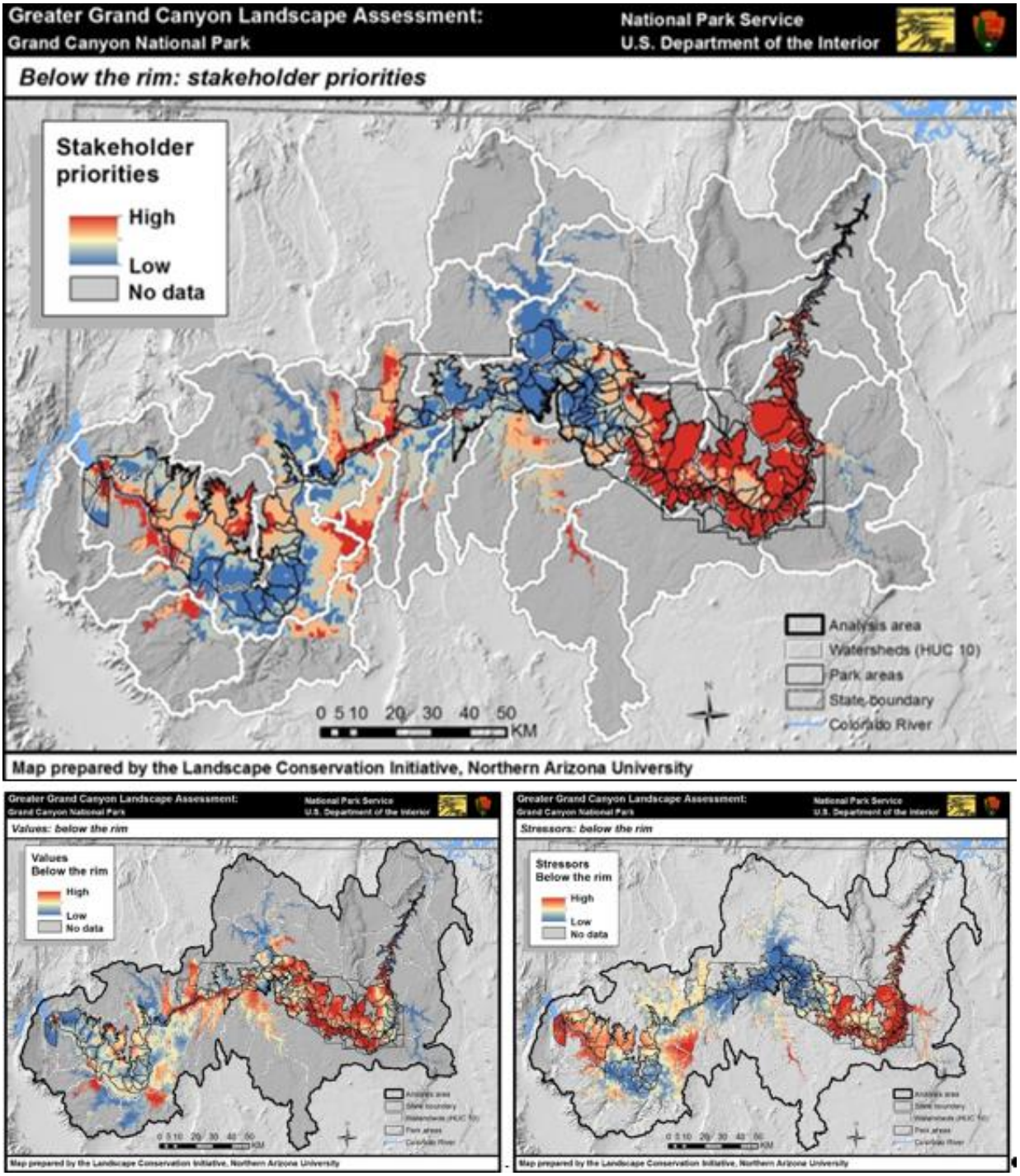


Figure 27. Values (bottom left) and stressors (bottom right) collaboratively selected through an iterative process, were overlain to generate below-the-rim priorities (top) (Landscape Conservation Initiative).

4.4.5. Relative Importance of Resources and Stressors

Clearly not all resources and stressors are of equal value in prioritizing areas across a highly variable landscape. Yet approaches for incorporating both objective characterizations of resource conditions

and subjective values held by a diverse and differentially engaged a broad group of stakeholders pose daunting challenges in landscape analysis.

Many variations on ad hoc, intuitive methods have been developed and employed to guide spatial prioritizations, drawing upon multiple variables as represented by spatial data layers. Although the origin of the data sets for each layer, and the methods used for their spatial interpretation and representation, are fundamental considerations in any such effort, even high-quality data can be used in inappropriate and misleading ways. Spatial overlays are commonly used to represent stakeholder values and management needs when identifying priority locations for management actions (e.g., Moilanen et al. 2011). Often these employ all available data, using weighting schemes to enhance the influence of particular variables, much as we have done here. When a large number of data layers are employed, each modified by a detailed weighting scheme, these arbitrary decisions can overwhelm the information content of the data and undermine results. For example, heavy weights on some variables can overwhelm the data when the range of resource conditions is narrow, and the incorporation of too many data layers can result in the propagation of the modest biases inherent even in robust data sets, with each layer contributing underappreciated yet possibly overwhelming uncertainty to the final outcomes.

Given these common problems, many researchers have turned to more formalized and objective processes. One common framework for setting priorities is a conservation software product called Marxan (Ball et al. 2009) that employs an optimization algorithm that adjusts for the inclusion of multiple data sources and is largely free of the biases associated with arbitrary weighting schemes. Programs based on optimization algorithms typically maximize the benefit of a set of prioritized spatial locations, using overall cost as a constraint on the optimization algorithm. If desired, the results can then be compared and contrasted with other considerations, such as stakeholder values or efficiency of the viability of implementing the identified priorities. Adjustments, modifications, and mixed methods are required when spatial data are limited or mismatched. Recent approaches have implemented optimization methods at two or more resolutions to compare the effects of scale landscape prioritization (Arponen et al. 2012), though these efforts do little to adjust for observed scaling effects through objective analytical processes.

Where social values and ecological variables combine, which is typically the case in real-world management situations, a more complex approach can be employed, with interview-derived social values interpreted spatially and analyzed in concert with ecological features. Hierarchical analytical processes are available to weight the combined set of variables and generate a single spatial layer that may take the form of a prioritization model or map. In some of these approaches, stakeholders can alter weights and visually examine the effects on the resulting maps (Pert et al. 2013), much as GGCLA stakeholders used preliminary results to modify their guidance to our analysts. The integration of social and ecological data can be partially automated in conservation software such as Zonation, to enhance the utility, adoption, and cost-effectiveness of proposed solutions in a framework that is more formalized than the one employed here (Karimi et al. 2015).

After a thorough review of possible approaches, we developed methods for the GGCLA that were computationally relatively simple and that emphasized the participatory aspects of landscape

prioritization. Several considerations led to this choice. First, a pervasive mismatch in scale and resolution among data sets meant that more automated, quantitative approaches would require a reduction in information content in order to meet the specifications and assumptions of statistical modeling software. Second, missing indicator data and lack of detailed spatial information in a number of cases made it impossible for us to robustly employ hierarchical processes or formal optimization software such as Marxan. Most important, however, was the recognition, repeated consistently by resource managers and stakeholders alike, that they were leery of "black box" approaches that discounted the experiential knowledge of practitioners or removed resource specialists and the public from critical steps in the prioritization. Furthermore, because the GGCLA landscape prioritization is intended to provide novel insight into those areas of this complex landscape that are most in need of management attention, rather than to determine specific actions to be undertaken in explicit locations, the benefits of traditional objective, quantitative methods were less central and less meaningful for our purpose.

In an effort to emphasize the value of this approach while acknowledging the limitations imposed by sometimes compromised data sets and our inability to implement a more quantitative spatial prioritization, we generated linear combinations of stakeholder-identified variables, as outlined above, using unweighted variables, as well as several permutations of the stakeholder weighting schemes that emerged from Workshop 2. In all cases, differences at the scale of our area of analysis were inconsequential, and when "zooming in" to areas showing greater variation, patterns were finely differentiated, at the scale of individual pixels or land areas of a few dozen acres or less. In general, we did not think that the differences warranted the presentation of multiple sets of results, and for the reasons given above we selected the prioritization that was directly informed by stakeholder guidance, recommendations from subject matter experts, and the judgment of our team of analysts.

By explicitly incorporating stakeholder input at multiple stages in this process, including the development of weighting factors (Table 8, 9), we were able to bring existing quantitative and qualitative information together in a spatial prioritization effort that added value by integrating diverse and disparate data sources into a unified framework, while engaging stakeholders. This interdisciplinary effort generated good will and the social capital that, if valued and cultivated, will prove invaluable when implementing management decisions in the future.

Table 8. Prioritization of resource values developed from stakeholder input during the Workshop 2. Guidance was interpreted and modified in light of data availability and further refinement of spatial data layers representing focal resources. The scales for some resources, as represented in Chapter 5, were inverted in order to capture the intent of the stakeholder group. For example, the inverse of ecological integrity is used to represent the degree of human modification, a stressor across the landscape. Likewise, the proximity to trails was used to represent the gradient of visitor impacts below the rim.

Location	Values	Inverted Scale?	Relative Weight
Above the Rim	Biorichness	no	5
	Spring Density	no	5
	Cultural Landscapes	no	5
	Mule Deer Connectivity	no	3
	Mountain Lion	no	2
	Night Sky	no	1
Below the Rim	Biorichness	no	5
	Spring Density	no	5
	Cultural Landscapes	no	5
	Bighorn	no	2
	Mountain Lion	no	2
	Wilderness Character	no	2
	Night Sky	no	1

Table 9. Prioritization of resource stessors developed from stakeholder input during the Workshop 2. Guidance was interpreted and modified in light of data availability and further refinement of spatial data layers representing focal resources. The scales for some resources, as represented in Chapter 5, were inverted in order to capture the intent of the stakeholder group. For example, the inverse of ecological integrity is used to represent the degree of human modification, a stressor across the landscape. Likewise, the proximity to trails was used to represent the gradient of visitor impacts below the rim.

Location	Stressors	Inverted Scale	Relative Weight
Above the Rim	Climate Change	no	5
	Ecological Integrity	yes	5
	Overflights	no	2
	Fire Behavior	no	2
Below the Rim	Ecological Integrity	yes	5
	Soundscape	no	2
	Distance from trails	yes	2

4.5. Areas In Need of Management Attention

While implementing the GGCLA participatory prioritization approach in an iterative process that refined both data inputs and analytical approaches, we identified priority areas for management attention independently for areas above and below the canyon rim. Stakeholders felt that within these two regions, different resources represented the broadly held values that should drive prioritization. Similarly, perceived stressors differed somewhat above and below the rim. In these distinct regions of the GGCLA area of analysis, we conducted separate analyses, combined them, and overlaid stressors to identify priorities. Below we present the results, discuss patterns, and touch on the driving variables for each.

4.5.1. Above the Rim

High-value areas above the rim included virtually the entire Kaibab Plateau, the south rim, and adjacent areas of the Tusayan Ranger District of the Coconino National Forest. The entirety of the Havasu Creek watershed, most prominently its upper reaches, also emerged as a large high-value area, as did the Shivwits Plateau and much of the Parashant Wash drainage in western Grand Canyon. Other hotspots include the higher-elevation areas of the Mohawk Canyon and Whitmore Wash drainages on the north rim and the upper reaches of Bulrush Wash, including much of the Kaibab Paiute Reservation. Portions of upper House Rock Valley and the Vermilion Cliffs also emerged with high value in the stakeholder-informed prioritization process.

Stressors showed a different spatial pattern. There was notable overlap with values on the south rim, in dispersed areas on the Kaibab Plateau, on the Shivwits Plateau and portions of the Parashant, the Mohawk-Whitmore area, and in the area of the Kaibab Paiute Reservation. Additional areas where stressors were perceived to be high included the upper reaches of the Spencer canyon, Grapevine Wash, and Snap Canyon drainages running into the western Grand Canyon, along the East Kaibab Monocline, and in and around canyons draining south and west into upper Marble Canyon.

The overlay of values and risks produced a textured map of priority areas, with areas of overlap between high value and high risk predictably emerging as top priorities. In Figure 26, areas above the rim are grouped into four equal quartiles to clearly illustrate how intermediate priorities emerge based on specific combinations of values and stressors. Much of the Havasu Creek watershed emerges as moderately high priority, due to high value and intermediate stress, and certain portions of the Spencer Canyon watershed receive high priority due to extreme stress and despite moderate value. Conversely, high-value areas in the upper reaches of the Havasu-Cataract watershed show high priority, due to very high perceived value, despite low stressors. These few examples demonstrate how priority maps, when developed through a transparent process that generates intermediate products, such as the value and stressor maps presented here, allow the user to explore the data underlying each priority area.

By examining patterns in the individual layers and the data sources that inform them, managers, decision makers, and the public can “drill down” to each pixel, park management unit, or watershed to determine the drivers of patterns. By moving between foundational data sets, their spatial representation, the aggregation of multiple values and stressors, and ultimately the overlays that identify priorities, a more complete appreciation of the relationship between objective resource data

and subjective stakeholder values emerges, and the multifaceted nature of landscape prioritization can be appropriately interpreted, applied, and communicated to a broader public.

4.5.2. Below the Rim

Biorichness and spring density led to a focus on the eastern Grand Canyon with respect to values below the canyon rim. From Nankoweap to Kanab Creek, the majority of the inner canyon emerged as high priority, with the steep-sided canyons draining the south rim particularly consistent in their top rankings. Mohawk and Whitmore Canyons on the north side of the Colorado River, and Diamond Creek, Lower Havasu, and Spencer Canyon on the south also were among the highest priorities. The highest reaches of the largest canyon below the rim were ranked relatively low, however, in contrast to the upper portions of several of the same drainages, which had high value in the above-the-rim prioritizations.

Stressors also ranked high in the eastern canyon, where human modification (as represented by the inverse of ecological integrity) and stress on the acoustic environment were elevated. Cataract Canyon, the Granite Park–Prospect Valley area, and the extreme western canyon also showed high levels of stressors, whereas the central portion of the canyon, where human modification values were low, ranked at the bottom for stressors. Of all the prioritization results, this map of below-the-rim stressors may be most in need of deeper examination. Although well-documented patterns in biorichness illustrate marked differences between the eastern and western portions of the canyon, the sharp geographic differentiation in stressors is more difficult to explain. This could be in part the result of biases in a relatively sparse data base. If this is the case and influential data gaps are present, recognition of this could guide important future data collection.

Overlaying below-the-rim values and stressors preserved some of the patterns observed for stressors in the eastern part of the canyon, while inclusion of values moderated the rankings in the central and western portions of the area of analysis. In general, stakeholder priorities above and below the rim showed general correspondence, with a few sharp contrasts along edges where images were combined. This correspondence suggests that stakeholder-informed approaches for capturing general patterns in values and stressors converged, and therefore likely represent robust patterns manifest in the differently tailored approaches described in Tables 8 and 9.

4.6. Prioritization of Areas for Management Attention

We combined the images from Figures 26 and 27 to produce a single map of priorities across the entire GGCLA area of analysis. Data informing this final prioritization map (Figure 28) are rescaled to continuous values between 0 and 1, which are visualized in 10 equal quantiles in Figure 28 to differentiate priorities to a greater degree than presented in the preceding figures. Overall, patterns reinforce the large area of high priorities seen in intermediate maps across the Kaibab Plateau, in the central portion of eastern Grand Canyon, and on the south rim and northern portion of the Tusayan Ranger District. The identification of this large and continuous priority area is driven by several factors, including underlying but more subtle patterns in biorichness and wildlife habitat, elevated fire hazard in forested regions, and the concentration of aircraft overflights above certain sections of the canyon. Considerable variation is evident within this large area, with certain drainages, particularly those draining the south rim, emerging as more vulnerable than others. Combining maps

from above and below the rim emphasizes the strong patterns highlighting the Shivwits Plateau and Parashant watershed, and the upper Mohawk-Whitmore drainages. The upper, forested regions of several of the largest watersheds, including Havasu and Kanab Creeks in particular, emerge as areas deserving management attention. Somewhat surprisingly, large areas in the higher elevations of the southwestern portion of the area of analysis also rank highly.

Although our analysis does not directly link processes in the upper watersheds to their influence in downstream areas, results from this participatory mapping process show the importance of prioritizing upstream areas, where fire and other stressors may increase vulnerability of high-value areas in the inner canyon. Such awareness is already widespread, but the GGCLA prioritization is the first effort to identify which watersheds are most at risk (see Table 10), and to illustrate where the highest-value downstream areas are vulnerable to upstream areas facing multiple stressors. This increased understanding of the integrated geography of values and risks can provide valuable information to decision makers when selecting which of many upland areas should receive the attention of restoration ecologists, and which downstream areas might need additional protections or increased planning for mitigation or emergency efforts to safeguard at-risk species or unique cultural resources, based on their vulnerability to upstream stressors.

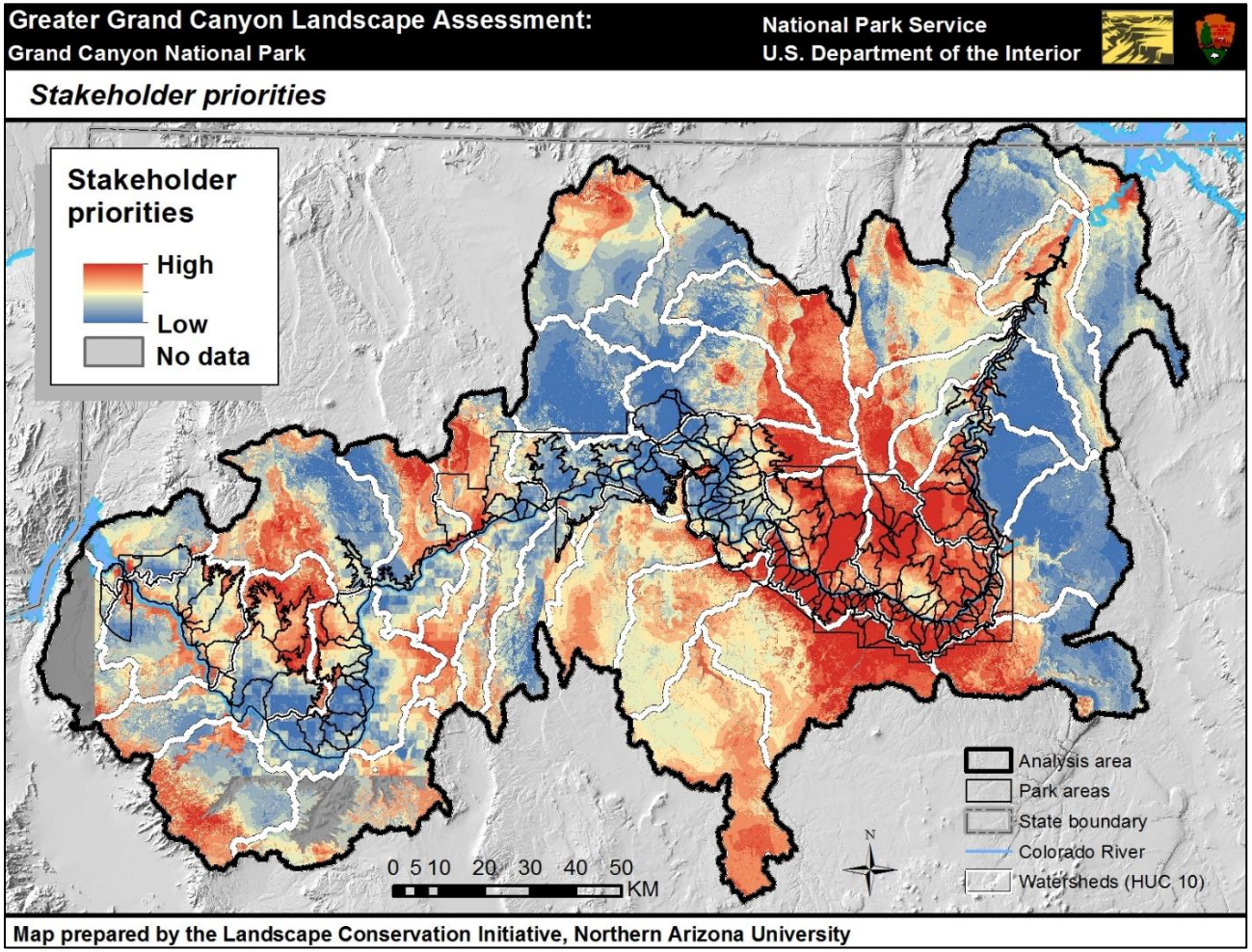


Figure 28. Final management priorities for the GGCLA analysis area are the combination of independently derived priorities for above and below the rim, combined in a single map image. Values are scaled from low (blue) to high (red), in 10 equal quantiles. Gray (no data) indicates areas where one or more stakeholder-identified data layers contained gaps that precluded unbiased analysis. Interpretation of this map should focus on broad geographic trends. Where results call attention to fine-scaled detail, consulting intermediate map products showing aggregated values and stressors (Figures 2 and 24) and maps of individual resources (Chapter 5) will provide insight into the drivers of observed patterns in the distribution of collaboratively derived priorities. See text for additional details and interpretation (Landscape Conservation Initiative).

Table 10. Prioritization of the 34 HUC 10 watersheds in the GGCLA. Areas and proportions of each watershed are presented in acres. CR = Colorado River.

Watershed	Total Area	Area Above Rim	Area Below Rim	Lower Priority (<50%)				Medium Priority (50–75%)				High Priority (75–90%)				Top Priority (Top 10%)			
				Above Rim Area	Above Rim Prop.	Below Rim Area	Below Rim Prop.	Above Rim Area	Above Rim Prop.	Below Rim Area	Below Rim Prop.	Above Rim Area	Above Rim Prop.	Below Rim Area	Below Rim Prop.	Above Rim Area	Above Rim Prop.	Below Rim Area	Below Rim Prop.
Water Holes Cnyn–CR	164,206	163,047	0	132,354	81.18	0	0.00	17,002	10.43	0	0.00	4,222	2.59	0	0.00	3,279	2.01	0	0.00
Lower Paria River	150,197	150,195	0	138,288	92.07	0	0.00	7,273	4.84	0	0.00	2,101	1.40	0	0.00	425	0.28	0	0.00
House Rock Wash	192,672	191,515	1,155	92,306	48.20	704	60.97	73,107	38.17	385	33.31	17,320	9.04	66	5.72	6,198	3.24	0	0.00
North Canyon Wash	100,749	99,918	827	43,202	43.24	158	19.14	15,387	15.40	604	73.04	22,823	22.84	65	7.82	18,327	18.34	0	0.00
Tanner Wash–CR	163,933	155,849	7,086	95,613	61.35	3,275	46.22	45,532	29.22	3,323	46.89	12,367	7.94	280	3.95	485	0.31	4	0.00
Shinumo Wash–CR	140,300	125,486	14,248	98,905	78.82	6,892	48.37	8,146	6.49	2,622	18.40	10,874	8.67	2,411	16.92	7,547	6.01	2,127	14.92
Tatahatso Wash–CR	153,184	85,006	66,545	72,387	85.16	4,362	6.55	4,560	5.36	8,738	13.13	3,933	4.63	31,612	47.50	4,066	4.78	21,340	32.07
Bright Angel Creek–CR	188,244	50,589	136,169	93	0.18	5,200	3.82	3,417	6.75	30,098	22.10	19,280	38.11	66,489	48.83	27,439	54.24	34,099	25.04
Shinumo Creek–CR	166,588	45,954	119,856	34	0.07	5,536	4.62	5,717	12.44	27,764	23.16	18,072	39.33	28,852	24.07	22,036	47.95	57,561	48.03
Tapeats Creek–CR	175,667	43,066	131,216	761	1.77	97,091	73.99	4,448	10.33	29,306	22.33	16,910	39.27	4,329	3.30	20,947	48.64	253	0.19
Albers Wash	107,530	83,530	23,998	55,720	66.71	20,684	86.19	22,751	27.24	3,156	13.15	2,645	3.17	129	0.54	14	0.02	28	0.12
Tuckup Canyon–CR	136,198	55,783	79,682	36,258	65.00	76,423	95.91	17,969	32.21	2,623	3.29	1,153	2.07	511	0.64	402	0.72	0	0.00
Prospect Valley	63,789	14,247	49,542	5,073	35.61	9,405	18.98	7,554	53.02	28,607	57.74	1,258	8.83	10,405	21.00	39	0.27	1,121	2.26
Mohawk Canyon–CR	200,313	110,149	89,452	49,795	45.21	49,876	55.76	40,991	37.21	27,837	31.12	11,934	10.83	8,858	9.90	5,486	4.98	2,820	3.15
Parashant Wash	230,612	170,877	59,728	84,242	49.30	54,772	91.70	43,954	25.72	4,618	7.73	37,782	22.11	331	0.55	2,456	1.44	0	0.00
Whitmore Wash–CR	158,739	53,015	104,572	27,891	52.61	64,892	62.05	10,546	19.89	30,597	29.26	7,847	14.80	7,467	7.14	5,632	10.62	1,554	1.49
Diamond Creek*	176,842	87,935	88,903	46,573	52.96	21,481	24.16	29,468	33.51	18,265	20.54	7,322	8.33	1,861	2.09	390	0.44	12	0.01
Granite Park Cnyn–CR	216,562	13,397	201,265	175	1.31	144,294	71.69	612	4.57	45,364	22.54	8,270	61.73	10,140	5.04	4,339	32.39	849	0.42
Bulrush Wash	185,369	185,155	213	121,081	65.39	213	100.00	42,683	23.05	0	0.00	14,021	7.57	0	0.00	4,027	2.18	0	0.00
Snake Gulch	179,137	168,269	10,869	51,247	30.46	10,602	97.55	37,061	22.02	231	2.12	52,917	31.45	34	0.31	26,159	15.55	1	0.01
Hack Canyon	135,304	122,742	12,562	120,743	98.37	12,549	99.90	989	0.81	10	0.08	49	0.04	0	0.00	0	0.00	0	0.00
Grama Cnyn–Kanab Crk	145,749	122,687	23,062	112,059	91.34	22,976	99.63	8,030	6.54	86	0.37	910	0.74	0	0.00	11	0.01	0	0.00
Jumpup Cnyn–Kanab Crk	147,422	92,570	54,846	49,124	53.07	52,322	95.40	15,806	17.07	1,716	3.13	17,477	18.88	805	1.47	10,161	10.98	1	0.00
Heather Wash	244,158	242,936	1,223	36,208	14.90	329	26.89	84,160	34.64	847	69.27	43,289	17.82	47	3.84	75,509	31.08	0	0.00
Upper Havasu Creek	228,612	223,046	5,567	45,069	20.21	320	5.74	132,133	59.24	2,099	37.70	39,064	17.51	3,125	56.14	798	0.36	23	0.42
Middle Havasu Creek	140,938	119,868	21,070	49,920	41.65	12,546	59.55	51,947	43.34	8,210	38.97	9,204	7.68	313	1.49	8,194	6.84	0	0.00
Lower Havasu Creek	176,904	124,800	52,103	28,070	22.49	31,513	60.48	83,209	66.67	19,779	37.96	9,590	7.68	755	1.45	2,435	1.95	54	0.10
Spencer Canyon*	170,552	129,902	40,643	69,591	53.57	14,556	35.81	18,184	14.00	6,312	15.53	33,714	25.95	5,998	14.76	6,083	4.68	363	0.89
Surprise Canyon–CR	227,130	107,006	119,384	36,666	34.27	76,409	64.00	18,236	17.04	31,118	26.07	35,012	32.72	11,275	9.44	15,991	14.94	483	0.40
Burnt Spring Cnyn–CR	178,164	61,853	112,828	47,078	76.11	47,923	42.47	7,086	11.46	47,484	42.09	6,475	10.47	16,201	14.36	984	1.59	1,121	0.99

* Portions of three watersheds could not be included in the prioritization, due to gaps in one or more input data layers. For these watersheds only, the area listed in each category is the actual area prioritized; the proportion listed is the area prioritized that falls within each category, rather than the total area of the watershed.

Table 10 (continued). Prioritization of the 34 HUC 10 watersheds in the GGCLA. Areas and proportions of each watershed are presented in acres. CR = Colorado River.

Watershed	Total Area	Area Above Rim	Area Below Rim	Lower Priority (<50%)				Medium Priority (50–75%)				High Priority (75–90%)				Top Priority (Top 10%)			
				Above Rim Area	Above Rim Prop.	Below Rim Area	Below Rim Prop.	Above Rim Area	Above Rim Prop.	Below Rim Area	Below Rim Prop.	Above Rim Area	Above Rim Prop.	Below Rim Area	Below Rim Prop.	Above Rim Area	Above Rim Prop.	Below Rim Area	Below Rim Prop.
Grapevine Wash*	109,864	105,543	4,321	19,288	18.27	3,652	84.52	7,788	7.38	669	15.48	2,072	1.96	0	0.00	536	0.51	0	0.00
Snap Canyon–CR	92,822	64,503	27,709	39,688	61.53	21,808	78.70	12,861	19.94	2,766	9.98	2,981	4.62	1,545	5.58	141	0.22	1,548	5.59
Lee Canyon–Little CR	181,402	172,620	8,782	84,742	49.09	7,426	84.56	28,749	16.65	209	2.38	25,519	14.78	41	0.47	28,364	16.43	1	0.02
Sheep Wash–Little CR	181,183	163,655	17,509	135,433	82.76	12,005	68.57	22,946	14.02	2,515	14.36	2,867	1.75	1,614	9.22	961	0.59	77	0.44

* Portions of three watersheds could not be included in the prioritization, due to gaps in one or more input data layers. For these watersheds only, the area listed in each category is the actual area prioritized; the proportion listed is the area prioritized that falls within each category, rather than the total area of the watershed.

4.6.1. Interpreting Priority Maps

The possible applications of results from the GGCLA prioritization are many. We hope that the brief discussion offered here, along with a few summary maps and tables, will illustrate the power derived from the participatory approach that integrates multiple sets of values and stressors to produce a synoptic view of shared priorities across the 5.2 million acres of analysis. It also serves as a starting point for increasingly deep and sophisticated collaboration among these many partners. Yet it is also possible to over-interpret these broad-brush perspectives. No prioritization effort across such a large area can capture everything of value, nor consider all stressors, nor represent the multitude of viewpoints that are evident in how humans experience and interact with the Grand Canyon, or any national park. Each subject matter expert holds greater depth and detail regarding the distribution, status, and trends of particular landscape features, yet no individual has the range of subject matter expertise and the social perspective to represent a cross section of viewpoints and resources in a manner that reflects current trends in a transparent and spatially explicit form, as illustrated here.

Decision makers, stakeholders, and the engaged public should keep in mind that there are many ways that the values and perceptions of stakeholders might be aggregated and conveyed; there are many resources that might be identified as central to gaining a valid perspective on the Grand Canyon region. Likewise, there are many analytical and cartographic methods that might be applied. Thus, these maps and table should be viewed as one viable, incisive, and instructive formulation of priorities across the area of analysis. Others are possible, and it is through the examination and comparison of different ideas and analyses that even greater insight will come. Yet in studying and interpreting the results presented here, it is useful to keep in mind that no similar effort has been undertaken previously. These results are new, novel in kind and in the inclusiveness and thoroughness of execution. They are informed by many voices and by a process of deliberation and collaboration that reflects different ways of knowing, valuing, and appreciating the Grand Canyon. And they provide a new, unique, and transparent way for land and resource managers to understand patterns at the landscape scale, while preserving the ability to dig down, below the surface of the maps, to see the resource data, cultural values, and public engagement that make the region one of the most unique and beloved public places in the world.

4.6.2. Priorities, Decisions, and Management in a Dynamic Landscape

The essential task of setting priorities is never complete because resources are forever changing and public values and perceptions race ahead of the myriad forces that drive changes on the ground. Thus, prioritization is a part of the dynamic and adaptive process of land and natural resource management (Holling 1978), wherein the deviation of current from desired conditions identifies the need for prompt action. One of the most valuable aspects of participatory analysis is its iterative nature, allowing elevated and informed dialog between experts and amateurs, across many technical subjects, and between those entrusted with critical decisions regarding invaluable public assets and those with little decision authority but a wealth of personal experience. This is where science has a highly practical role to play. Data sets have inherent value, but it is the quality of analysis, interpretation, and communication that determines the level of public deliberation and decision, and that gives data relevance in society (Sisk et al. 2006). The value of ambitious science and planning efforts, such as the RCA for Grand Canyon NP, is greatly enhanced by the participatory analysis that

engages the public in a deep deliberation about current conditions, management needs, and opportunities. The design of the stakeholder process at the heart of the GGCLA amplifies this value, while the analytical approach combines social and scientific processes in a way that invites continuing dialog.

The products presented in this chapter are an initial, minimal set derived from some of the most obvious and accessible analyses. Questions posed at multiple scales, from the park-unit scale to the entire region, can be undertaken with efficiency and ease in the future. New data, changing conditions, and novel perspectives on current and future objectives will continue to influence management of these lands and resources (Polasky et al. 2011). The flexible, transparent, and inclusive framework presented here is an appropriate and invaluable tool for grappling with the dynamic nature of issues affecting the Grand Canyon region. Public participation, clear priorities, and active exploration of contested land and resource issues are critical ingredients for developing sound policies that protect public values and public places in an uncertain future.

4.7. Literature Cited

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Chapter 5. Focal Resource Conditions

5.1. Introduction

Resource Condition Assessments evaluate existing data and report on the current conditions of a subset of important park resources, the factors influencing the conditions of those resources, and critical data and knowledge gaps about those resources. In this chapter, which describes the background and current condition of selected indicators for the GGCLA focal resources, current trends for these indicators are also described where data permit. Focal resource condition assessments are described first, followed by descriptions of the stressors for those resources.

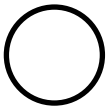
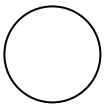
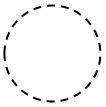
Focal resources, indicators, and stressors were identified during the stakeholder workshop and technical work groups described in Chapter 3. During the assessment process, those indicators were used when data were available. When they were not available, resource and analysis experts and Grand Canyon NP staff worked together to identify valid alternative indicators.

In each of the following assessments, a brief overview and background for each resource serves to orient readers from a variety of technical backgrounds to the importance of the focal resource or stressor in the GGCLA. Methods for assessing the current condition and trend of each indicator are described, and when data permit, a spatial assessment of current condition is performed. These assessments include output maps and a brief summary of condition by land ownership.

For the majority of assessments, current condition and trend relative to a reference framework is provided for each assessment in table format. The tables include a list of indicators, a description of the reference framework used to identify condition and trend for that indicator, and a brief summary of the condition and trend. Colored circles indicate current condition, arrows indicate trend, and circle perimeter weight indicates level of confidence (Table 11).

Each resource assessment also includes a summary of the condition and trend, a list of identified data needs, and a description of the overall level of confidence. And finally, a master list of data needs, compiled from the full set of resource assessments, is accessible via Appendix C: Data and Research Needs.

Table 11. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

Condition Status		Trend in Condition		Confidence in Assessment	
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low
No Color*	Current Condition is Unknown or Indeterminate	No Arrow	Trend in Condition is Unknown or Not Applicable	–	–

* An open (uncolored) circle indicates that current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment; this condition status is typically associated with unknown trend and low confidence.

5.2. Ethnographic Value of GGCLA Focal Resources

One distinctive aspect of the GGCLA is its focus on involving stakeholders in the resource analysis process. Traditionally associated tribes represent a significant category of stakeholders for the GGCLA analysis area. The physical, natural, and cultural resources of the Grand Canyon are highly valued by these tribes. Although different tribes may have different cultural perceptions of the resources in the canyon, they all feel strongly that the Grand Canyon should be conserved in its entirety. This not only is reflected in the available literature, but also was evident during our conversations with members of various tribes and in discussions during the GGCLA Cultural Technical Work Group meeting. This means that most, if not all, natural resources in the GGCLA analysis area have cultural value and meaning for traditionally associated tribes.

5.2.1. Methods

In gathering the information about the ethnographic value of GGCLA focal resources for the traditionally associated tribes, we consulted the following tribal representatives and Grand Canyon NP specialists: Timothy Begay, Navajo Nation Historic Preservation Department; Ellen Brennan, Cultural Resource Program Manager, Grand Canyon NP; Charley Bulletts, Director of Cultural Resources, Kaibab Band of Paiute Indians; Peter Bungart, Senior Archaeologist, the Hualapai Tribe; Janet Cohen, Tribal Program Manager, Grand Canyon NP; Jennifer Dierker, Archaeologist, Grand Canyon NP; Leigh Kuwanwisiwma, Cultural Preservation Office, the Hopi Tribe; and Terry Morgart, Cultural Preservation Office, the Hopi Tribe.

We also consulted the available literature recommended by tribal representatives and Grand Canyon NP staff. Some of the documents were not publically available and permission was granted for use of the information for this report by the tribal representatives. Other documents were obtained through online searches.

Eleven tribes are considered traditionally associated with the Grand Canyon; however, in this report we have only included information gathered about the values of the four tribes that actively participated in the GGCLA project: the Hopi Tribe, the Hualapai Tribe, the Navajo Nation, and the Kaibab Paiute Band of Indians.

5.2.2. Tribal Perspectives on Grand Canyon Physical, Natural, and Cultural Resources

The natural resources of the Grand Canyon region are highly valued in tribal culture. For example, the cultural significance for the Hopi people is derived from the perceived inherent value of water, minerals, plants, and animals, as well as Hopi use of specific resources. The Hopi people believe they have a spiritual obligation to nurture all living things in the Grand Canyon. For them, plants are imbued with cultural and spiritual value and animals are like people because they are the offspring of the goddess Tikuoi Wutis and Masao, the earth god. The Hopi people continue to gather animal, plant, and mineral resources in and around Grand Canyon for food, medicinal, and ceremonial purposes (Ferguson 1998).

The biological and cultural resources of the Grand Canyon are also integral to the culture of the Hualapai Tribe. All physical elements in the canyon—including the water, air, rocks, plants, insects, fish, and wildlife—are believed to have powers of observation and awareness. The tribe attaches high

importance to protecting and enhancing these resources. The Hualapai people continue to collect animal, plant, and mineral resources in and around Grand Canyon for food, medicinal, and ceremonial purposes (Jackson-Kelly et al. 2013).

Southern Paiutes believe that they were created in the traditional lands around Grand Canyon and that the Creator gave them the responsibility to care for the land and its resources. The Southern Paiute understand that all natural resources, plants, animals, soil, minerals, and water, have been "placed on this land with the breath of life, just as humans" (Stoffle et al. 1995), and that each has a purpose in life and interacts with all other living things. They should therefore be protected from contamination, alteration, and movement (Stoffle et al. 1994), and must be shown respect, especially if they are to be disturbed. The Southern Paiute people continue to gather animals, plants, and mineral resources from in and around Grand Canyon for food, medicinal, and ceremonial purposes.

The Navajo also believe that the natural world, spirituality and history together form the basis of life (Roberts et al. 1995). The Navajo people continue to gather animals, plants, and mineral resources in and around the Grand Canyon for food, medicinal, and ceremonial purposes.

5.2.3. Ethnographic Value of GGCLA Focal Resources

Ethnographic information about the value of GGCLA focal resources was not identified for all resources. In some cases we found general information about these resources, and this is presented where applicable. In some cases we are able to present information specific to the four traditionally associated tribes. Much of the following information comes from the Grand Canyon NP ethnographic database.

Category 1: Landscape

Fire

American Indian tribes have historically used fire as a tool to improve game habitat and conditions for plant growth. Periodic ground fire also removed accumulated debris from the forest floor, reducing the potential for destructive crown fire (Lewis 1995). Navajos have traditionally burned ricegrass to release the seeds, but in early efforts to manage forests for timber resources, the BIA and the U.S. Forest Service outlawed the use of Indian-set fires (Lewis 1995).

Biorichness

American Indian tribes value the diversity of all native plant and animal life in the Grand Canyon and believe it should be protected and preserved.

Ecosystem integrity

The Hopi believe that all physical resources and processes are interdependent and have symbiotic relationships. In the Hopi world view, six fundamental entities need conservation: minerals, geographical features and landscapes, all wild plant life, animals, water in springs, ponds, rivers and streams, and the process of continued renewal or rejuvenation of life, which also refers to Hopi traditional cultivated crops. Other tribes hold the similar belief that all physical resources interact and are interdependent.

Category 2: Vegetation

Plants play an important role in the lives of tribes associated with the Grand Canyon. The Hopi have four main classes of use for plants: clan totem and religious use, medicinal use, wild and domesticated foodstuffs, and utilitarian use. Ninety plants in the Grand Canyon are associated with clan totems and religious use. The Hopi seek to protect plants and promote plant growth for human as well as animal use (Lomaomvaya et al. 2001).

Plants have been widely used by the Southern Paiute peoples for centuries, and 68 plants continue to be utilized for food, medicine, ceremonies, and economic activity. Prayers are directed to plants because the plant is perceived as an anthropomorphic entity. Southern Paiute children continue to be taught about the traditional use of these plants (Stoffle et al. 1994).

Riparian communities

Because riparian plants are associated with water, they have powerful symbolic value in the Hopi religion (Lomaomvaya et al. 2001). Plants of the riparian ecozone have the highest cultural significance for the Southern Paiute (Stoffle et al. 1994).

Rare and endemic plant species

Hopis believe that they have a spiritual obligation to care for native plants, whether or not they use them. Hopis want to maintain the cultural values and knowledge about plants in the Grand Canyon for the benefit of Hopi generations to come. They express concern about the welfare of rare species (Lomaomvaya et al. 2001).

Desert scrub

The Hopi use desert plants in religious life, for medicines, and for food and utilitarian items (Lomaomvaya et al. 2001).

Category 3: Wildlife

As with plants, all wildlife has importance for traditionally associated tribes of the Grand Canyon area. The Hopi view all wildlife—animals, birds, and insects—as children of the earth and consider them as brothers and sisters. The Hopi have great respect for their abilities and their prowess (Lomaomvaya et al. 2001).

The Southern Paiutes traditionally believe that all wildlife species, including insects, are important to the earth. They show respect for animals by saying traditional prayers when hunting and taking the life of an animal. Animals are attributed with rights and human qualities and are viewed as relatives of humans (Stoffle et al. 1994).

Mountain lions

Mountain lions were hunted by American Indian tribes and used for food, as well as for mats, blankets, and rugs.

Bighorn sheep

Bighorn sheep were hunted, and other uses include food, religious ceremonies, medicine, and utilitarian applications. For the Hopi, bighorn sheep are associated with a clan, petroglyphs, and a

shrine, as well as a food source. They are important to the Hualapai, both economically and spiritually. Bighorn sheep and their habitat are protected on the Navajo Nation, where they have traditionally been used for food, clothing, medicine, and ceremonial purposes (Cole n.d.). The Southern Paiute hunted bighorn sheep throughout the year for food and for their horns, which they used as spoons.

Mule deer

The Hopi, Hualapai, Navajo, and Southern Paiute all hunt mule deer for food and for buckskins (Ferguson 1998). The Southern Paiute portrayed mule deer in petroglyphs and lined willow baby baskets with buckskin (Stoffle et al. 1994).

Eagle

Eagles are extremely important to the Hopi and considered sacred. They are important in Navajo oral tradition and history. Southern Paiutes consider all birds as important and pray to the birds when they are captured (Stoffle et al. 1994).

Condors

The Hopis, who are concerned about all endangered species, support condor reintroduction as long as it does not affect eagle populations (Lomaomvaya et al. 2001).

Mexican spotted owl

In general, owls are important to the Hopi, Hualapai, and Navajo. For the Hopi, owls represent a clan and are important for ceremonial use and in oral tradition and history.

Goshawks

Goshawks were selected as an important resource by stakeholders in our engagement process. They are important to the tribes, as are all wildlife and plants.

River avifauna

For the Hopi, many river avifauna, such as yellow warblers, canyon wrens, hummingbirds, and mourning doves, are important as representing Hopi clans, in oral tradition and history, and for ceremonial use.

Category 4: Fisheries

Native fish species

Native fish were eaten by the Hopi and were important symbolically and religiously. Hopis, especially the Water Clan, are particularly concerned about the welfare of the humpback chub. The Navajo are also concerned about the humpback chub, both as a resource within their lands and for how it may affect their ability to develop their land. It is important for the Southern Paiute to maintain traditional fishing, which includes the humpback chub, for religious and food purposes.

Category 5: Physical resources

Caves

Caves in the Grand Canyon are fertile sources of archaeological and other resources and are important for traditionally associated tribes.

Springs and seeps

Water is a precious resource for all the tribes. Springs are seen as a blessing to the Hopi, who believe that springs have a spiritual life. The Hopi collect water from Vasey Spring for ceremonial use (Ferguson 1998). Vasey Spring is also important to the Navajo. Pumpkin Spring is used for purification by the Southern Paiute, who believed that "Water Babies" were often present at the springs and were responsible for an extensive underground connection between springs. Water Babies are believed to be very dangerous if angered by actions that compromise springs (Stoffle et al. 1994).

Category 6: Cultural resources

Archaeological resources

Archaeological resources are addressed in detail in the Ch. 5 Resource Condition Assessment

Ethnographic resources

Ethnographic resources are addressed in detail in the Ch. 5 Resource Condition Assessment

Category 7: Visitor experience

Recreational resources

Tribes are concerned about the effects of recreational use on cultural and archaeological sites. The Southern Paiute have been concerned about the effects of visitor use on places like Deer Creek, a place that is considered sacred and that was critical to the tribe's survival when Euro-Americans encroached upon their homeland and forced them out. Visitor impacts include deterioration of the riverbank, trailing and trampling of plants, and damage to cliffs from rappelling activity.

Natural acoustics

The natural acoustic environment includes all the natural sounds that occur in the park. Noise from overflights and recreational activity can affect the "feeling" of an important site, and therefore the condition of that site (National Park Service 2006). The Southern Paiutes believe that songs are derived by spiritual guidance in the canyon and on the river and that certain places in the canyon give songs to a person who is receptive to hearing them (Stoffle et al 1995, p. 16).

For the Southern Paiutes there are two categories of natural acoustic environment. The first is connected to specific trails that the tribe uses for carrying messages and goods. Songs help the runner to traverse complex trails by providing landmarks and directions for the routes. The second category connects songs to the trail to the afterlife. Songs sung at a funeral guide the deceased to the afterlife.

Daytime viewshed

Geologic features, including mountains and buttes, are related to tribal beliefs about their origins and traditions. It is important for tribal peoples to be able to see important places on the landscape—to preserve viewsheds without human construction. Air pollution would be considered disturbance for daytime viewsheds.

Night skies

Dark night skies are important for the Kaibab Paiute Band of Indians, and are the focus of oral traditions and Paiute legends (personal communication with C. Bulletts, 5 December 2014).

Wilderness

The U.S. government defines wilderness as lacking humans, “an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain” (Wilderness Act of 1964). This definition resulted in the removal of American Indian peoples from their traditional lands in national parks and is at odds with the American Indian concept of nature as an inhabited world (Stoffle et al. 1977).

5.3. Focal Resource Condition Descriptions

The remainder of Chapter 5 reports on the condition and trend of seven categories of resources in the GGCLA area. Landscape-scale stressors to those resources are also reported in Category 8. Resource condition is often reported by watershed (Figure 29). Contents of the remainder of this chapter are as follows:

Category 1: Landscapes

- 5.5. Biorichness
- 5.6. Ecological Integrity
- 5.7. Fire

Category 2: Vegetation

- 5.8. Riparian Communities
- 5.9. Rare and Endemic Plant Species

Category 3: Wildlife

- 5.10. Mountain Lion
- 5.11. Desert Bighorn Sheep
- 5.12. Mule Deer
- 5.13. Eagle
- 5.14. California Condor
- 5.15. Mexican Spotted Owl
- 5.16. Northern Goshawk
- 5.17. River Avifauna
- 5.18. Northern Leopard Frog
- 5.19. Invertebrates

Category 4: Fisheries

- 5.20. Native Fish

Category 5: Physical Resources

- 5.21. Caves
- 5.22. Seeps and springs

Category 6: Cultural Resources

- 5.23. Cultural Resources
- 5.24. Archaeological Resources
- 5.25. Ethnographic Resources

Category 7: Visitor Experience

- 5.26. Daytime Viewshed
- 5.27. Natural Acoustic Environment
- 5.28. Night Sky
- 5.29. Recreational Resources
- 5.30. Wilderness Character

Category 8: Stressors

5.31. Altered Hydrologic Regime
5.32. Climate Change
5.33. Development
5.34. Ungulates: Introduced Species and Expanding Ranges
5.35. Exotic Plants
5.36. Groundwater Withdrawal
5.37. Overflights
5.38. Resource Extraction
5.39. User Impacts

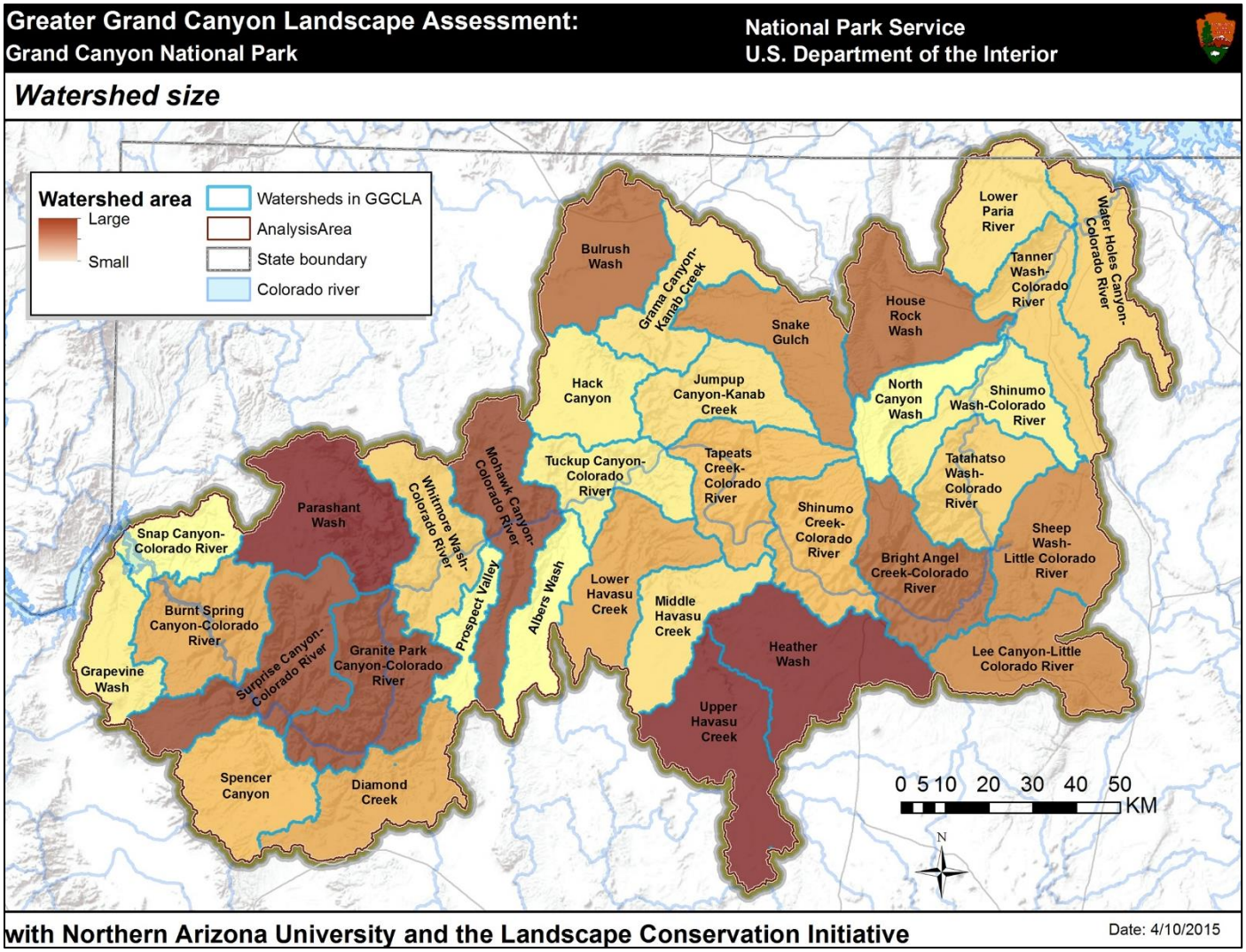


Figure 29. Throughout Chapter 5, Resource Condition Assessments refer to specific watersheds where resource condition was of a certain value. This map is provided as a reference for reading the remainder of Chapter 5 (Landscape Conservation Initiative).

5.4. Literature Cited

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5.5. Landscape: Biorichness

5.5.1. Description



Immense topographic and elevational diversity generates high vegetation community richness, contributing to zones of exceptionally high biorichness in the analysis area. Drought conditions and future climate change may limit productivity and reduce surface water availability, impacting that richness (NPS Photo).

The immense topographic and elevational diversity within the Grand Canyon contributes to its high number of taxa, also known as biorichness, which incorporates both taxonomic richness and diversity of ecological communities. Grand Canyon NP hosts more than 1,750 vascular plant species, 167 fungi species, 155 bryophyte taxa, 195 lichen species, and 8,480 invertebrate species, as well as 7 known endemic plant species. Documented vertebrates include 92 mammal, 366 bird, and 61 herpetofaunal species (L. Makarick and G. Holm, personal communication, 2015).

Although these numbers are a good indication of the remarkable biorichness in the region, the lack of comprehensive inventories both within the park and beyond its borders precludes the use of comprehensive numbers of taxa to assess biorichness patterns across the GGCLA area. We therefore developed a biorichness potential index to fill this gap, using known indicators of biorichness to estimate spatial patterns of taxonomic richness. In Figure 30, dark green represents the highest potential biorichness, obtained this index. These areas are prominent below the rim, just to the east of Grand Canyon Village; north of the park between the Vermilion Cliffs and Hwy 67; and near the western edge of the park near Toroweap and within the Hualapai Indian Reservation.

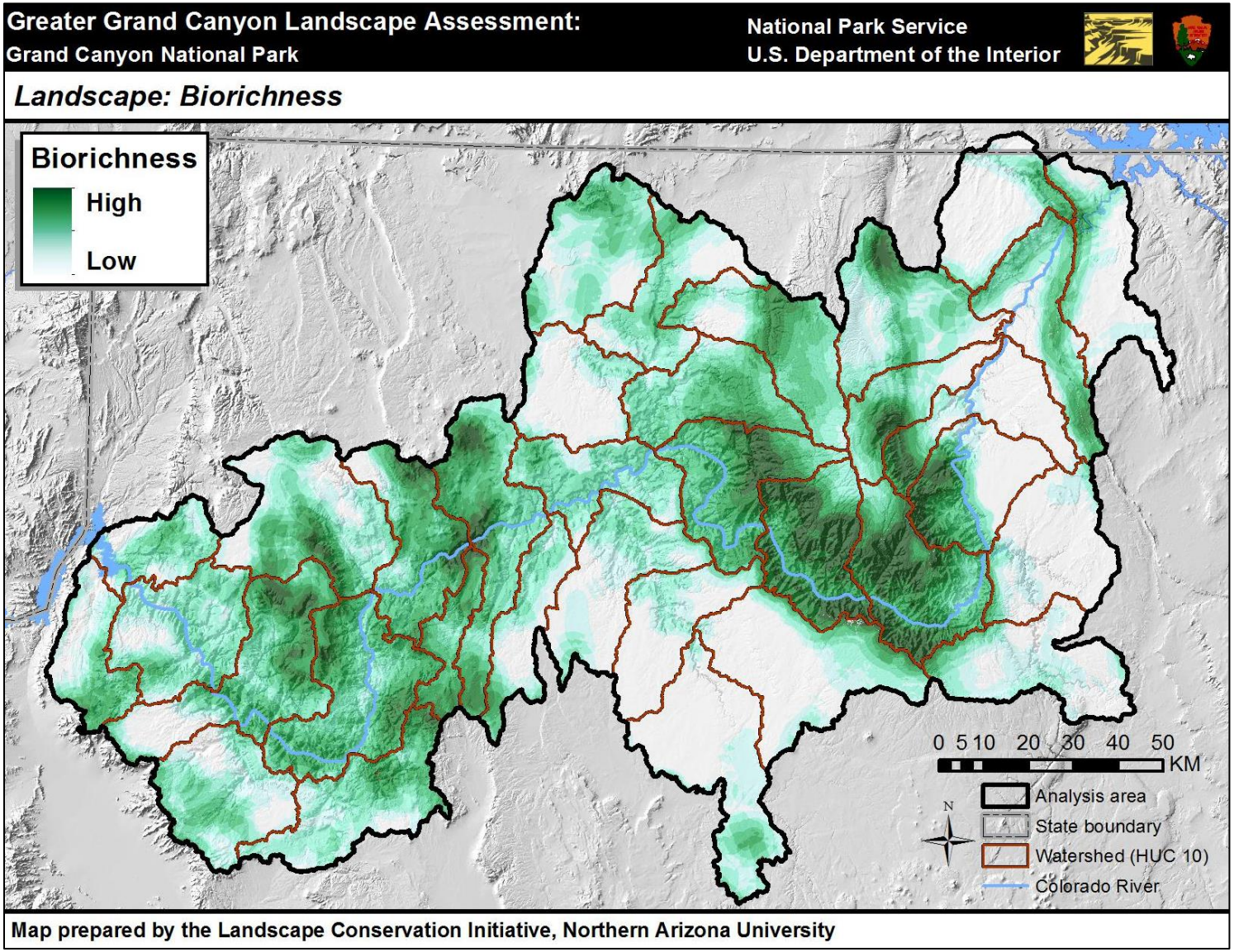


Figure 30. Areas within the GGCLA area predicted to have high biorichness.

5.5.2. Indicators/Measures

- Geophysical diversity
- Surface water availability
- Vegetation community diversity
- Net primary productivity

5.5.3. Methods

To develop the biorichness potential index, we identified the following indicators: the variety of geologic parent material types present (Anderson and Ferree 2010), net primary productivity (Gaston 2000), surface water availability (Naiman and Décamps 1997), and number of vegetation community types. We developed a mean biorichness index by summing the values of four biorichness indicators (see Table 12) at each of three spatial scales (10, 50, and 100 km^2), then calculating the average biorichness index value across the three spatial scales of analysis. For each indicator, we calculated a focal statistic based on a circular moving window corresponding to the size of the scale of analysis. We reclassified the results for each indicator at each scale of analysis into five quantiles and calculated the biorichness index as the sum of quantile values (1–5) of the four indicators at a given scale of analysis. We then derived the mean biorichness index by averaging the biorichness index across the three scales of analysis. The result of these calculations is the identification of locations across the landscape with the potential to have high biorichness (Figure 30).

The rationale for choosing these indicators and the data sources chosen to represent them are described below.

Geophysical Diversity

This indicator is based on recent evidence that geophysical characteristics, including diversity of geologic classes, elevational range, and quantity of calcareous bedrock, are very strong predictors of plant species diversity (Anderson and Ferree 2010). The number of unique parent material types was therefore integrated into the index as a measure of geophysical diversity. Data source: USGS Lithology (1:5,000,000; Soller et al. 2009).

Surface Water Availability

In arid regions, the presence of surface water and surrounding ecosystems (i.e., riparian communities) represents sudden and dramatic shifts in biotic communities (Naiman and Décamps 1997), manifested in ecotones. The presence of surface water in the analysis area is indicative of a change in ecological community and thus increased biorichness across the upland-riparian gradient. This indicator was included in the biorichness index as $(\sqrt{A})/\sqrt{(d')}$ where A is the total area of water features and d' is the average cost distance (based on slope) of any given pixel to the nearest water feature. Data source: USGS National Hydrography Dataset (1:24,000; USGS 2008).

Vegetation Community Diversity

The change in vegetation community over spatial scales is by definition a direct indicator of regional species diversity. Vegetation communities are defined by a combination of dominant species and

elevation, and a transition between community types indicates a transition in both rare and dominant species. Therefore, a higher number of vegetation community types in the same spatial area is indicative of a greater number of plant species. Plant communities exert strong influence on animal species assemblages, so richness of non-plant species changes along with plant communities. This indicator was integrated as a direct count of unique existing vegetation types (equivalent to NVCS group level). Data source: Landfire v1.2.0 (30 m; U.S. Geological Survey 2013).

Net Primary Productivity

Net primary productivity, or NPP, varies with biorichness (Costanza et al. 2007) to varying degrees, depending on the focal system. It is considered a standard component of biorichness models because NPP is an indicator of energy received by the system and therefore of rate of biological processes, for example, rate of plant growth and consumption and rate of nutrient flow through the system (Gaston 2000). This indicator was incorporated into the index as the mean of the 10-year average (2002–2011) maximum Normalized Difference Vegetation Index (NDVI). Data from eMODIS; USGS Earth Resources Observation and Science Center (250 m; USGS 2014).

5.5.4. Condition and Trend

Table 12. Summary of biorichness condition and trend by indicator.

Indicator	Reference Framework	Relative Condition	Summary Comments
Geophysical diversity	Comparison with other systems in the region.		This indicator remains constant over time.
Surface water availability	Projections for surface water availability in the future, relative to the past.		Drought years have reduced surface water availability, and climate change projections coupled with increasing groundwater pumping demand suggest reduced surface water in the future.
Vegetation community diversity	Comparison with vegetation/ substrate relationships across the region.		Extreme topographic diversity in the GGCLA promotes vegetation type diversity.
Net primary productivity	Comparison with previous NDVI and projected future conditions in the analysis area.		Drought years have reduced NDVI over recent decades and will likely continue to do so.

5.5.5. Summary

Our index of biorichness resulted in a continuous biorichness potential surface across the analysis area. To obtain spatial summary statistics of this surface, we examined the full range of output values

and identified natural breaks in these data, using these breaks to divide the results into 10 biorichness levels (Table 13). This approach enabled us to identify regions likely to display high biorichness across the GGCLA area. Just 4.4% of the land area emerges as the highest category of biorichness (i.e., displayed as darkest green in Figure 30). The two top categories together account for 11% of the area. Lowest biorichness areas, most of which are located in the relatively flat lands south of the canyon, account for another 4% of the land area. Total land area per biorichness category is summarized by hectares and percentages in Table 13.

Table 13. Biorichness levels for the GGCLA area.

	Biorichness Level									
Land Area	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Hectares (in thousands)	90.4	169.9	251.3	308.6	328.9	357.0	296.3	208.7	148.4	99.5
Percentages	4.0	7.5	11.1	13.7	14.6	15.8	13.1	9.2	6.6	4.4

Spatially across the analysis area, biorichness can be assessed using HUC 10 watersheds, 34 of which occur in the analysis area. Zones with the highest average biorichness, or index values above 8, include zones 10 (Shinumo Creek–Colorado River), 15 (Mohawk Canyon–Colorado River), and 9 (Bright Angel Creek–Colorado River). Zones with the lowest average biorichness, or index values below 3.5, include zones 3 (Lower Paria River), 1 (Water Holes Canyon–Colorado River), 22 (Hack Canyon), and 27 (Middle Havasu Creek).

Different jurisdictions across the analysis area display a range of mean biorichness values, as assessed using the index (Figure 31). Highest average biorichness (mean index value of 7.3 ± 1.8) occurs in Grand Canyon NP. Relevant to current biorichness trends, 18 vertebrate species are currently considered special status or threatened by federal, state, or tribal listings. The presence of such at-risk species demonstrates the need for concern over both future declines and the continued existence of habitat types and connectivity that have become rare elsewhere.

Stressors likely to impact biorichness in the analysis area include riparian area disturbance via groundwater development and Colorado River water management; uranium mining; invasive plants and animals and grazing on lands outside the park; and climate change resulting in reduced snowpack and reduced Colorado River flows, diminishing surface water and net primary productivity. The impact of these stressors on biorichness will need to be carefully monitored over time so that the need for mitigation, adaptation, and/or restoration can be identified before critical or irreversible changes occur (National Parks Conservation Association 2010).

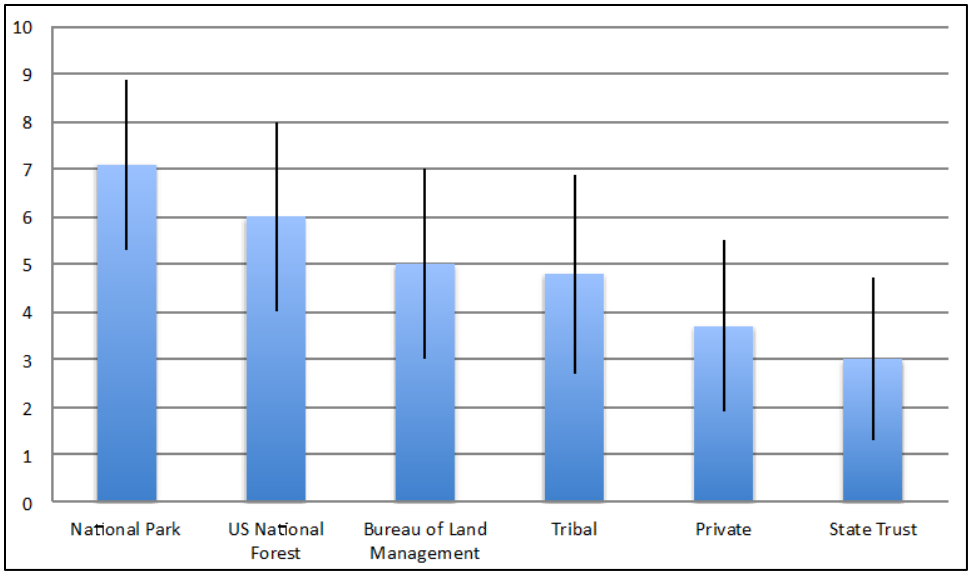


Figure 31. Mean biorichness (+ s.d.) of the GGCLA area jurisdictions.

5.5.6. Data Needs

- Lack of comprehensive species inventories targeted at different taxonomic groups across the analysis area precludes the direct use of species richness or species occurrence data as indicators of biorichness for this analysis.
- A number of disparate species inventory datasets exist, but they are generally of limited scale and variable in methods and quality.
- Critical data gaps include invertebrate species inventories, as well as assessments of the response of threatened and endemic species to changes in climate, groundwater availability, and fire.

5.5.7. Level of Confidence

The indicators used for this analysis are remotely sensed data sources known to reflect high biorichness. We can therefore treat our analysis with high confidence at the scale of analysis, although model validation is ongoing.

5.5.8. Sources of Expertise

This section was prepared by Clare Aslan. This analysis was performed by Brett Dickson and Christine Albano of Conservation Science Partners.

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5.6. Landscape: Ecological Integrity

5.6.1. Description



Ecological integrity, which is defined as the degree to which a system is operating via natural evolutionary and ecological processes, is the inverse of the degree of human modification. The highest ecological integrity in the GGCLA occurs in areas below the rim of the canyon, as well as in the region directly east of the Vermilion Cliffs (Grand Canyon NP Photo).

Ecological integrity at the landscape level is defined as an indicator of a system with natural evolutionary and ecological processes, and minimal influence from human activities (Theobald 2013). It is calculated as a multi-scale index using the inverse of the degree of human modification for the GGCLA analysis area. Locations with higher ecological integrity values represent areas that have a higher degree of naturalness, whereas low values indicate a high degree of human modification.

Ecological integrity is deeply relevant to the mission of national parks, including Grand Canyon NP. The level of ecological integrity in a landscape refers to the ability of the landscape to sustain a community of organisms with species composition, diversity, and functional organization comparable to that found under natural conditions within the region (Parrish et al. 2003). National parks strive to maintain natural habitats and to offer sanctuary to species, and monitoring and maximizing ecological integrity across park landscapes is complementary to that central goal. Ecological integrity assessment includes species-specific measurements, where ecological and evolutionary processes are compared against natural processes relevant to a specific species (Carignan and Villard 2002), and broader, landscape-scale assessments focused on the amount of human modification across the landscape (Theobald 2010; Theobald et al. 2012). We selected the landscape approach because the GGCLA occurs at the landscape scale and encompasses all species groups

5.6.2. Indicators/Measures

- Residential and commercial land cover
- Agricultural land cover
- Energy production and mining
- Transportation and service corridors
- Human intrusion and disturbance

5.6.3. Methods

Ecological integrity was calculated using a Python script in ArcGIS v10.2 in three steps. First, data layers were generated that represented factors from a list of potential stressors from the Conservation Measures Partnership (www.conservationmeasures.org). For each factor, the estimated impact was calculated as the product of the magnitude (intensity, the degree to which a land use modifies a location) and the estimated extent (the areal extent or footprint of a given activity, typically expressed as the proportion of a 30 meter cell). The values listed below for magnitude for each layer were derived from either expert opinion or empirical evidence presented in published literature (Theobald 2013). Second, the data layers representing each factor were combined using an "increasive function" that accounts for higher impacts for areas with multiple stressors as compared to a single stressor, but the sum of all stressors cannot exceed 1.0 (Theobald 2013). And third, the average value of the degree of impact was calculated at five scales—5, 25, 101, 544, and 3,980 km^2—which equal the average area for watersheds at hydrologic unit codes (HUCs) 16, 14, 12, 10, and 8, respectively. These five layers were then combined to calculate a multi-scale average (Figure 32). These ecological integrity indicators and the data sources that represent them are described below.

Residential and Commercial Land Cover

This indicator includes urban and built-up areas and housing. Data for urban and built-up areas in the analysis area were derived from the National Land Cover Dataset v3 (NLCD; Fry et al. 2011), with roads removed. The four classifications relevant to the GGCLA area were developed open space; developed low intensity; developed moderate intensity; and developed high intensity. Each classification was assigned an impact magnitude as follows: developed open space = 0.1; developed low intensity = 0.3; developed moderate intensity = 0.7; and developed high intensity = 0.9. All were assessed at a 30 meter footprint. For housing, data were obtained from the Arizona Department of Water residential and domestic groundwater wells data set (ADWR 2013). These data were assigned a magnitude of 0.67, and were assessed at a kernel density of 400 m.

Agricultural Land Cover

Quantity of cropland was evaluated using 30 meter resolution data downloaded from the NLCD (Fry et al. 2011). The ecological impact of cropland was assigned a value of 0.5.

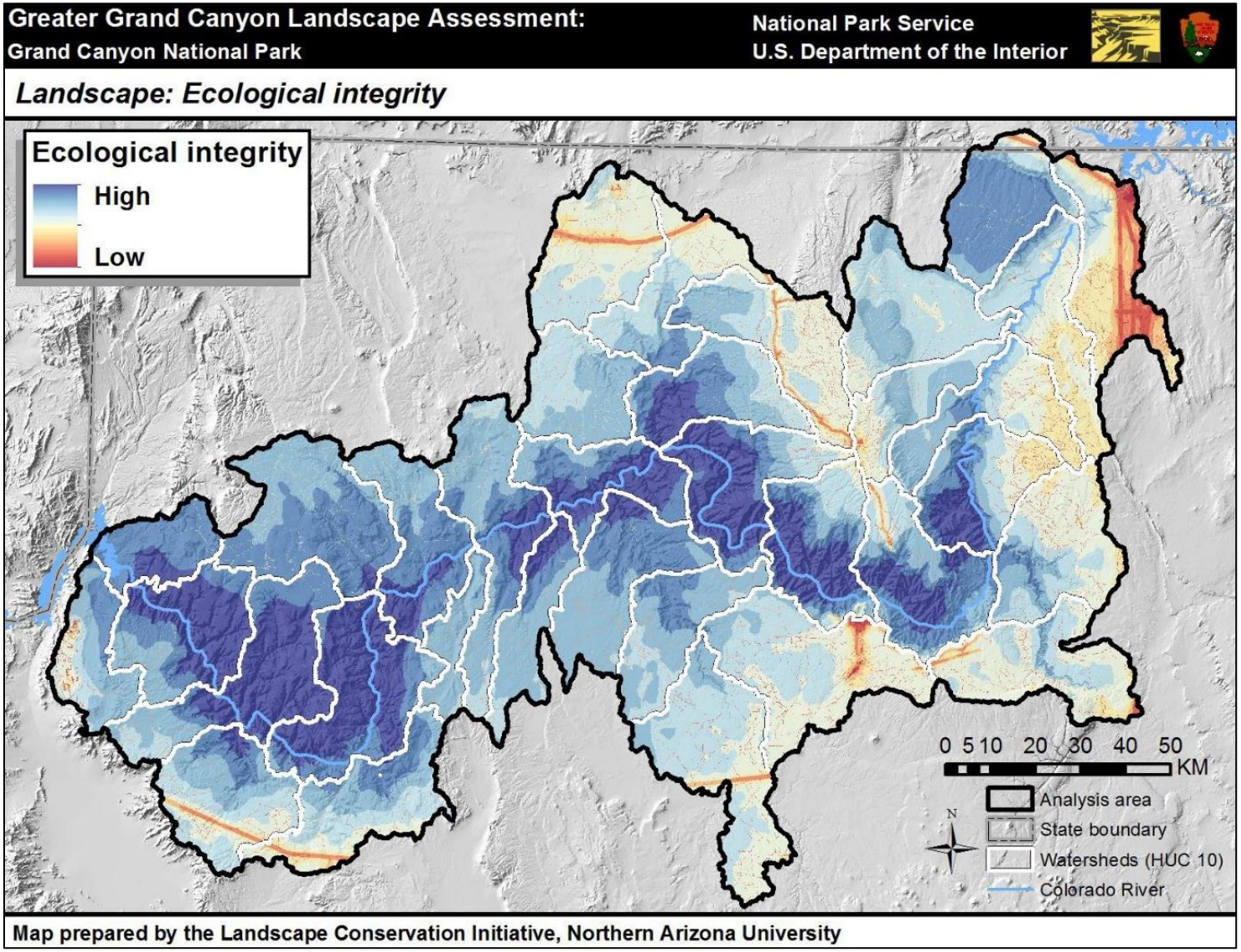


Figure 32. Ecological integrity of the assessment area, calculated as a multi-scale index using the inverse of the degree of human modification (Landscape Conservation Initiative).

Energy Production and Mining

Presence of energy production and mining was determined from mine data downloaded from the USGS Mineral Resource Data System (USGS 2011), as well as data provided by the National Park Service. The ecological impact of mining was assigned a value of 0.25, and kernel density was set equal to 400.

Transportation and Service Corridors

This indicator includes the presence of roads, railroads, and powerlines. Roads and railroads were delineated using data derived from the 2013 Tiger Census (U.S. Census 2013). All roads were assigned impact values of 1. Highways were evaluated at a 30 meter footprint, secondary roads at a 15 meter footprint, local roads at a 10 meter footprint, and four-wheel-drive roads at a 3 meter footprint. Powerline presence was evaluated using data from the 2008 Tiger Census (U.S. Census 2013), and the Western Governors' Association (2013) Crucial Habitat Tool. Powerlines were assigned impact values of 0.125 and were evaluated at a kernel density of 500 meters.

Human Intrusion and Disturbance

This indicator includes two components: 1) recreational use, accessibility, and human modification; and 2) buildings, campsites, and backcountry sites. For the first component, existing spatial data on road distributions were obtained from the Federal Highway Administration (2010) and Theobald (2010). These data included travel time for land-based recreation in minutes, calculated from major roads, with roads, trails, and off-trail locations weighted by slope (higher weight assigned to steeper slopes). The water body of the Colorado River itself was assumed to be inaccessible, although campsites and trails accessed from the river were assigned modification values as described here. Although Glen Canyon Dam itself represents a strong human modification, as a point-scale impact its effect would disappear in the landscape-scale modeling applied here; effects of the dam are discussed and evaluated separately in the Altered Hydrological Regime resource condition assessment. Impact magnitude was calculated as 0.1272*e-0.002a, and a 30 meter footprint was used. For the second component, data on locations of buildings, campsites, and backcountry sites were provided by the Bureau of Land Management, the National Park Service, and the U.S. Forest Service. Buildings were assigned impact values of 1 and were designated as polygons. Campsites were assigned impact values of 0.25, using kernel densities of 45 m. Backcountry sites were assigned impact values of 0.125, using kernel densities of 45 m.

Vegetation Community Diversity

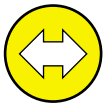
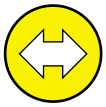
The change in vegetation community over spatial scales is by definition a direct indicator of regional species diversity. Vegetation communities are defined by a combination of dominant species and elevation, and a transition between community types indicates a transition in both rare and dominant species. Therefore, a higher number of vegetation community types in the same spatial area indicates a greater number of plant species. Plant communities exert strong influence on animal species assemblages, so richness of non-plant species changes along with changes in plant communities. This indicator was integrated as a direct count of unique existing vegetation types, equivalent to the NVCS group level. (Data source: U.S. Geological Survey 2013, Landfire v1.2.0, 30 m.)

Net Primary Productivity

Net primary productivity, or NPP, varies with biorichness (Costanza et al. 2007) to varying degrees, depending on the system. It is considered a standard component of biorichness models because NPP is an indicator of energy received by the system and therefore of the rate of biological processes (for example, rate of plant growth and consumption and rate of nutrient flow through the system; Gaston 2000). This indicator was incorporated into the index as the mean of the 10-year average (2002–2011) maximum Normalized Difference Vegetation Index (NDVI). (Data source: eMODIS; U.S. Geological Survey 2014, Earth Resources Observation and Science Center, 250 m).

5.6.4. Condition and Trend

Table 14. Summary of ecological integrity condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Residential and commercial land cover	Historical regional density of residential and commercial structures in similar habitats		Proposed and approved developments would greatly increase developed land cover in Tusayan and the LCR confluence.
Agricultural land cover	Broader regional agricultural land cover in similar habitats		Due to its dry climate and low resident density, agricultural land cover is low in the analysis area.
Energy production and mining	Broader regional (i.e., Colorado Plateau) density of energy production and mining		Thousands of uranium claims exist in the analysis area, although a current moratorium has prevented new claims.
Transportation and service corridors	Broader regional density of transportation and service corridors		Relative to surrounding areas, the park has very low density of transportation and service corridors. However, the surrounding region (particularly national forest) has a high density of corridors allowing access for a diversity of activities.
Human intrusion and disturbance	Broader regional level of human intrusion and disturbance		The analysis area has some of the highest recreational visitation rates of any national park. Centers of recreation, both within and just outside the park have extremely high use. Population growth in the region will increase this use.

5.6.5. Summary

The index of ecological integrity, developed by combining the indicators of human modification listed above, permitted spatial examination of the areas with highest and lowest ecological integrity. Breaking down ecological integrity values across the landscape by jurisdiction, the highest mean value of ecological integrity occurs in Grand Canyon NP (8.89 + 1.32; see Figure 33), followed by BLM areas (7.25 + 1.73).

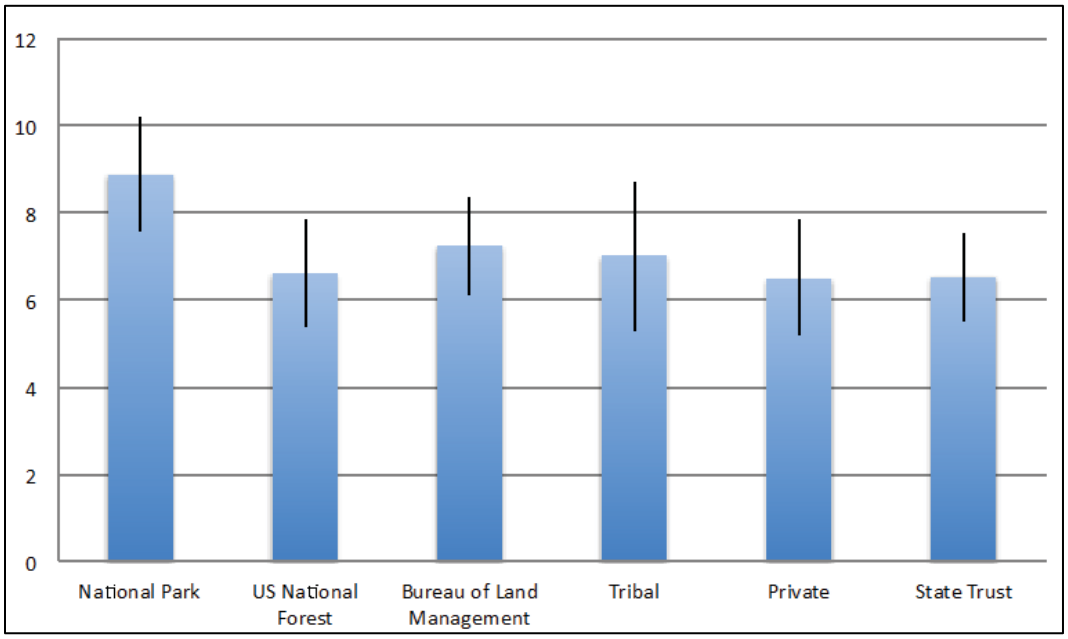


Figure 33. Mean ecological integrity of the jurisdictions within the GGCLA area.

Among HUC 10 watersheds, the highest average ecological integrity values (above 9.1) occur in watersheds 19 (Granite Park Canyon–Colorado River), 31 (Burnt Springs Canyon–Colorado River), 30 (Surprise Canyon–Colorado River), and 13 (Tuckup Canyon–Colorado River). Lowest average ecological integrity values (below 6.0) occur in watersheds 1 (Water Holes Canyon–Colorado River), 20 (Bulrush Wash), 34 (Lee Canyon–Little Colorado River), and 6 (Tanner Wash–Colorado River).

5.6.6. Level of Confidence

The indicators used for this analysis are publically available, spatially explicit records of human modifications and developments. Accuracy is generally high for the larger features. Smaller features, such as small dirt roads which are difficult to detect via remote sensing, are less well represented but nevertheless frequently recorded, and the records are regularly updated. We can therefore consider our analysis with fairly high confidence.

5.6.7. Sources of Expertise

This section was prepared by Clare Aslan. This analysis was performed by Dave Theobald of Conservation Science Partners.

5.6.8. Literature Cited

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5.7. Landscape: Fire

5.7.1. Description



Prescribed burn. Over a century of wildland fire suppression in the Greater Grand Canyon Landscape Assessment area has altered the natural fire regime in many vegetation types. Suppression has had the greatest negative effects in forested communities that once experienced frequent and low-severity fires. Land managers are actively working to restore fire as a natural disturbance process across much of the landscape, but climate change and altered fuel conditions are still expected to increase fire severity in Southwest forests. In addition, climate and land use changes have introduced more frequent fire in desert shrub and woodland communities that are not well adapted to fire, and this is also expected to increase in the future (NPS Photo).

The heterogeneity in ecosystem composition and distribution across the Greater Grand Canyon Landscape Assessment (GGCLA) area contributes to the complex and variable role of fire as a natural disturbance factor. Wide variability in topography and vegetation communities creates stark differences in levels of fire adaptation across the landscape. Fire studies over the last few decades have provided information on historical fire regimes (fire size, intensity, timing, and distribution) across different vegetation types, and also provide a reference for fire and fuels management in the region (Fulé et al. 2003a; Huffman et al. 2008). This information remains relatively specific for some vegetation communities (e.g., low-elevation ponderosa pine) and much less so for others (e.g. high-elevation mixed-conifer; Fulé et al. 2003b).

Fires were mostly suppressed in the Grand Canyon region between the late 1870s and late 20th century (National Park Service 2012). Vegetation changes caused by past fire suppression and land use activities, such as livestock grazing, have generally increased live and dead fuel loading in forested communities. This has resulted in potentially hazardous arrangements of close-standing vegetation, which increases the risk of higher-intensity crown fires (National Park Service 2012). In

addition, invasive plants such as cheatgrass (*Bromus tectorum*) and Mediterranean sage (*Salvia aethiopis*) have spread into the region and often thrive in the wake of fire and other disturbance. Cheatgrass is a particular threat to sparsely vegetated desert shrub and woodlands, where the invasive grass/fire cycle can threaten the resilience of native ecosystems that did not evolve with frequent fire (Brooks et al. 2004).

Changes in fuel structure throughout the Grand Canyon region (plant density, species composition, and biomass distribution) have contributed to concordant changes in fire dynamics and ecosystem function (changes in fire intensity, watershed nutrient cycling, and soil moisture retention; National Park Service 2012). Differences in fire regimes between the pre-suppression era and more recent fire records can be assessed to provide an indication of how far vegetation communities have deviated from natural conditions, and can aid in the design of fire management strategies to restore ecosystem function. However, this may require a synthesis of multiple sources of historical fire data for comparison with modern records and observations (Swetnam et al. 1999).

Current fire management goals vary across the landscape, and increasingly managers look to restore fire as a natural disturbance process, within the limits of understanding and resource protection goals. Over the past two decades, Grand Canyon NP has been able to take advantage of opportunities to manage unplanned wildfires for multiple objectives, such as to support ecological processes or to protect natural and human resources. In addition, since the park introduced aerial ignition for prescribed fires in 1998, it has implemented prescribed fires under a wider range of environmental conditions, to more fully meet fuel-reduction objectives. Since 1980, approximately 185,000 acres have burned. The majority (~140,000 acres) burned as prescribed fire in up to three separate burn events over the same area, or as naturally ignited fires managed for multiple objectives. Wildfires that were actively suppressed and not managed for any other objective accounted for only 22,000 acres (Grand Canyon national fire perimeter dataset, see below).

Within the greater Grand Canyon area, the Kaibab National Forest, the Bureau of Land Management, and the Lake Mead National Recreation Area also manage wildfire for multiple objectives and conduct prescribed fire and fuel thinning projects. More than 30 years of proactive fire management has made progress towards restoring natural fire regimes, particularly in vegetation communities such as ponderosa pine where the historical fire regime is relatively well understood. In many areas, multiple fire and fuel treatments will still be needed to restore and maintain desired ecological conditions.

5.7.2. Indicators/Measures

- Fire return interval
- Fire severity in ponderosa pine vegetation types
- Re-burns in pinyon-juniper, desert shrublands, and desert scrub

5.7.3. Methods

Vegetation Types

Vegetation communities can be divided into eight broad types with distinctive historical fire regimes to help interpret current conditions and trends in fire and fuels (Table 15 and Figure 34). These vegetation types are also consistent with fire monitoring associations identified by the Grand Canyon for fire management purposes (National Park Service 2012, Appendix F). To achieve consistency across the greater Grand Canyon landscape, we started with Landfire 1.3 (www.landfire.gov, 2012) existing vegetation types (EVT) and re-classed the types according to the descriptions given below. Landfire has incorporated fire disturbance since 2001 into the EVT dataset to reflect post-fire vegetation change, but the pre-fire vegetation was more appropriate for our purposes. Therefore, we rolled back the vegetation types within these disturbance events to the original Landfire 1.0.5 (2001) EVT.

Table 15. Vegetation types across the Greater Grand Canyon Landscape Assessment area.

Type	Elevation Range (m)	Vegetation Composition
Ponderosa south rim	1,950–2,290	Ponderosa dominates but pinyon pine (*Pinus edulis*), Utah juniper (*Juniperus osteosperma*), and Gambel oak (*Quercus gambelii*) may be present.
Ponderosa north rim	2,240–2,600	Ponderosa dominates but other overstory species include white fir (*Abies concolor*), quaking aspen (*Populus tremuloides*), Douglas fir (*Pseudotsuga menziesii*), and Engelmann spruce (*Picea engelmannii*).
Ponderosa pine with white fir encroachment	2,380–2,650	Occurs at the transition between ponderosa pine to mixed conifer. Ponderosa dominates, along with white fir and quaking aspen.
Mixed conifer	1,944–2,400 & 2,550–2,800	Relatively dry sites have stands dominated by ponderosa pine and Douglas fir. More mesic sites have stands dominated by various combinations of ponderosa pine, Douglas fir, white fir, quaking aspen, Engelmann spruce, and subalpine fir (*Abies lasiocarpa*).
Spruce-fir	2,500–2,800	Canopy dominated by Engelmann spruce, quaking aspen, and/or white fir with subalpine fir, ponderosa pine, and Douglas fir occasionally present.
Desert shrubland	350–2,800	Total cover is sparse. Dominant shrub is big sagebrush (*Artemisia tridentata*).
Pinyon-juniper woodland and savannah	350–2,620	Total cover is sparse. Canopy is dominated by pinyon pine and/or Utah juniper.
Desert scrub	350–2,320	Total cover is sparse. Dominant shrub species include creosote bush (*Larrea tridentata*), white bursage (*Ambrosia dumosa*), and blackbrush (*Coleogyne ramosissima*).

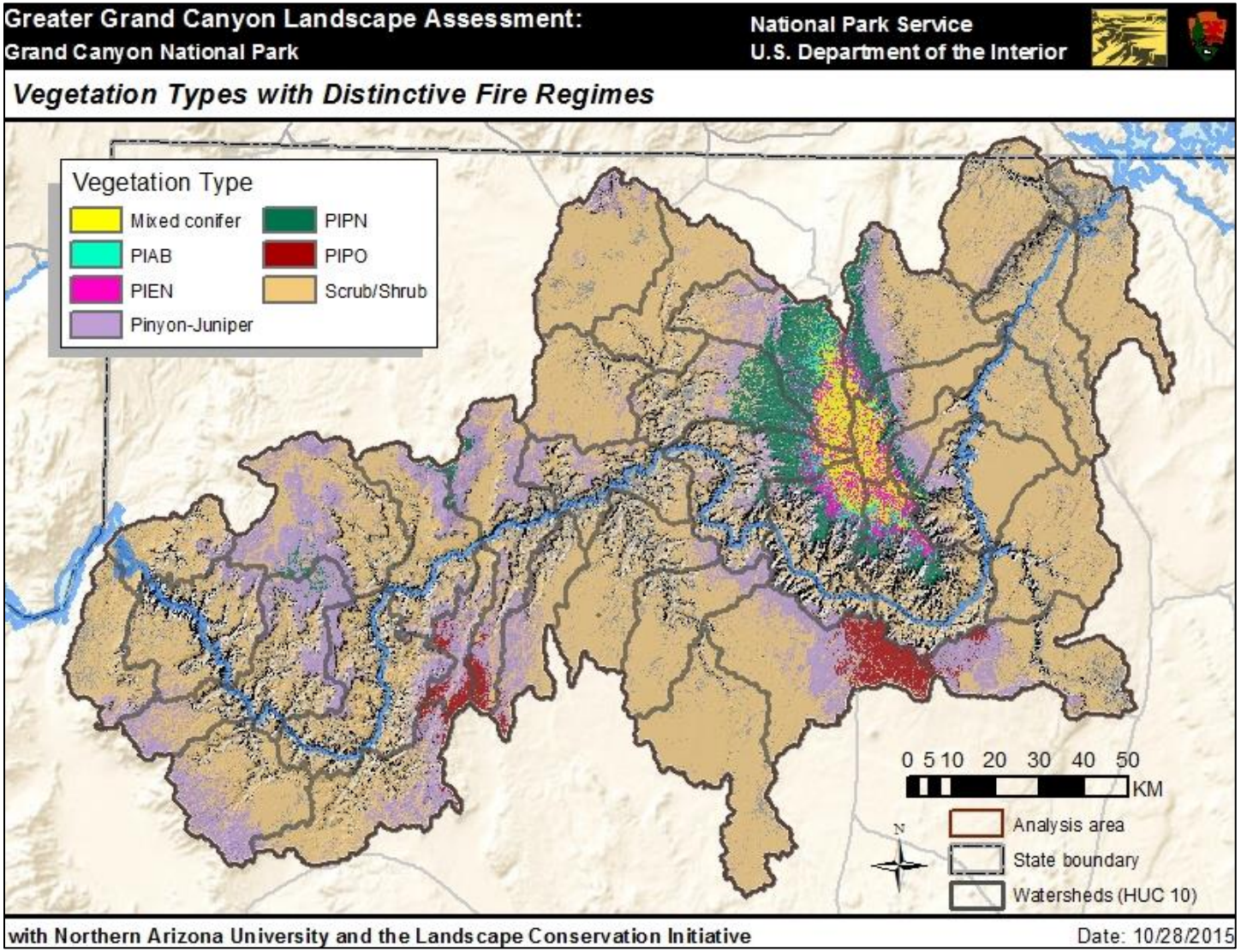


Figure 34. Distribution of the eight vegetation communities used to interpret current conditions and trends in fire and fuels across the area. Vegetation data were derived from the Landfire database (www.landfire.gov) and re-classed according to fire management goals.

Data Sources

Historical fire perimeters for both prescribed fires and wildfires were compiled from two data sources. We started with a ground truthed fire perimeter dataset maintained by Grand Canyon NP that spans 1910–2014. Outside of the park boundary, we used fire perimeter data from the Monitoring Trends in Burn Severity project (MTBS; www.mtbs.gov), which maps fires ≥ 1,000 acres since 1984. To achieve consistency in the period of fires across the greater Grand Canyon landscape, we included only fires in Grand Canyon NP that occurred since 1984.

We started with a ground-truthed fire severity dataset that is maintained by the park and contains severity of fires > 300 acres occurring from 2000 to 2014. For fires outside of the park and fires inside the park that occurred prior to 2000, we used fire severity data from MTBS. From this combined dataset, we pooled all fire patches that burned as either high or moderate/high severity.

Departure from Historical Conditions

We used recent (1984–2014) fire regime departures from historical conditions to assess current fire regime condition class (FRCC). Historical conditions, which refer to pre-European settlement (~1880), provide a baseline against which to compare current fire regimes. To represent fire regime condition, we combined into a single index the fire return interval for forested vegetation types, high fire severity in ponderosa pine vegetation types, and re-burn events in pinyon-juniper woodland and savannah (PIED), desert shrubland, and desert scrub for the time period 1984 to 2014.

Fire Return Interval

Fire regimes are often described in terms of an average fire return interval (FRI), which we define here as the expected number of years between successive fire events within a given area. For each HUC 10 watershed, we used the fire perimeter dataset to calculate the total burned area within each vegetation type. We then divided the total burned area by the available land area in each vegetation type, and divided this number by 31 (number of years spanned by the fire perimeter dataset) to determine the annual burn probability. The estimated historical fire return interval is greater than 31 years in the PIED, shrub, and scrub vegetation types (Huffman et al. 2008). We excluded these vegetation types when determining this indicator because the number of surpassed intervals is not a meaningful metric in this case.

We defined the recent fire return interval (in years) as the inverse of annual burn probability for 1984–2014. Information on historical fire return intervals for all other vegetation types was determined from peer-reviewed studies (Table 16). Numerous studies in the Grand Canyon region enable assessment of reference conditions of FRI in forested vegetation types; fire frequency and timing can be inferred from multiple lines of evidence in these forests (Friederici 2004). We determined the vegetation type departure from historical fire return intervals based on the following discrete classes:

- 4 = Extreme (5 or more intervals surpassed, see Table 16)
- 3 = High (between 2 and 5 intervals surpassed)

- 2 = Moderate (between 0 and 2 intervals surpassed)
- 1 = Low (the last fire occurred within the interval time period)

Table 16. Estimates of historical (~1700–1880) fire return intervals.

Vegetation Type	Fire Return Interval
Ponderosa south and north rim, (PIPO, PIPN); ponderosa with white fir encroachment (PIAB)	7 years (Wolf and Mast 1998; Fulé et al. 2002, 2003a, 2003b)
Mixed conifer	9 years (Wolf and Mast 1998; Fulé et al. 2002, 2003a)
Spruce-fir (PIEN)	23 years (Fulé et al. 2003b)

To determine the HUC-level departure for fire return interval, we calculated an area-weighted mean departure (by vegetation type). We also estimated an average FRI across the entire distribution of each of the forested vegetation types.

Fire Severity

Fire regimes are also often described in terms of fire severity, which refers specifically to the degree of consumption of aboveground and belowground organic matter from fire (Keeley 2009). Within the Grand Canyon fire monitoring types, quantitative severity management objectives exist for north rim ponderosa (PIPN), south rim ponderosa (PIPO), and ponderosa pine with white fir encroachment (PIAB), since it is fairly well understood that historical fire regimes were of low severity in these types (Grand Canyon National Park 2012). Historical fire severity is much more variable in other vegetation types. For instance, fire scar and tree age evidence in mixed-conifer and spruce-fir forests of the canyon's north rim suggest that historical fires were highly mixed in their severity and likely controlled largely by aspect (Fulé et al. 2003b; Yocom-kent et al. 2015). As an indicator of fire severity condition, we used the fire severity dataset to determine the amount and patch size of high-severity fire in PIPN, PIPO, and PIAB within each HUC 10 watershed. We based the indicator on the following park management objectives for these vegetation types.

- 1 = Over any 10-year period, high-severity fire occurred in patches greater than 5 acres (10 acres in PIAB) and/or across more than 5% (15% in PIAB) of the area of the vegetation type.
- 0 = Over any 10-year period, high-severity fire occurred in patches smaller than 5 acres (10 acres in PIAB) and across no more than 5% (15% in PIAB) of the area of the vegetation type.

To determine the HUC-level departure for fire severity, we calculated an area-weighted mean departure (by vegetation type). We also estimated severity metrics across the entire distribution of ponderosa vegetation types.

Re-burns

Recent large re-burns have occurred over cheatgrass-invaded areas in PIED, shrubland, and scrub vegetation in the greater Grand Canyon landscape. Cheatgrass and other nonnative grasses increase the fuel loading and continuity in otherwise sparse vegetation that is not well adapted to fire.

Recurrent fire is of particular concern in these vegetation types because it can encourage initial and increased invasion by cheatgrass and other nonnative grasses, and promote an invasive grass/fire cycle that can lead to homogenous invasive grasslands. Using the fire perimeter dataset, we determined whether a re-burn has occurred in PIED, shrubland, and/or scrub within each HUC 10 watershed. In this analysis we included only wildland fires and excluded all prescribed fires, since prescribed fire may obscure the negative effects of re-burns in this case.

- 1 = re-burn (> 5,000 acres) has occurred
- 0 = re-burn (> 5,000 acres) has not occurred

To determine the HUC-level departure for re-burns, we calculated an area-weighted mean departure (by vegetation type).

Cumulative Fire Regime Condition Class

For each HUC 10 watershed, the cumulative FRCC was the sum of the area-weighted mean condition for each of the three indicators: fire return interval, fire severity, and re-burn events.

We used estimates of historical (~1700–1880) fire return intervals, based on the Weibull median probability interval (WMPI; Grissino-Mayer 1999) to estimate the recent departure in FRI for the listed vegetation types. The estimates are based on large fires that occurred on the greater GrandCanyon landscape and that scarred at least 25% of "recording" trees (Fulé et al. 2002, 2003a, 2003b). Recording trees are those with open fire scars ("cat faces"), leaving them susceptible to repeated scarring by fire (Dieterich and Swetnam 1984).

5.7.4. Condition and Trend

Table 17. Summary of fire regime condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Fire return interval	Fire return interval (in years) in comparison to estimated historical fire return intervals by vegetation type	HUC 10 watersheds 2, 3, 7, 8, 9, 12,19, 22, 23  HUC 10s 5, 6, 10, 13, 14, 15, 16, 17, 28, 32  All Others 	Fire return interval was found to be at greatest departure and less frequent than historical estimates in the conifer forests on the north and south rims of the canyon. Increases in prescribed fire and wildfire managed for multiple objectives in these forests is expected to bring the FRI closer to historical conditions.

Table 17 (continued). Summary of fire regime condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Fire severity	Percent of fire severity and fire severity patch size in ponderosa vegetation, in comparison to estimated historical fire severity in ponderosa vegetation	HUC 10s 7, 9, 19, 22, 23  HUC 10s 2, 5, 6, 8, 32  All Others 	Increases in the patch size and/or amount of fire severity were found in the PIPN and PIAB vegetation types. Fire severity is expected to increase across Southwest forests, which will likely have greatest negative impacts on ponderosa and mixed conifer forests.
Re-burns	Re-burns in PIED, shrubland, and scrub in comparison to historically low fire frequency in these vegetation types	HUC 10s 27, 28, 29  HUC 10s 9, 19, 22, 31  All Others 	In the last 20 years, increased abundance of cheatgrass in the greater Grand Canyon landscape has facilitated large re-burns in desert communities. Since these communities are not well adapted to fire, re-burns can inhibit the recovery of native vegetation and lead to post-fire increases in cheatgrass, which would promote the invasive grass/fire cycle.

Fire Return Interval

Across their entire distribution, we found that ponderosa communities have an average FRI of around 50 years (Table 18), which is approximately seven times less frequent than historical estimates. The HUC 10 watersheds with the greatest departures from historical FRI encompass large areas of ponderosa and mixed-conifer forests on the north and south rims of the canyon (see Table 18 and Figure 34). As a result, contemporary ponderosa forest conditions reveal structural changes, including increased pine seedling survival, pine invasion into meadows, canopy closure, and increased pine litter and deadwood forest floor accumulations (National Park Service 2012). Since 1998, Grand Canyon NP has increased the number of acres burned annually through the prescribed fire program, and long-term monitoring plots indicate that prescribed fire is moving ponderosa stands toward desired conditions (Grand Canyon National Park 2014). For example, across all PIPO, PIPN, and PIAB vegetation types, in total 88 prescribed burn units have had at least one prescribed fire, and the restoration objective for mean fuel loading was achieved after these fires.

Table 18. Fire return intervals and fire severities for forested vegetation types, across their entire distribution in the greater Grand Canyon landscape.

Vegetation Type	Proportion of Total Area Burned	Annual Burn Probability	FRI (years)	Proportion Burned High Severity	Mean Max High-Severity Patch Size (acres)
PIPO	0.5880	0.0189	53	0.0094	60
PIPN	0.5764	0.0186	54	0.0629	247
PIAB	0.6468	0.0209	48	0.0325	22
Mixed conifer	0.2574	0.0083	120	NA	NA
PIEN	0.5202	0.0168	60	NA	NA

Historical fire frequencies in lower-elevation mixed-conifer forests are estimated to be on the order of those in ponderosa forests, but slightly higher in higher-elevation and northerly aspect sites (Fulé et al. 2003b). Our results indicate that mixed-conifer forests have also largely departed from historical FRIs, with an average interval of 120 years across their entire distribution (Table 17). As a result, total tree densities and canopy cover has also increased in these forest types (Fulé et al. 2004). No specific trend assessment is available for mixed-conifer forests, but increases in prescribed fires targeted at the mixed conifer type are expected to increase structural resilience. Our results indicate that spruce-fir communities are closer to their historical FRI than the ponderosa and mixed-conifer associations, but still average a three-fold increase in return interval across their distribution (Table 17). For Grand Canyon NP fire management, spruce-fir vegetation types are generally thought to be within the natural fire regime for fire return interval, and prescribed fire is not the management focus.

Fire Severity

Departures in historical fire severity have occurred primarily in the PIPN vegetation type (Table 17, Figure 35). Six percent of their distribution has burned in high-severity fire over the last 31 years, but most of this has occurred in the last 20 years. The average maximum patch size of high-severity fire in PIPN has been 247 acres. This suggests that recent fire severity has increased primarily in the higher-elevation ponderosa communities on the north rim. One large example of this was the Warm Fire of 2006 that burned a total of 59,000 acres on the Kaibab Plateau across several very large high-severity patches. It is expected that current fuel conditions, and increased warming and drought conditions in the future, will increase the occurrence of high-severity fires in ponderosa and mixed conifer associations.

Re-burns and Trends In Desert Communities

Approximately 20,000 acres in HUC 29 (Burnt Spring Canyon–Colorado River) burned in 1994-1995 through pinyon-juniper and shrubland vegetation, and nearly 15,000 acres re-burned less than 10 years later. In 2005, 7,000 acres burned in HUC 27 (Spencer Canyon) and HUC 28 (Surprise Canyon–Colorado River), and the entirety burned again in 2012 in a 17,000-acre fire. The Bridger-Knoll fire in 1996 burned approximately 53,000 acres in HUCs 19 (Snake Gulch), 21 (Grama Canyon–Kanab Creek), and 22 (Jumpup Canyon–Kanab Creek), and numerous patches within this perimeter have re-burned between 2004 and 2012.

These short-interval re-burns across the region have likely been facilitated by increases in cheatgrass abundance, and will likely promote further invasion as a result. A detailed analysis of predicted cheatgrass presence and fire connectivity in the region of the Bridger-Knoll fire showed abundant cheatgrass growth immediately prior to the large fires that burned in 2012. This analysis helped identify a network of fuelbreaks that could be implemented to interfere with fire connectivity between large patches of cheatgrass with a relatively high likelihood of burning in the future (Figure 36; Gray and Dickson in review). Although this analysis was only done for a small subset of the greater Grand Canyon landscape, similar analyses may be warranted in areas that have experienced re-burns facilitated by cheatgrass.

Our analysis showed that re-burns occurred in desert shrub-dominated communities, but we know that many of these acres also burned through interspersed PIED communities. Historically, small surface fires likely occurred in pinyon-juniper on the order of decades, but high-severity fires likely occurred only every 200 or more years (Floyd et al. 2008; Huffman et al. 2008). Additionally, at the ponderosa-pinyon-juniper ecotone, surface fires in ponderosa stands did not historically spread through pinyon-juniper communities (Huffman et al. 2008). Fuel treatments in ponderosa stands have been observed to increase the abundance of cheatgrass at some sites (McGlone et al. 2009), which would facilitate cheatgrass invasion and fire spread into pinyon-juniper communities at the ponderosa ecotone. Following severe fire in PIED, a shrub or grass-dominated successional stage may persist for decades, even as pinyon and juniper invade (Gori and Bate 2007). Similar to desert shrub and scrub, recurrent fires over short intervals in PIED could interfere with natural succession patterns. Since cheatgrass capitalizes on land use disturbance as well as extreme climatic fluctuations, and both are expected to increase across the region in the future, re-burns will likely continue and there is potential for the invasive grass/fire cycle to establish in some areas.

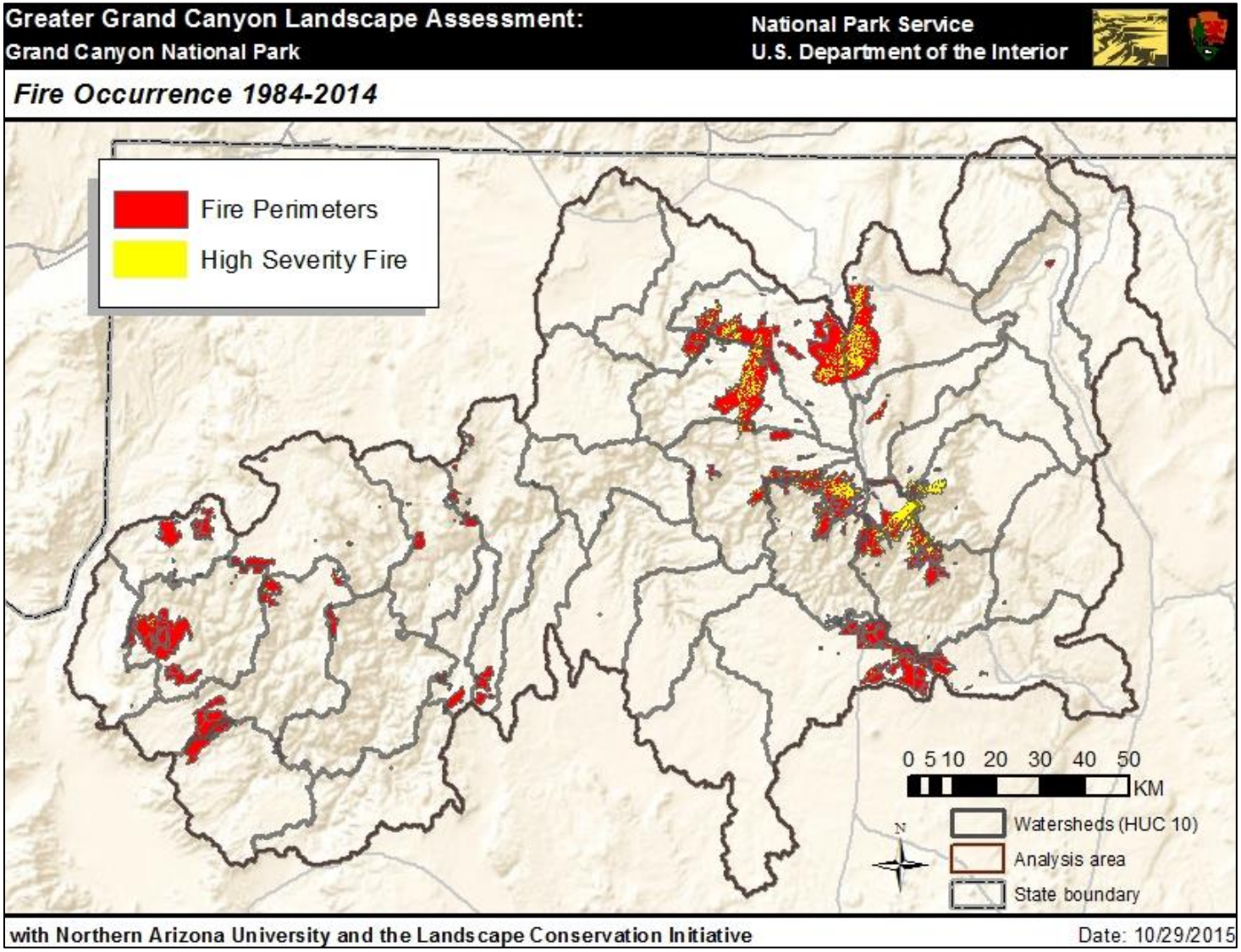


Figure 35. Distribution of all fires and high-severity fire patches that burned from 1984 to 2014 in the greater Grand Canyon landscape. Data were compiled from the Grand Canyon NP and the Monitoring Trends in Burn Severity project (www.mtbs.gov).

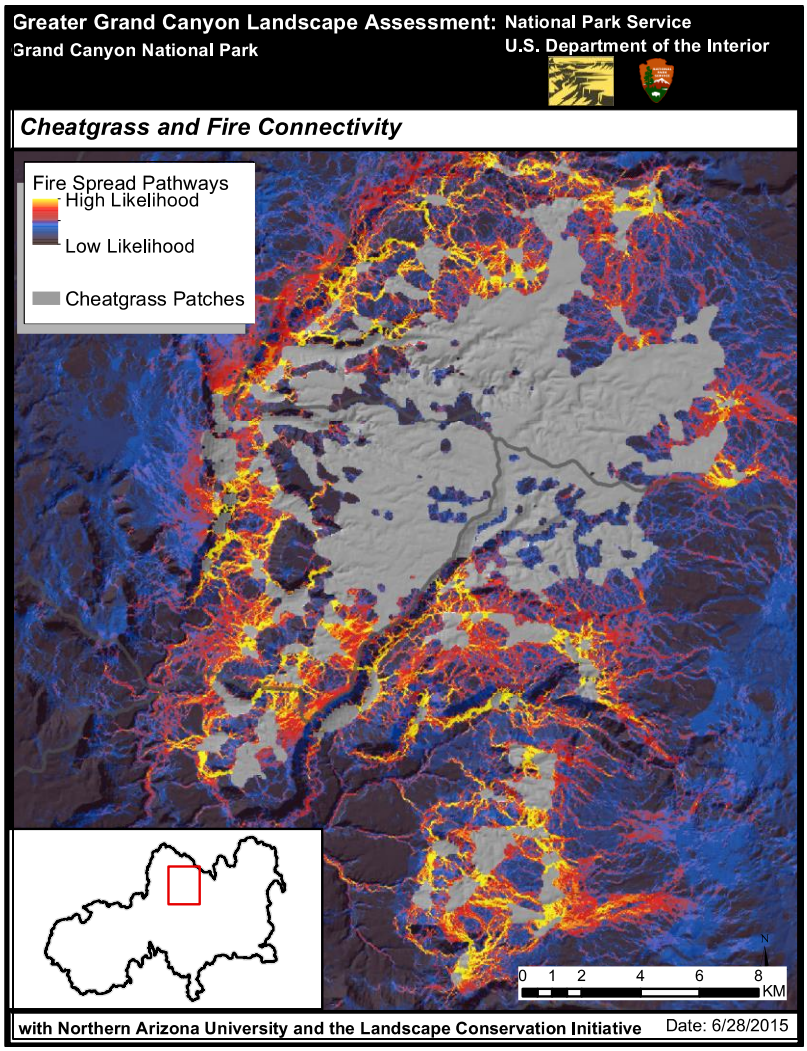


Figure 36. Highest likelihood fire spread pathways between cheatgrass patches >10 hectares (yellow = high likelihood, black = low likelihood) across the west side of the Kaibab Plateau. Fire spread pathways were derived by modeling the connectivity between all possible pairs of cheatgrass patches using the program Circuitscape (McRae and Shah 2011). This model was subsequently used to identify a network of fuelbreaks to interfere with fire connectivity.

Cumulative Fire Regime Condition Class

Figure 37 shows the cumulative FRCC for each HUC 10 watershed, reflecting the sum of the three indicators and binned according to three quantiles. Watersheds with the greatest fire regime departure are those that connect the north and south rim conifer forests, and transition south and west off the Kaibab Plateau to pinyon-juniper and desert shrub and scrub communities. Desert shrub and scrub–dominated watersheds at the western edge of the greater Grand Canyon landscape have also departed greatly from historical conditions, due to large and recent re-burn events.

To determine the HUC 10 watershed-level FRCC for each indicator, we calculated an area-weighted (by vegetation type) mean condition and then categorized HUC 10 watersheds into three quantiles of condition (Table 17).

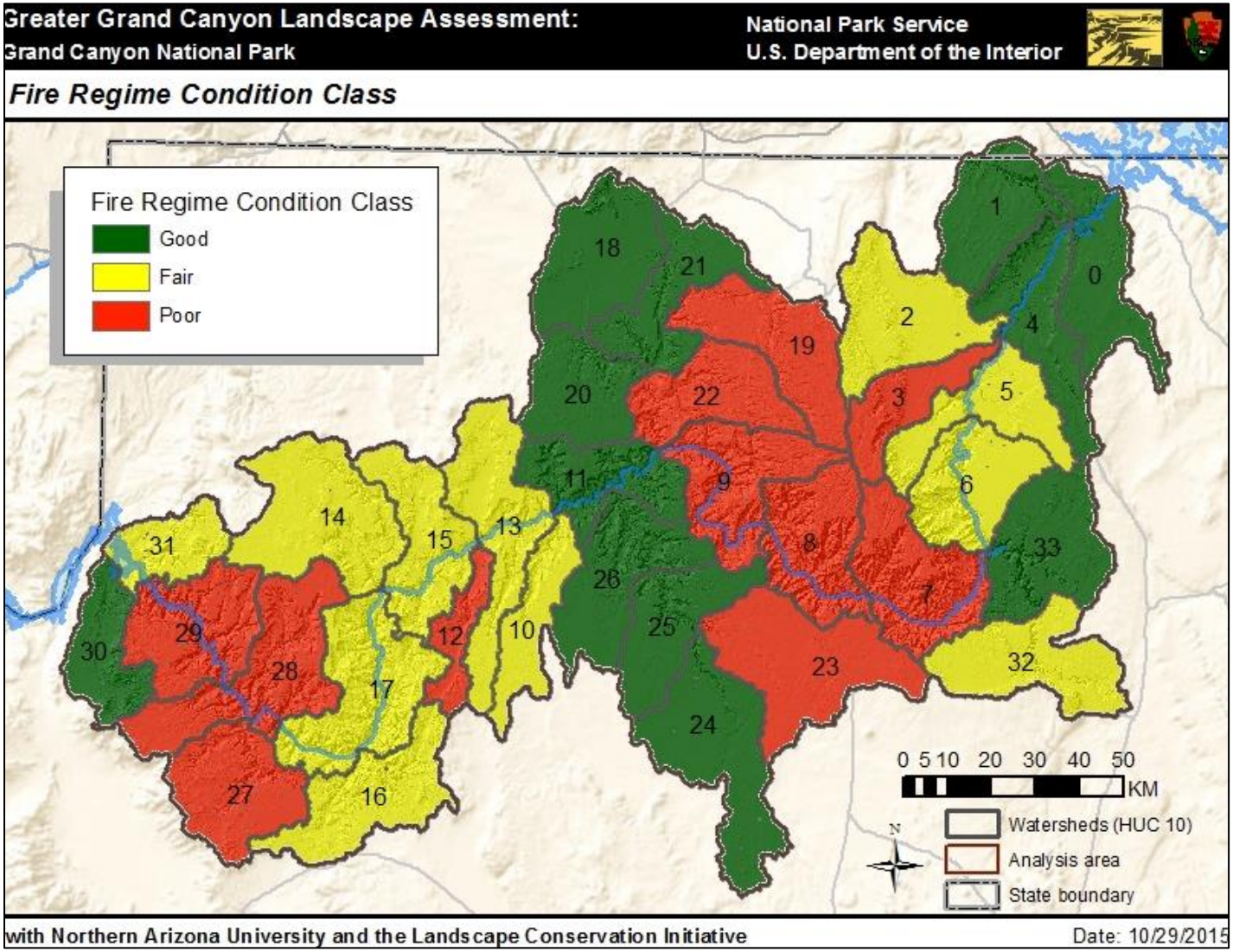


Figure 37. Relative cumulative fire regime condition by HUC 10 watershed in the greater Grand Canyon landscape. For each HUC 10 watershed, the cumulative fire regime condition was the sum of the area-weighted mean condition for each indicator, categorized into three quantiles of cumulative condition.

5.7.5. Summary

The fire regime in many vegetation types shows significant departure from historical conditions. Due to decades of wildland fire suppression, the fire return interval has decreased in the last 31 years in ponderosa pine and mixed conifer forests. Fire severity has increased in higher-elevation ponderosa pine forests. Meanwhile, in vegetation types that are not adapted to fire, such as desert shrub, climate change and land use changes have introduced more frequent fire. Efforts to restore historical fire regimes include the beneficial use of fire for restoration objectives, and experimental implementation of cheatgrass fuelbreaks. Future climate change is likely to continue to augment both the frequency and severity of fire in the region.

5.7.6. Data Needs

- Improved estimates of higher-elevation forest fire return intervals
- Maps of cheatgrass presence and/or abundance

5.7.7. Level of Confidence

The spatial data and quantitative estimates that informed current and historical fire regime components determine the level of confidence in this assessment. Given the straightforward procedures for delimiting fire perimeters, any errors are likely to be negligible for the purpose of this assessment. Grand Canyon NP has maintained a rigorous, ground-truthed dataset of mapped fire severity since 2000. Although the methods are comparable, there is not as much confidence in the MTBS fire severity data.

The condition assessment also relies on the vegetation type map and estimates of the fire regimes for the defined types. To achieve consistency across the entire Grand Canyon landscape, the vegetation map was derived from a national dataset. However, the broad vegetation types we delineated aligned closely with a similar dataset that was derived by Grand Canyon NP and was used as a guideline to assess the final vegetation map (NPS unpublished data). For the ponderosa forested vegetation classes, the extensive body of literature on historical fire return intervals leads to a high level of confidence in these estimates. However, for the higher-elevation forested types with a more variable fire return interval (e.g., spruce-fir forests), there is less confidence in assigning a single value to the return interval.

5.7.8. Sources of Expertise

This section was prepared by Miranda Gray. This analysis was performed by Miranda Gray at Conservation Science Partners, with support from Jill Rundall and Jesse Anderson at Northern Arizona University.

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5.8. Vegetation: Riparian Communities

5.8.1. Description



Riparian communities in Grand Canyon NP occupy approximately 16,000 acres of diverse habitats. Stressors include exotic plant species, altered hydrology, visitor use impacts, fire, beavers, and climate change (NPS photo).

In the arid West, only about 2% of the land is covered by riparian-dominated vegetation, and in Arizona it is a mere 0.4% (Zaimes et al. 2007). In Grand Canyon NP, riparian areas represent roughly 1% of the total area, but they support more than 20% of the native plant species recorded in the park and provide habitat for more than 80% of the wildlife species (Stevens et al. 1999; Kearsley et al. 2015). It is estimated that 90% of riparian areas in Arizona have been degraded or destroyed (Zaimes et al. 2007), but the Grand Canyon's riparian areas are largely intact and the tributaries are arguably nearly pristine (Barnes 2013). Riparian ecosystems in desert landscapes have disproportionately high value for their limited spatial extent (Webb et al. 2007; Zaimes et al. 2007; Barnes 2013).

Riparian communities serve as the link between terrestrial and aquatic ecosystems. They have high biorichness and productivity, as well as they stabilize the waterways and serve as filters. Riparian areas are extremely diverse relative to the matrix of desert scrub surrounding them in the GGCLA area, where there are two basic types of riparian areas: hydro-riparian and xero-riparian (Johnson et al. 1984). Hydro-riparian areas, which occur along perennial watercourses with year-round flows, include areas with natural flows near springs, seeps, perennial streams, and the main stem Colorado River with its dam-regulated flows (Figure 38). Occasional increases in water flow may occur during

monsoon or winter storms, and during high-flow events (HFEs) along the river corridor. These areas generally have finer-grained soils with riparian obligate or preferential plant species dominating the landscape (Zaimes et al. 2007). Hydro-riparian habitats comprise about 0.5% (6,300 acres) of Grand Canyon NP but host 29% of the park's rare and endemic species (Brian 2000; Kearsley et al. 2015). Relatively dense stands of tall trees and shrubs support unique wildlife assemblages.



Figure 38. Hydro-riparian area in a tributary (NPS photo).

Xero-riparian areas occur in intermittent and ephemeral drainages or in the pre-dam high-water zone along the river (Figure 39). In the tributaries, these tend to be areas of high disturbance and instability. Nutrients are often replenished after heavy precipitation in the watershed. Plants in these areas are much more tolerant of extended dry periods, and soils tend to be coarser sands and gravels (Zaimes et al. 2007). Xero-riparian habitats represent about 0.8% (9,800 acres) of Grand Canyon NP but contain about 28% of the rare species (Brian 2000; Kearsley et al. 2015). Despite their reduced diversity and productivity, xero-riparian areas support five to ten times more species diversity and population densities of birds than is found in the desert habitat matrix that surrounds them (Johnson and Haight 1985).

Riparian habitats in the canyon can also be found along the main stem of the Colorado River, which is under the influence of Glen Canyon Dam, or along the tributaries to the main stem, which are, generally, more natural systems. There are 277 river miles of main stem riparian areas, with 740 side canyons. Eight of the side canyons have perennial water and numerous others have ephemeral or intermittent flows. Riparian areas along the tributaries consist of a suite of xero- and hydro-riparian habitats. Overall, the riparian areas in the tributaries face fewer impacts than those along the Colorado River main stem, and are more consistently intact ecosystems.



Figure 39. Xero-riparian area in a tributary (NPS photo).

5.8.2 Indicators/Measures

- Riparian community extent
- Native riparian species richness and composition
- Occurrence of exotic species
- Proportion of native and exotic species

5.8.3. Methods

This analysis was compiled from multiple sources of data, covering various aspects of riparian communities. These sources revealed several important indicators: the extent of both the hydro-riparian and xero-riparian communities, the richness and composition of the native riparian species, the occurrence of exotic species, and the ratio of native to exotic species.

5.8.4. Extent of Riparian Communities

This indicator measures the spatial extent of riparian communities in the assessment area. The distribution of these communities is based primarily on the availability of water, its abundance, and patterns of availability through time. The extent of both hydro-riparian and xero-riparian areas will change with water levels and variation in annual flow volumes, flood events, and the deposition and erosion of soils. Riparian community extent was determined using vegetation maps, evidence from repeat photography, and campsite monitoring.

Methods for Extent

Vegetation Mapping

The distribution of riparian areas throughout Grand Canyon NP and the Grand Canyon–Parashant National Monument has been mapped as part of a park vegetation classification and mapping effort (Kearsley et al. 2015). The information reported here is for Grand Canyon NP only. Semi-automated image segmentation was combined with a regression-tree analysis to produce a map of 226 National Vegetation Classification System (NVCS) Association-level classes, 46 of which are riparian. Most

of the classes occurred in patches below the minimum mapping unit (0.5 hectares), or were lumped into higher-level categories (e.g., NVCS Alliances), due to difficulties in distinguishing types using aerial imagery. However, patches of hydro-riparian types—such as tamarisk (*Tamarix* spp.), cottonwood-willow (*Populus fremontii–Salix gooddingii*) woodlands, and willow-baccharis shrublands (*Salix exigua–Baccharis* spp.); and xero-riparian types, such as mesquite (*Prosopis* spp.), acacia (*Acacia gregii*), and Apache plume-brickellbush (*Fallugia paradoxa–Brickellia longifolia*) shrublands—could be mapped. Both the main stem river and its tributaries were mapped during this project, but no plots were done along the river. A similar effort was made to map the section of river under Glen Canyon NRA management from Lees Ferry to the dam during the spring and fall of 2015; it will be available in the fall of 2016.

Repeat Photography

In their book *The Ribbon of Green*, Webb et al. (2007) present repeat photographs of several tributaries and the main stem of the Colorado River. Repeat photography qualitatively demonstrates the long-term changes that occur in an ecosystem over time. Webb et al. (2007) precisely matched photos from several expeditions into the canyon beginning in the late 1800s, and repeated the photographs in the early 1990s. These photos provide some of the best images portraying the differences in riparian vegetation before and after construction of Glen Canyon Dam. Sankey et al. (2015) digitized and analyzed aerial photos from 1965, 1973, 1984, 1990, and 1992, and used data from Ralston et al. (2008), Davis (2012, 2013), and Kearsley et al. (2015) to analyze the changes in vegetation along the river corridor using high-resolution imagery. They looked at five distinct zones along an elevational gradient from the river's edge where each zone has had different frequencies of inundation since the dam.

Campsite Monitoring

As part of the monitoring associated with the Colorado River Management Plan, park staff implemented a monitoring program from 2007 to 2010 to detect changes in vegetation in and around campsites along the river. Changes in total vegetation cover were derived from these transects along the 30,000 cubic feet per second (30k CFS) and 90k CFS lines (Zachmann et al. 2012).

<u>Richness and Composition of Native Riparian Species</u>

Riparian areas often have high species richness due to access to water and nutrient-rich soils. We determined native riparian species richness and composition using vegetation mapping data, repeat photography, and results from Colorado River Management Plan monitoring and other studies.

Vegetation Mapping

Riparian vegetation was surveyed in the tributaries for the vegetation classification and mapping project (Kearsley et al. 2015). Data were collected in 1,497 plots, each measuring 400 m^2. All species were noted, along with ocular estimates of their cover.

Repeat Photography

Repeat photography done by Webb et al. (2007) provides excellent insight into changes to the native species richness over time, especially as it relates to dam operations. Photos exist for some of the tributaries and also along the river.

Colorado River Management Plan Monitoring and Other Studies

Along the main stem, vegetation data collected for the Colorado River Management Plan (CRMP) from 2007-2010 consisted of five points of ocular estimations of plant cover at 45 sites along a 50 meter transect. Transects were located at the 30k and 90k CFS elevations but not all sites had an old high-water zone. Species-level data were obtained from this source. Ralston et al. (2008) measured richness and cover in four post-dam vegetation zones at 80 sites along the river. Data were collected immediately after the high-flow event in 2008 and again 6 months later. A few summaries of data from two studies along the river by the Grand Canyon Monitoring and Research Center (GCMRC) were also used for this analysis. Vegetation estimates and species lists were compiled at transects along the river at varying elevational gradients and geomorphic settings.

Occurrence of Exotic Species

Riparian corridors are often the main pathways for the introduction of exotic species. The presence and abundance of exotic species can affect native species richness, but not always negatively. Typically, native richness will be suppressed in areas that are heavily invaded by exotic species. However native plant richness can also be positively correlated with exotic richness (Belote et al. 2010). This positive correlation may occur because the system is not saturated, and ample and diverse resources exist for a variety of species both native and exotic (Belote et al. 2010). Once established, local extinction of exotics is unlikely. The Grand Canyon NP vegetation program maintains a running list of exotic species found in the park, and as of 2016 it had documented 204 species. Treatment and/or removal of exotic species in riparian areas is based on a combination of priorities such as ecosystem-level influence, treatability, and invasibility (Table 19). We determined the occurrence and cover of exotic species using vegetation mapping data, repeat photography, and results from Colorado River Management Plan monitoring and other studies.

Table 19. Riparian area exotic species of high and medium priority for control as defined by the vegetation program at Grand Canyon NP. These species were actively controlled with mechanical or chemical treatments in 2016.

Priority	Scientific Name	Common Name
High	*Alhagi maurorum*	Camelthorn
	Brassica tournefortii	Sahara mustard
	Cortaderia species	Pampas grass
	Elaeagnus angustifolia	Russian olive
	Rubus discolor	Himalaya blackberry
	Tamarix ramosissima	Tamarisk
	Tribulus terrestris	Puncturevine
	Ulmus pumila	Siberian elm
Medium	*Marrubium vulgare*	Horehound
	Sisymbrium altissimum	Tumble-mustard
	Sisymbrium irio	London rocket
	Solanum elaeagnifolium	Silverleaf nightshade

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	Ulmus pumila	Siberian elm
Medium	*Marrubium vulgare*	Horehound
	Sisymbrium altissimum	Tumble-mustard
	Sisymbrium irio	London rocket
	Solanum elaeagnifolium	Silverleaf nightshade

Vegetation Mapping

The number of exotic species in hydro-riparian and xero-riparian areas was drawn from the plot data collected for the 2015 vegetation map. Although the plots did not include the Colorado River corridor, they represent a geographically extensive survey of tributary riparian areas, and the exotic species found in the tributaries and washes would also likely be present in the main stem corridor. While the types of exotics in the corridor are likely similar, the number is likely different due to differences between tributary and corridor in flow regimes, sedimentation, and human use.

CRMP Monitoring and Other Studies

Along the river corridor, exotic species richness was derived from both the CRMP and data from Ralston et al. (2008). In addition, Kennedy and Ralston (2010) analyzed aerial images to determine the effects of river regulation on vegetation, and also reported exotic species presence data. Repeat photographs from Webb (2007) also provide context for the increase in exotic species recruitment along the river.

Ratio of Exotic to Native Species

This indicator measures the relative abundance of native and exotic species in riparian plant communities. Competitive interactions between natives and exotics can lead to a reduction in the richness and abundance of native species and an alteration of ecological communities when exotic species spread throughout riparian habitats. For example, abundant exotic annual grass litter increases the probability and severity of fire in areas where fire has been uncommon, including riparian areas. Also, the proliferation of exotic woody species along waterways (e.g., tamarisk) can decrease the force of scouring floods and lead to channelization via encroachment into channel

margins (Webb et al. 2007). Conditions that lead to high productivity of native species in riparian areas also permit the establishment and proliferation of exotic species.

Terrestrial Ecosystem Monitoring Project

Data used to determine the proportion of natives to exotic species for the main stem river corridor were derived from the 2001 to 2005 surveys of vegetation conducted for NAU's Terrestrial Ecosystem Monitoring project. Data on areal cover by species were also used to generate the ratio of natives to exotic cover. No distinction was made between hydro-riparian and xero-riparian habitats. The CRMP data can be used to determine the ratio of natives to exotics in the hydro- versus xero-riparian habitats. Ralston et al. (2008) also provided data and a discussion on native and exotic cover and richness along the river at various elevations.

Tamarisk Removal Project

Paired transects were installed in the tributaries as part of the tamarisk removal project in the early 2000s (Belote et al. 2010). Within each tributary, transects were set up in areas that had been invaded by tamarisk, and also in tamarisk-free reference areas that were in the same tributary. Data were collected along transects both before and after tamarisk removal treatment occurred. Belote et al. (2010) analyzed the data to see if there was a difference in native species richness between tamarisk-infested areas and reference areas. Data analyzed from Belote et al. (2010) were used to determine the ratio of exotics to natives in a subset of tributaries. This dataset was further analyzed for this assessment and additional summaries are included. Data for the tributaries are lacking, but qualitative assessments based on photos and institutional knowledge can provide valuable insight into current conditions and future needs.

Results

The most recent vegetation map identifies 3,513 acres of riparian area along the river (Kearsley et al. 2015). The abundance of riparian vegetation on the main stem is directly influenced by releases from Glen Canyon Dam, which fluctuate based on hydropower demands and other factors.

5.8.5. Extent of the Hydro-Riparian and Xero-Riparian Communities

Hydro-riparian communities have proliferated since 1963, the first year of dam operations, but these habitats bear little resemblance to the "wet sand communities" described in the 1940s by Clover and Jotter (1944). Repeat photography (e.g., Webb 1996) visually depicts the vast increase in hydro-riparian areas along the river corridor. Well-established hydro-riparian vegetation now extends from around the 20k CFS line and above.

In contrast, the extent of xero-riparian habitats in the pre-dam high-water areas has been declining because of the lack of inundation under post-dam flows, drought, and increased base flows. This has led to the expansion of hydro-riparian vegetation in higher zones, according to Sankey et al. (2015), who describe changes to riparian community extent in relation to the completion of Glen Canyon Dam and various stages of dam operations since 1963. They conclude that riparian vegetation cover has increased along the river corridor, and clonal, drought-tolerant, woody vegetation is responsible for most of the increase. Kennedy and Ralston (2010) have reported an increase of 270% in

vegetation cover along the river along the 20k CFS line from 1965 to 2002. Results were similar in the old high-water zone with an estimated increase of 232%.

Analysis of the CRMP data showed an increase in total vegetation cover in the hydro-riparian zone from 32% to 39% and from 24% to 36% in the xero-riparian zone. Although there may have been an overall increase in vegetation cover in the xero-riparian zone, which contradicts other studies, there is substantial evidence that the current plant community composition is shifting away from the historic composition and that this observed increase in cover might be influencing the community in other ways. The data also showed that total vegetation cover was higher in the new high-water zone (Zachmann et al. 2012). In 2008, a high flow event flushed or buried vegetation below 45k CFS levels, and Zachmann et al. found increased vegetation cover across all vegetation classes after that high-flow event.

The only available data for the tributaries are from the most recent vegetation map (Kearsley et al. 2015), which identifies 2,773 acres of riparian areas in the tributaries. Repeat photography (Webb et al. 2007) depicts an increase in riparian extent in the few tributaries that were documented: Kanab, Bright Angel, Tapeats Creek, and Havasu. However, riparian extent in the tributaries is closely tied to floods and can change rapidly and dramatically.

Richness and Composition of Native Riparian Species

The vegetation classification map reports 203 plant species in hydro-riparian habitats and 385 in xero-riparian habitats throughout the entire park. Trends in native species richness for the tributaries are difficult to accurately assess due to limited data; however, Belote et al. (2010) specifically analyzed the species richness associated with the tamarisk removal project in the tributaries. Native species for all years and all transects numbered 367, and the average per transect was 20. Belote et al. expected to see richness increase after tamarisk was removed from the site, but such a trend was not evident. Instead, they reported an overall decrease of native forb richness, which was likely due to dramatically lower precipitation levels from 2004 to 2008. A notable increase in native species richness after exotic plant removal is likely to take more than three years (Belote et al. 2010) but qualitative data from observations by plant biologists indicate a positive trend in native species richness in the tributaries.

According to data from the CRMP, 269 species were recorded in transects along the 30k CFS line and 241 species in the 90k CFS zone. The most common species in the hydro-riparian zone were tamarisk, arrowweed (*Pluchea sericea*), seep willow (*Baccharis* spp.), Apache plume, mesquite, Bermuda grass (*Cynodon dactylon*), and coyote willow. In the xero-riparian areas, the most common species were desert baccharis (*Baccharis sarothroides*), mesquite, graythorn (*Ziziphus obtusifolia*), prickly pear cactus (*Opuntia* spp.), and saltbush (*Atriplex* spp.). In comparison, the most common species in the tributaries were acacia, brickellbush, and alkali jimmyweed (*Isocoma acradenia*), all xero-riparian species.

Ralston et al. (2008) recorded richness along the river corridor after a high-flow event (HFE) but only reported total richness and exotic richness. Richness was reported by vegetation zone along an elevational gradient. Richness was about the same (six species) regardless of the vegetation zone.

The total number of species (native and exotic) observed in April 2008 was higher than in September due to the presence of winter and spring annuals. Ralston et al. (2008) also examined six wetland species (*Carex*, *Equisetum*, *Juncus*, *Phragmites*, *Schoenoplectus*, and *Typha*) and found that all except *Typha* increased after the HFE but only *Schoenoplectus* increased significantly. There is some speculation that the cover of *Typha* may decrease as a result of the HFEs and the subsequent decrease in litter and coarsening of sand.

There have been several reports on unique, relic, or novel ecosystems that are disappearing along the river corridor. Waring et al. (2011) reported a decrease in honey mesquite recruitment in the old high-water zone since the dam but an increase in colonization in the hydro-riparian areas along the river corridor. Pre-dam, Goodding's willow was reported above Lees Ferry and near Cardenas Creek (Mast and Waring 1997). However, the lack of HFEs within the historic range of variability has made recruitment of seedlings all but impossible. On a collecting trip in 2012, vegetation crew members noted that all trees appeared to be in the same cohort and observed no recruitment. In contrast, Diamond Creek appears to have a stable if not expanding population of Goodding's willow. Beaver populations have increased dramatically along the river corridor, possibly because of the lack of consistent high flows and inundation. They are playing a prominent role in the loss of mature Goodding's willow and cottonwoods along the river. The dam and highly fluctuating flows that continued into the early 1990s created novel marsh ecosystems at several backwaters along the river (Stevens et al. 1995). These marshes were comprised of obligate wetland species but there has been a slow transition to woody shrubs as the marshes dried out due to decreased flows and fluctuations (Kearsley and Ayers 1999; Stevens et al. 1995)

Occurrence of Exotic Species

Repeat photographs show an increase in tamarisk in both tributaries and along the main stem (Webb et al. 2007; Webb 1996). According to the recent vegetation map, exotic species represent approximately 13% of the species in hydro-riparian habitats and 7% of the species in xero-riparian habitats in tributaries. Data from the tamarisk removal project (Belote et al. 2010) showed exotic richness of around three species per transect for reference areas and four for tamarisk-infested areas (post-treatment). Grand Canyon NP's vegetation program keeps records of when new species have been collected within the park, but it is not clear whether changes through time follow patterns of introduction or merely reflect sampling efforts.

Along the river, CRMP data revealed a slight increase in exotic plant cover in the hydro-riparian zone, from 15% in 2007 to 18% in 2010, as well as an increase in the xero-riparian zone from 4% in 2007 to 8% in 2010. Ralston et al. (2008) reported exotic cover in four different hydrologic zones along the river corridor, measured in April immediately post-HFE and then again in September of that same year. Exotic vegetative cover averaged 4% in the hydro- and low-riparian zones and 6% in the middle- and upper-riparian zones. Exotic species richness and cover was higher in April than September due to the winter/spring annuals, especially for grasses such as cheatgrass (*Bromus tectorum*) and red brome (*Bromus rubens*; Ralston et al. 2008). The Ralston et al. data suggest that along the river corridor, areas that are subjected to intermittent disturbance may be more likely to experience invasion by exotic species. The most common exotic species along the river are tamarisk,

Bermuda grass, red and ripgut (*Bromus diandrus*) bromes, camelthorn, Russian thistle, and bentgrass (*Agrostis stolonifera*). The GCMRC annual report for 2014 reported that Bermuda grass and red brome were the most frequently encountered species. Although there are no data to support it, personal observations (L. Makarick and M. McMaster) also indicate a dramatic increase in the presence and cover of tall fescue, especially in Marble Canyon, in the past 10 years.

Ratio of Exotic to Native Species

Currently, the ratio of exotic to native plant species richness along the river is 2:3. Trends in the areal extent of exotic species in riparian areas cannot be assessed with existing data, because past mapping of vegetation did not include cover estimates for all species. However, the proliferation of tamarisk and other exotics in the river corridor since the beginning of dam operations indicates an increase in exotic species there and in tributaries.

Along the river corridor, tamarisk is found throughout but is co-dominant with native shrubs in many areas (Sankey et al. 2015). In general, the riparian area is expanding towards the river as a result of the dam and colonization of sandbars under current flow regimes. Baccharis, coyote willow, arrowweed, and phragmites are dominant species near the river. Kennedy and Ralston (2010) reported that the vegetation composition below the 20k CFS line consisted of 44% tamarisk, 28% wetland grasses and sedges, 6.4% riparian shrubs, 13.7% arrowweed, 8% sparse desert shrubs and grasses, and 2.1% mesquite-acacia. Photographs from Webb (1996) visually depict the mixture of native and exotic species along the river.

Data from the CRMP monitoring transects along the river corridor show a strong difference in the ratio of natives to exotics between the hydro-riparian zone and the xero-riparian zone. In 2007, there was approximately 17% cover of native species and 15% cover of exotics in the hydro-riparian zone. By 2010, the percent cover had increased to 21% and 20% respectively. In contrast, in the xero-riparian zone in 2007 there was 20% cover of native species and only 7% of exotics. In 2010, native cover had increased to 28% and exotic cover remained relatively stable at 8%.

There was no tamarisk in original photos of Tapeats Creek in 1872, but in the photograph from 2003 tamarisk was present but not dominant and perhaps even overwhelmed by natives (Webb et al. 2007). Also in Kanab Creek at Showerbath Springs, photos from 1872 show a redbud tree and little other vegetation. However, the repeat photo from 1995 shows a tamarisk- and brickellbush-dominated system with a few scattered Russian olive trees and the original redbud (Webb et al. 2007). The current spread of the tamarisk beetle (*Diorhabda* sp.) through the Southwest could impact future tamarisk densities in Grand Canyon.

5.8.6. Condition and Trend

Table 20. Summary of riparian community resource condition and trend by indicator.

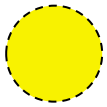
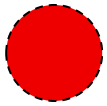
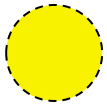
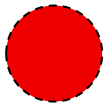
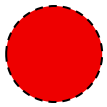
Indicator	Reference framework	Relative condition	Summary comments
Hydro-riparian community extent	Acreage: 3,513 river; 2,773 tributary. These data come from the most recent vegetation map (Kearsley et al. 2015).		Colorado River corridor hydro-riparian communities are currently subject to flow variation driven by water and power demands. The trend since dam operation of GCD has been proliferation of riparian communities. Estimates indicate a 270% increase in vegetative cover. However, the few areas that supported Goodding's willow forests are threatened and the marshes created as a result of the dam are disappearing. The extent of these areas along the river corridor is likely to continue increasing. Less is known about hydro-riparian extent in tributaries but repeat photography indicates a general increase over time. Tributaries are subject to dramatic changes due to floods and fire that can cause a dynamic change in hydro-riparian habitats.
Xero-riparian community extent	Acreage: 226 river; 9,608 other.		Extent of the pre-dam floristic composition along the main stem has declined. Data indicate an increase in total vegetation cover but there is little to no recruitment of mesquite trees in this zone. Because of the lack of inundation of this zone, there is a risk of losing the historic floristic composition. Little is known about the condition or trends for xero-riparian habitats in the tributaries.
Native riparian species richness and composition	Number of species in tributaries: 203 in hydro-riparian; 385 in xero-riparian. Number of species along the main stem: 269 in hydro-riparian; 241 in the xero-riparian.		Along the river, it appears that native cover and richness are increasing over time in both hydro- and xero-riparian zones. However, the richness in hydro-riparian zones may be due to increases in exotic richness. In general, richness is greater in the spring and especially in years of good winter precipitation. Due to uneven sampling efforts over time and limited data, trend analysis in the tributaries is not possible. However, in areas where the tamarisk has been removed, it appears that richness and diversity are at least stable and possibly increasing.

Table 20 (continued). Summary of riparian community resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Occurrence of exotic species	Number of exotic species along the main stem: 36 in hydro-riparian; 13 in xero-riparian. Number of exotics in the tributaries (veg map): 27 in hydro-riparian; 28 in xero-riparian; 19 from tamarisk transects.		Along the river, exotics are increasing at a greater rate in the hydro-riparian zones due to fluctuating flows and more disturbance. Exotic cover is increasing in the xero-riparian areas as well, but at a slower rate. Occurrence of exotics in the tributaries has decreased as a result of the tamarisk removal project but long-term trend data are not available for these areas. However, repeat photography suggests an increase in exotics in the tributaries over time.
Ratio of native to exotic species	Ratio: 2.45:1 (from veg map). Along river in hydro-riparian; 21:20, in xero-riparian; 7:2.		Data from GCMRC and CRMP indicate that the ratio of natives to exotics is relatively equal in hydro-riparian areas and exotic presence is likely to continue to increase. No historical data are available for trend analysis, but proliferation of notable exotics such as tamarisk implies likely increases in exotic representation, especially in the hydro-riparian areas. Xero-riparian areas support fewer exotics and more natives, a trend that is likely to continue under current flow regimes. Data from the tributaries suggest that they are following a similar trajectory as the xero-riparian areas with fewer exotics overall. However, long-term trends in tributaries are unknown.

5.8.7. Summary

Prior to the construction of Glen Canyon Dam, the riparian vegetation along the main stem consisted predominantly of woody species established along the historic high-flow line in xero-riparian areas (Clover and Jotter 1944). Hydro-riparian habitats were rare and ephemeral, and existed mostly in sections of the river that were wider (e.g. Lees Ferry) and supported floodplain-like zones (Clover and Jotter 1944). More than 50 years after the dam was completed, the river now supports a significant hydro-riparian ecosystem along most of its length. These riparian areas provide important resources, such as vegetation structure for birds (Horncastle et al. 2015), recreation opportunities (camps), and shoreline habitat for young fish (Webb 1996). However, these novel hydro-riparian zones along the river are heavily impacted by dam regulation, recreation, and exotic plant species.

Alterations to riparian-dominated communities along the Colorado River corridor, resulting from contemporary, regulated flows, have had both positive and negative impacts on the system. The increase in hydro-riparian extent along the 277 miles (446 kilometers) of river has created a novel ecosystem that supports an incredible diversity of wildlife and plants that did not exist in those areas before the completion of Glen Canyon Dam. The establishment of new riparian areas during a time of significant loss of these places across the Southwest can be seen as an important and perhaps positive impact. However, these areas could have even higher biodiversity, more native plant species,

and improved ecological function if there were more proactive management of river flows, fluctuations, high-flow events, exotic plants, and riparian habitat creation. The Long Term Experimental Management Plan EIS may result in implementation of a river management plan that would promote healthy riparian ecosystems throughout the river. A recent GCMRC report discusses the importance of analyzing vegetation data within three segments (Marble Canyon, Eastern Grand Canyon, and Western Grand Canyon) to best see trends over meaningful timescales. River flows affect each section in different ways and result in varying vegetative responses.

The effects of flow regulation extend beyond just interactions with plants along the river shoreline. The population increase of beavers along the river has not been quantified but has had a dramatic effect on the establishment of large trees along the corridor. Although large groves of cottonwoods or Goodding's willow were historically rare along the river, within this new hydro-riparian context, the possibility exists for these riparian woodlands to thrive. However, this condition will not likely be achievable without proactive management and protection of these trees from beaver.

The xero-riparian areas along the river tell a different story. The lack of inundation has dramatically altered the floristic composition of these areas, and without active recruitment of mesquite, these zones will continue to change and evolve into a new "type" of xero-riparian habitat. Climate change may be an equal player in promoting alterations to the xero-riparian systems. Repeat photographs depict a changing floristic composition that may be linked to both a decrease in number of days with frost and an overall decrease in precipitation. In the western Grand Canyon, brittlebush and barrel cactus are far more common than in the late 1800s, and both species are less tolerant of frost than mesquite. There is also evidence that mesquite trees are dying back at a greater rate due to years of drought (Waring et al. 2011).

The condition of the tributaries is only known from the tamarisk removal data and repeat photographs. An assumption could be made that since the tributaries are natural systems with little or no human influences on flow regimes, they are more intact and less at risk than other riparian areas. However the tributaries are at risk of exotic plant invasions, and a lack of funding and resources has precluded the park from consistent surveys and management in these areas, raising the possibility that new exotic plant species populations will establish and become difficult to mitigate. In Glen Canyon NRA, crews located 12 new populations of ravenna grass in canyons that are rarely visited by park staff. In Grand Canyon NP, vegetation staff members have found small populations of pampas grass several miles up remote tributaries. Without more frequent surveys, such infestations will not likely be located or treated.

Impacts from visitors are different in the tributaries and the main stem. Along the river corridor, camps are rapidly disappearing as vegetation encroaches on open sandy areas, and arrowweed is the main culprit. Park staff have tried to manage arrowweed in several camps, but without continued funding and staff time these efforts may be wasted. Impacts from visitors on the tributaries are less than on the main stem mostly because there are so few visitors along the tributaries. However, in canyons like Hance Creek, where visitation is high in a narrow canyon, problems arise with trampled riparian vegetation and human waste disposal.

Overall, the future riparian community condition of Grand Canyon will depend on ecologically sound flow regimes in the river and protection from invasion by exotic plant species in the side canyons.

5.8.8. Data Needs

- Vegetation plot data have been collected in association with several projects, all with different research goals. Datasets are different and not necessarily comparable as is, but provide critical baseline and historic information. It would be worthwhile to integrate these datasets and generate usable, comparable data. Long-term trends would then be more readily identified both in the main stem and tributaries.
- Data on changes in vegetation along the river are abundant but much more limited for the tributaries. The tributaries provide a valuable reference point for natural, relatively undisturbed riparian areas and could provide insight to managers of other similar systems. Continued data collection and analysis of the tamarisk removal project is scheduled and will provide valuable insight on the successes and challenges of such a project, but more research and surveys are needed.
- Data on the current status of the marshes along the river corridor are urgently needed.
- Quantification of the beaver population and population growth rate is needed.
- There is a lack of knowledge about historical (pre- and post-dam) and current extent and status of riparian woodlands. Data, especially in the form of ground-truthing known areas, would provide valuable information for managers.
- Springs, especially those on rim areas subject to impacts from trespassing ungulates and inner canyon areas with high visitation, should be regularly surveyed for the presence of exotic species.

5.8.9. Level of Confidence

Data sets used in this analysis were collected by trained botanists using standard sampling and species identification methods. Although confidence in the precision or accuracy of measurements and observations is high, some uncertainties may persist.

5.8.10. Sources of Expertise

This section was prepared by Melissa McMaster, MSc, currently a plant biologist for Mariposa Ecological and Botanical Consulting, and formerly the plant biologist for backcountry areas for Grand Canyon National Park and Michael Kearsley, PhD, currently Grand Canyon National Park Resource Specialist, formerly the park's vegetation mapping coordinator.

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5.9. Rare and Endemic Plant Species

5.9.1. Description



There are 199 special-status plant taxa in the GGCLA area, including 32 known endemic plant species. The Bright Angel Creek–Colorado River HUC 10 watershed hosts the highest occurrence of special-status taxa. Grand Canyon NP actively propagates sentry milk-vetch, a federally listed endangered species, monitors its known locations, and has implemented reintroduction action (NPS photo).

High plant diversity in the Grand Canyon region stems in large part from the high topographic and elevational diversity, which contributes to a wide range of microhabitat conditions and protects many hard-to-reach sites from disturbance by humans and livestock. The GGCLA is home to 199 special-status plant taxa, including 32 known endemics (Table 21).

Special-status plant species include federally protected taxa (threatened or endangered species), state Species of Special Concern, candidate or former candidate species for listing under the Endangered Species Act, rare species, and endemic species.

Table 21. Endemic plant taxa (a subset of special-status plant species identified in SEINet) occurring in the GGCLA analysis area.

Area	Scientific Name
Grand Canyon NP only	*Argemone arizonica*
	*Astragalus cremophylax var. cremnophylax**
	Chylismia confertiflora
	Silene rectiramea
GGCLA region	*Agave phillipsiana*
	Agave utahensis var. *kaibabensis*
	Beckmannia syzigachne
	Castilleja kaibabensis
	Chrysothamnus scopulorum
	Chrysothamnus stylosus
	Cymopterus breviradiatus
	Cymopterus macdougalii
	Draba asprella
	Encelia frutescens
	Encelia resinifera
	Encelia virginensis
	Eremogone aberrans
	Ericameria arizonica
	Euphorbia aaron-rossii
	Flaveria mcdougallii
	Hesperoyucca newberryi
	Hesperoyucca newberryi
	Ipomopsis tridactyla
	Lorandersonia salicina
	Mentzelia canyonensis
	Mentzelia hualapaiensis
	Opuntia basilaris var. *longiareolata*
	Penstemon pseudopotus
	Phacelia filiformis
	Phemeranthus validulus
	Primula specuicola
	Rosa stellata ssp. *abyssa*

* Federally enlisted endangered species

5.9.2. Indicator/Measure

- Occurrence of rare and endemic plants

5.9.3. Methods

The occurrence of special-status plant species was assessed using records from the Southwest Environmental Information Network (SEINet), which assembles specimen records and can be queried by location, species, status, and other criteria. SEINet records for the Grand Canyon and surrounding region were downloaded and filtered for special-status species. The resulting 3,385 records included information pertaining to the location and year of each specimen collection as well as the collecting organization or individual and the current location of the specimen. Specific spatial information identifying the collection site with enough precision to use in a GIS was provided for 2,725 of these records. These were then combined with additional records provided by Grand Canyon NP, and the resulting set of 2,965 records was used to develop the map in Figure 40 as well as in the spatial summary statistics described here. Species with no spatial records included *Ipomopsis tridactyla*, *Phyllodoce empetriformis*, and *Silene menziesii*.

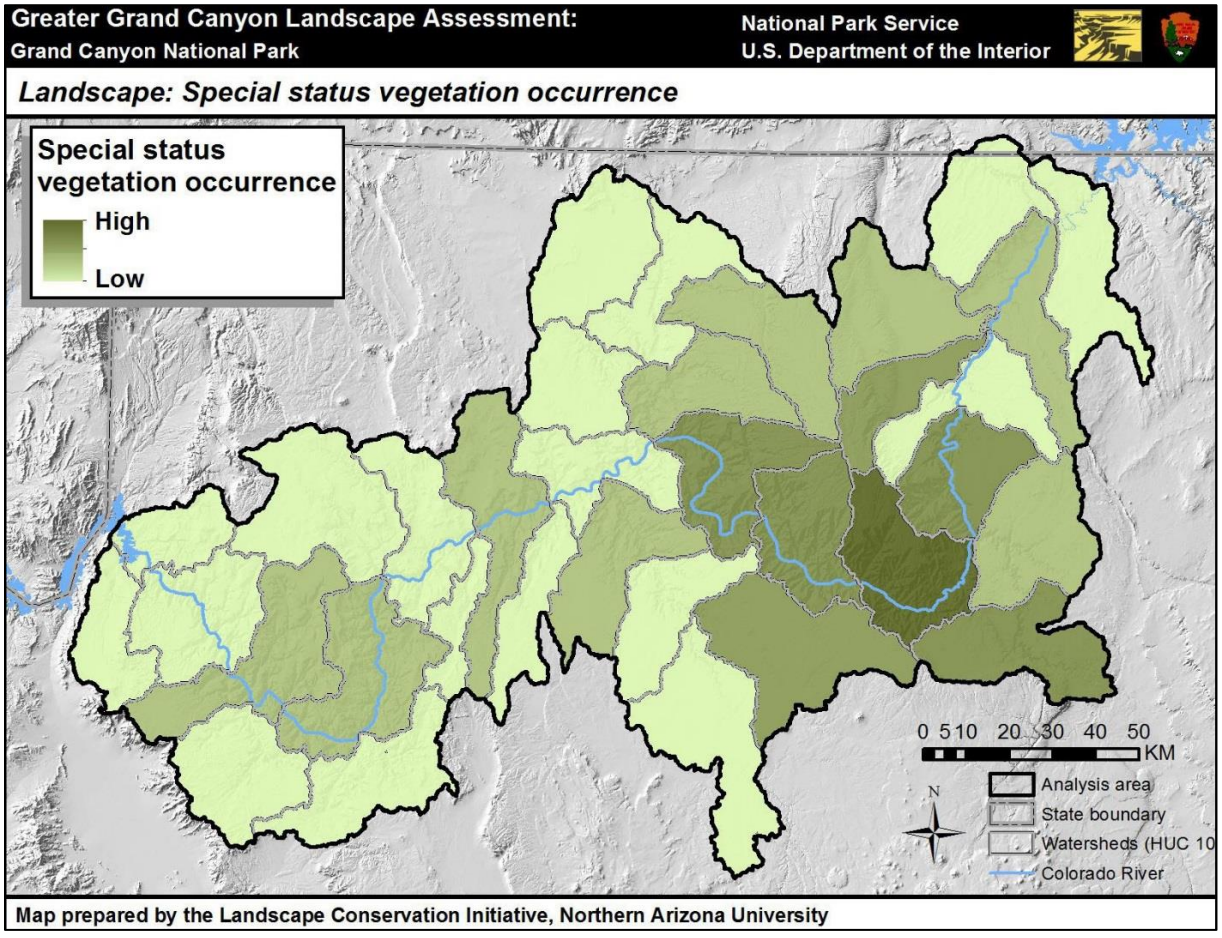
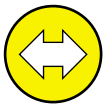


Figure 40. Occurrence of special-status vegetation across the GGCLA area. Special-status plant species include federally protected taxa (threatened or endangered species), candidate or former candidate

species for listing under the Endangered Species Act, state Species of Special Concern, rare species, and endemic species.

5.9.4. Condition and Trend

Table 22. Summary of rare and endemic plant species condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Occurrence	Occurrence of special-status plants across the analysis region.		No special-status plant extinctions have been recorded in the analysis area, and the park is actively working to propagate target species. However, sites outside the park are subject to various stressors, and special-status plant populations may be subject to these threats.

5.9.5. Summary

Spatial assessment of plant occurrence records identifies the highest occurrence of special-status plants in the Bright Angel Creek–Colorado River HUC 10 watershed, with 559 documented occurrences (see Figure 40). Other watersheds with a high occurrence of special-status plants include Shinumo Creek–Colorado River with 289 documented occurrences and Tapeats Creek–Colorado River with 196 occurrences. By contrast, very few records of special-status plants have been obtained in the watersheds of Spencer Canyon (4 occurrences), Upper Havasu Creek (6 occurrences), and Middle Havasu Creek (9 occurrences).

Stressors to special-status plant taxa in the GGCLA area include potential increases in uranium mine activity and water resource extraction, as well as intentional and unintentional disturbance from human activities such as collecting, canyoneering, off-road vehicle operation, and hiking.

Grand Canyon NP is working to protect special-status plants, with a focus on the park's one endangered species: sentry milk-vetch (*Astragalus cremnophylax* var. *cremnophylax*). Park staff and partners are actively propagating sentry milk-vetch, monitoring all known populations annually, and implementing actions listed in the 2006 Sentry Milk-Vetch Recovery Plan (USFWS 2006). As part of that plan, several new populations of the species have been planted at reintroduction sites in an effort to move the species toward down-listing. Park staff monitor the other known endemic species as time and staffing allow. The Kaibab National Forest is developing a rare and endemic plant guidebook.

5.9.6. Data Needs

- Spatial data are lacking for at least three special-status plant taxa (*Ipomopsis tridactyla*, *Phyllodoce empetriformis*, and *Silene menziesii*) known to occur in the analysis area.

- Surveys for special-status species are biased toward areas of high human visitation throughout the analysis area. Our ability to evaluate the spatial occurrence of special-status plants is therefore skewed by uneven sampling.
- Sampling across less-visited areas of the park would improve our understanding of spatial distributions of special-status species.
- Systematic entry of plant information into the SEINet database can facilitate future collaborations and better management across boundaries.

5.9.7. Level of Confidence

Occurrence records have a high degree of confidence as they were obtained from the SEINet database. However, lack of occurrence does not indicate absence with high confidence; collection records are biased toward locations that are heavily visited by people, and many sites have not been sampled.

5.9.8. Sources of Expertise

This section was prepared by Lori Makarick and Clare Aslan. This analysis was performed by Lori Makarick, Santiago Garcia, Mark Nebel, Melissa McMaster, and Steve Fugate of Grand Canyon National Park. Spatial analysis was performed by Jill Rundall, NAU.

5.9.9. Literature Cited

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5.10. Wildlife: Mountain Lion

5.10.1. Description



Mountain lion habitat quality is influenced by the availability of surface water and distance from developed roads. Road construction and development throughout the greater Grand Canyon landscape may impact mountain lion movements, as could groundwater withdrawal that reduces surface water availability. Major mortality sources in the analysis area are sport hunting, followed by collisions with motor vehicles. The primary prey of the mountain lion in the analysis area is elk, followed by deer. The prey base in the analysis area appears to be healthy (NPS photo by K. Fink).

Mountain lions, also known as cougars (*Puma concolor*), are the most widespread large predator in the western United States. Although likely declining in some areas (Stoner et al. 2006; McKinney et al. 2009; Lambert et al. 2011), they are sufficiently abundant to directly and indirectly affect ecosystems (Soulé et al. 2003). Mountain lions are particularly vulnerable to perturbations in fragmented habitat because of their large ranges, extensive resource requirements, low densities, slow population growth rates, and direct persecution by humans (Noss et al. 1996; Crooks 2000). Human populations and associated infrastructures in and near cougar ranges have increased rapidly enough during the last three decades to exacerbate risks to humans from mountain lions and to affect lion behavior and populations (Torres et al. 1996). Maintaining landscape connectivity and providing wildlife movement corridors can ameliorate the effects of human-induced fragmentation (Harris and Gallagher 1989; Beier 1995) and movement barriers. Landscape-level connectivity is essential to allow for the movement of animals among foraging and breeding sites, the dispersal of individuals from natal ranges, and genetic exchange between populations (Noss 1983; Terborgh and Soulé 1999).

Since the 1960s, many mountain lion populations in the West have increased primarily in response to increasing ungulate populations throughout the cougar range (Berger and Wehausen 1991). In

western North America, cougar management has primarily focused on regulating sport harvest, on removing threatening or depredating individuals, and on cougar predation on species of concern (Logan and Sweanor 2010), such as vulnerable ungulate populations or game species. In recent decades this concern has centered around declines of mule deer (*Odocoileus hemionus*) and the reduction or even extirpation of small, isolated bighorn sheep (*Ovis canadensis*) populations. Ripple and Beschta (2006, 2008) have suggested, however, that removal of cougars can trigger trophic cascades resulting in increasing numbers and densities of large ungulates.

In Grand Canyon NP, cougars are the only remaining large predator sufficiently abundant to exert a top-down effect on lower trophic levels. They directly (predation) and indirectly (competition) affect the abundance and distribution of prey species, including mesocarnivores (animals such as foxes whose diet consists of 50–70% meat). Competition with other large carnivores is nearly absent, with the exception of perhaps black bears (*Ursus americanus*), which are dispersed in very low densities around the Grand Canyon. Cougar abundance is ostensibly robust in areas with good-quality habitat, which is indicative of robust prey availability, namely mule deer and elk (Cervus elaphus). However, the survival and population resiliency of cougars in the area will be strongly influenced by human-related factors, such as land use (i.e., roads, development) and harvest management on adjacent jurisdictions outside of Grand Canyon NP.

5.10.2. Indicators/Measures

- Habitat quality
- Abundance
- Survival and mortality factors
- Diet and prey base
- Seasonal movement
- Body condition

5.10.3. Methods

Our assessment of mountain lion habitat quality incorporates the following elements: habitat quality, abundance, survival and mortality factors, diet and prey base, seasonal movement, and body condition. Habitat quality was assessed and mapped spatially using telemetry data from 30 individual mountain lions. This number provides a good representation of the population for drawing conclusions about certain general facets of mountain lion ecology such as diet composition, movements and ranges, and body condition, which have been consistent across multiple years. Understanding survival and abundance from this sample size is more difficult because relatively few animals have been integrated into the sample annually, and conclusions are subject to behavioral, environmental, and human variations.

Our analyses examined the probability of each individual moving through a given area between relocations. We then used general linear mixed models (GLMMs) to relate probability values to topographic and vegetation covariates.

Habitat Quality

Telemetry data from 30 pumas monitored from 2003 to 2013 were obtained through an agreement with Grand Canyon NP. For data analysis, periods of active movement were targeted by excluding relocations within 200 meters of adjacent relocations (total sample size of relocations = 56,500). Brownian Bridge movement models (BBMMs) were used to estimate the probability of each individual moving through a given area between relocations (Horne et al. 2007). BBMMs are based on the distance, elapsed time, and individual mobility between relocations, making them more suitable for estimating space use between relocations than traditional utilization distributions (UDs) that estimate intensity of space use. We used GLMMs to relate BBMM probability values to topographic and vegetation covariates derived from Landfire and NHD+, as well as TIGER/Line roads data.

Abundance

Data sources are derived from compilation of numbers of captured cougars, and extrapolations from other cougar studies in similar landscapes and prey base.

Survival and Mortality Factors

Causes of mortality are derived from mortality site investigations of collared cougars in Grand Canyon NP. Cougar deaths were also confirmed by sport hunters who reported harvesting a collared cougar. Age-specific radio-day, and survival for each collared animal between 2003 and 2013 were calculated based on a dynamic year determined by their age at capture. Kaplan-Meier limit estimators (Kaplan and Meier 1958) as modified for staggered entry by Pollock (1989) were used to estimate annual survival rates of cougars.

Diet and Prey Base

Data sources are GPS clustered kill sites of collared cougars monitored between 2003 and 2013 in Grand Canyon NP and on North and South Kaibab National Forest lands. Site investigations of cougar kills provided data on prey composition.

Seasonal Movement

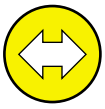
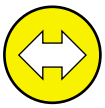
Data sources are GPS and satellite locations of collared cougars monitored between 2003 and 2013 in Grand Canyon NP and on North and South Kaibab National Forest land.

Body Condition

Data sources are biological samples and morphological measurements of captured cougars, including sex, estimated age using tooth eruption and wear characteristics (Anderson and Lindzey 2000), body mass, and body measurements. To test for weight and age differences between cougars captured on the north and south rims, we used a two-way factorial analysis of variance in assuming equal variances to account for small sample sizes.

5.10.4. Condition and Trend

Table 23. Summary of mountain lion resource conditions and trends by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Habitat quality	Quality at the regional scale via literature and spatial analysis		Cougars prefer habitat undisturbed by humans and demonstrate affinity for the canyon rims.
Abundance	Mark-recapture studies are required		Cougar captures and casual sightings and sign indicate a robust population, but mark-recapture studies are needed to confirm abundance.
Survival and mortality factors	Collared individual survival, compared with literature-derived standards		Most mortality is due to human impacts, especially hunting and collisions with motor vehicles.
Diet and prey base	Field kills, compared with literature-derived standards		Ungulates, especially elk, are abundant.
Seasonal movement	Collared individual survival, compared with literature-derived standards		Hunting outside the park is likely exerting a strong impact.
Body condition	Captured individuals, compared with literature-derived standards		Captured individuals exhibit body weights consistent with other studies.

Habitat Quality

Our assessment of habitat quality across the analysis area predicts high habitat quality in the eastern portion of the landscape, east of Grand Canyon NP and south of the Vermillion Cliffs, as well as on the Kaibab Plateau in the extreme north of the analysis area. Lower quality is predicted on USFS lands adjacent to the park on both rims. Mountain lion movements demonstrated higher probability of use at moderate slopes, at lower topographic positions (i.e., channel bottoms), and in more rugged terrain. Areas with greater tree cover and higher density of forest edges were favored. Movement probability decreased with slope-weighted distance from all water body types but increased with distance from two-lane or greater paved roads (Figure 41).

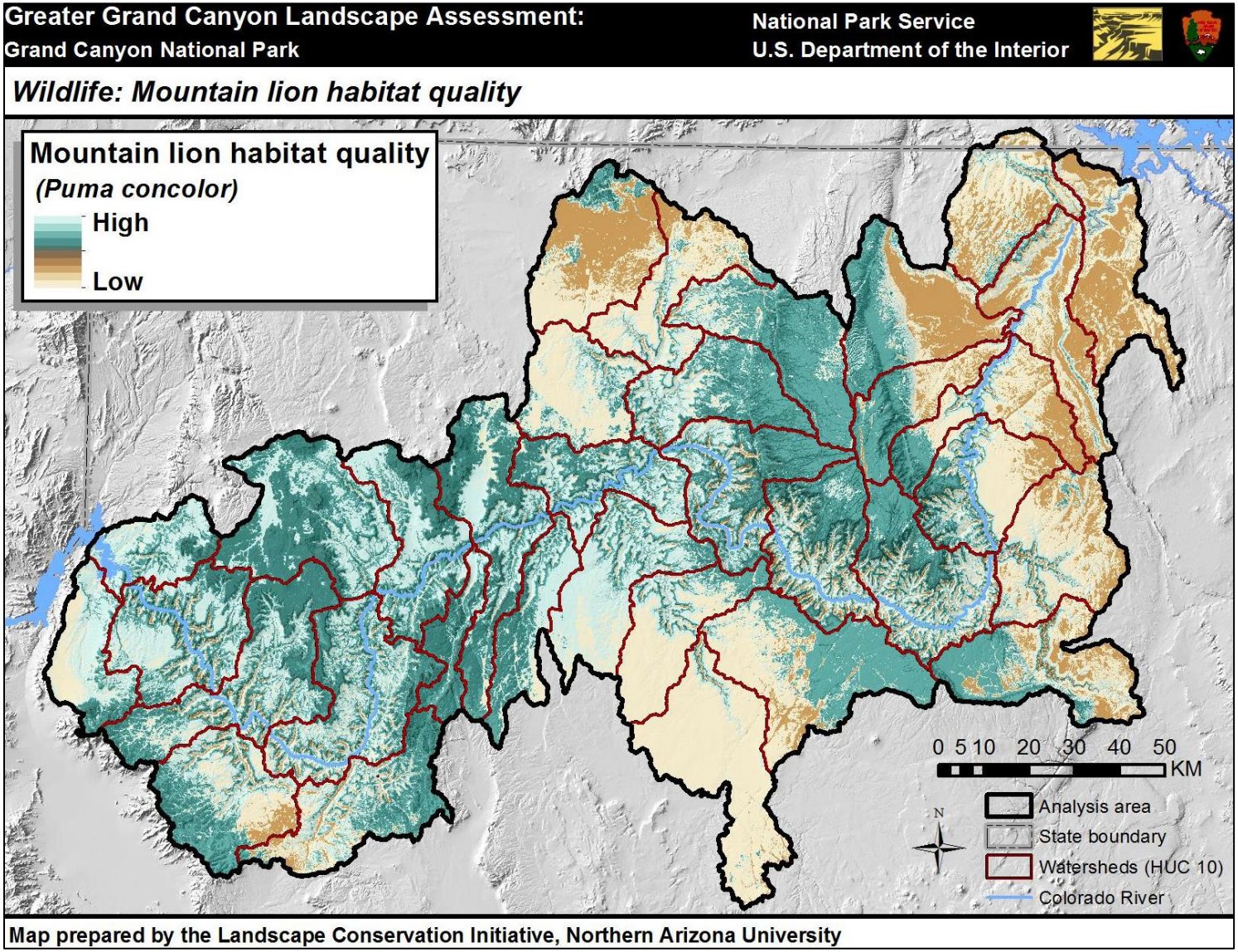


Figure 41. Mountain lion habitat quality.

Our spatial analysis allows examination of the distribution of areas of high puma habitat quality by jurisdiction and by HUC 10 zone. The breakdown of these elements by jurisdiction appears in Table 24.

Table 24. Puma habitat assessment by land management jurisdiction. Average (± s.d.) habitat quality by jurisdiction across the analysis area. Lowest quality is designated as 1 and highest as 10.

Indicator	BLM	USFS	Tribal	NPS	Private	State Trust Land	Other
Puma Habitat Quality	6.6 ± 1.6	7.8 ± 1.3	6.6 ± 1.6	7.4 ± 1.5	5.8 ± 0.8	5.6 ± 0.9	5.7 ± 1.2

HUC 10 zones with the highest average puma habitat quality, or values above 8, include zones 15 (Mohawk Canyon–Colorado River), 16 (Parashant Wash), and 14 (Prospect). Zones with the lowest average puma habitat quality, or index values below 5.5, are zones 1 (Water Holes Canyon–Colorado River), 26 (Upper Havasu Creek), 20 (Bulrush Wash), and 6 (Tanner Wash-Colorado River).

Abundance

Capture efforts at Grand Canyon NP have not been evenly distributed in time and space, and estimates of cougar abundance have not been systematically generated via mark-recapture methods, although methods for estimating cougar densities in the Grand Canyon are currently being refined. Choate at al. (2006) have concluded that intensive mark-recapture efforts were the only method to produce reliable estimates of cougar abundance, and Robinson et al. (2008) and Russell et al. (2012) have reported that mark-recapture genetics studies can produce valid population estimates in defined geographic management areas. The cougar population within Grand Canyon NP likely serves as a source population to adjacent areas.

Survival and Mortality Factors

Adult survival is an important factor in understanding a cougar population and its relationship to prey, management objectives, and responses to natural perturbations at both a local and regional level (Quigley and Hornocker 2010). Previous studies (McKinney et al. 2009; Ruth 2004; Logan and Sweanor 2001; Beier and Barrett 1993; Anderson et al. 1992) have reported a wide range of adult survival rates for pooled male and female (range 0.55–0.92) as well as individual genders (range 0.29–0.91 for males and 0.65–0.82 for females). In total, 31 radio-collared cougars (15 males, 16 females) were included for survival analyses in Grand Canyon NP. Annual survival rates of all marked cougars averaged 0.71, within the reported range from other studies.

Sport hunting is commonly reported to be the primary cause of mortality in hunted cougar populations (Lindzey 1988; Ruth et al. 1998; Logan and Sweanor 2001; Lambert et al. 2006; Laundré et al. 2007). Even though the Grand Canyon serves as an unhunted protected refuge for cougars, almost 60% of known mortalities to cougars collared in the canyon can be attributed to sport hunting outside of the park: 80% of male cougars that died were attributable to sport hunting, whereas sport hunting only accounted for 33% of collared female deaths (unpublished NPS data; Holton 2011).

However, several collared cougars abruptly disappeared while ranging outside the park's boundary, and unreported harvesting of some of these animals is suspected.

Secondary to sport hunting, collisions with motor vehicles (2 lions) and natural causes of intraspecific killing (1), disease (1), and trauma (1) account for the other causes of mortality to cougars in Grand Canyon NP. Among these other causes, roads may pose the greatest threat, particularly to dispersing cougars (Beier 1995; Murphy et al. 1999). Cougar survival has been reported to decrease with increasing road density (Ruth et al. 2011). Indirectly, the higher densities of roads found on adjacent USFS land may increase cougar harvest rates outside of the park. In more natural systems without sport hunting, intraspecific aggression is the primary cause of mortality for cougars (Logan and Sweanor 2001). Only one account of intraspecific mortality has been documented in the Grand Canyon. The incidence of disease and trauma-related mortalities may be underrepresented, masked by the higher human-caused sources of mortality.

Mortality rates outside the park are less well understood than those within the park. However, between 2003 and 2007 in bordering GMUs, 75 cougars were harvested: 18 cougars in GMU 9 (80:100 M to F ratio); 41 in GMU 12 (141:100); and 16 in GMU 13 (129:100). The Navajo Nation Department of Fish and Wildlife currently has a quota system in place and issues an unlimited number of permits to tribal members. The Hualapai Tribe distributes 10 adult cougar permits each year (Hualapai Tribe 2013). The tribe also maintains a rigorous predator bounty program to remove cougars and coyotes (*Canis latrans*) in order to promote harvestable numbers of ungulates. Areas adjacent to Grand Canyon NP maintain heavy hunting pressure and may serve as a sink population, with the park serving as a source population.

Diet and Prey Base

Arizona's native elk (*Cervus canadensis merriami*) disappeared from eastern Arizona in the late 1800s. To repopulate the region, from 1913 to the 1920s the state of Arizona translocated Rocky Mountain elk (*Cervus canadensis nelsoni*) from Yellowstone National Park to eastern and central Arizona. Elk are now abundant throughout the southern Grand Canyon region, with high densities of elk in GMUs 9 and 10, as well as on tribal lands that border the canyon. These populations are maintained by a highly regulated system of artificial waters. Because of this influx of elk, cougar diets in the southern Grand Canyon region have presumably changed. Cougars on the canyon's south rim eat substantial numbers of elk and deer, with elk comprising 67% of kills documented on the south rim. Mule deer are a secondary prey species for cougars on the south rim, but vary seasonally as female cougars tend to prey on mule deer more often in winter. This prey switching by female cougars, which can increase predation on the less abundant or secondary prey species (mule deer), has been shown to have negative effects on alternative prey (Hamlin et al. 1984; Sinclair et al. 2001). Coupled with competition between deer and elk for resources, cougar predation on mule deer can have a compounded effect, with mortality proportionally increasing as mule deer numbers decline (Sinclair et al. 2001).

Elk have not yet sufficiently encroached into the northern Grand Canyon region to displace mule deer as the most abundant large ungulate, comprising about 96% of cougar diets on the north rim, followed by marginal kills of desert bighorn sheep (*Ovis canadensis nelsoni*) and coyotes. Small prey

comprises only 3% of cougar diets on the south rim and less than 1% on the north rim. However the importance of small to middle sized (2–30 kg) prey to cougars is not well understood (Ackerman et al. 1984); smaller prey has been reported to improve the survival of cougars at particular life stages (Murphy and Ruth 2010). Most of the documented kills of small prey at Grand Canyon NP have been mesocarnivores, and 67% of these have been killed by female cougars.

Seasonal Movement

Cougars occur at relatively low densities and require large areas of suitable habitat that incorporate adequate large prey populations, minimal human interference, and sufficient ambush and stalking cover (Seidensticker et al. 1973; Currier 1983; Lindzey 1988; Koehler and Hornocker 1991). In addition to habitat arrangement, cougar movement depends on environmental factors such as locations of primary prey, locations of previously killed carcasses, and interactions with conspecifics (Dickson et al. 2013). Methods for estimating cougar home ranges in Grand Canyon NP are currently being refined and will be available in the near future. Estimates reported are conditional, introductory in nature, and should be interpreted as an initial means of comparison to other studies. Applying a 95% composite kernel density estimator (KDE), ranges for male cougars on the south rim averaged 518 km^2, and north rim males averaged 597 km^2. The mean annual range of adult female cougars on the south rim was 237 km^2. North rim female ranges were larger, averaging 381 km^2.

Cougars whose ranges incorporate habitat along and up to the rim demonstrate an affinity for utilizing the canyon edge habitat. This is likely attributable to the higher prey densities that can be found along edge habitat and the travel access along the rim and down into the inner canyon. Cougars also strongly select for daybed locations in areas of dense vegetation and away from human disturbance (Dickson and Beier 2002; Kautz et al. 2006; Cox et al. 2006; Arundel et al. 2007). Considering the degree of range overlap and recurrent use of the canyon-rim edges by cougars, these areas should be regarded as essential habitat.

Range concentration in non-hunted areas along the southern rim may be further attributed to jurisdictional boundaries. Roughly 60% of locations of marked cougars on both the north and south rims, averaged across all sex and age classes, were on adjacent Kaibab National Forest (NF) lands. Cougars ranged inside the park boundary about 35% of the time.

Natural barriers, such as rivers and other large bodies of water, may impede or otherwise affect population connectivity for large carnivores, potentially decreasing the genetic diversity within a metapopulation framework (Beier 1995; Robinson et al. 2008). The degree to which the Colorado River acts as a barrier for cougars is unknown. Movements between rims may be infrequent; only two female collared cougars have been documented crossing the river (unpublished NPS report, Holton 2011). The harsher topography and sparser prey base of the inner canyon as compared to the gentler topography and robust prey base on the canyon rims likely deters movement into the inner canyon and as a byproduct river crossings. Although major transportation features can function as strong filters and risk factors, cougars in Grand Canyon NP generally are not deterred from crossing two-lane paved roads to access suitable habitat. Four confirmed cougar road kills have occurred within a 10-mile stretch of paved road in the park in the last decade. Mortality of cougars associated with paved roads outside the park but within the greater Grand Canyon area is unknown. Cougar

movements in relation to unpaved road density in adjacent Kaibab NF districts and on Arizona state lands have not been thoroughly investigated. Van Dyke et al. (1986) reported that resident cougars on the North Kaibab selected home ranges with lower densities of roads. However, high road densities in otherwise suitable cougar habitat outside of Grand Canyon NP pose a particular threat to dispersing juveniles, which are more likely to encounter sport hunting in the North and South Kaibab ranger districts.

Body Condition

Between 2003 and 2012, 25 adult and 7 subadult cougars were captured on the south and north rims. Cougars are sexually dimorphic, with males markedly larger than females (30–50% difference; Gay and Best 1995; Pierce and Bleich 2003). Cougars of all ages and sexes captured (n = 29) on both south and north rims averaged 45.7 kg ± 9.9 kg. Adult cougars (≥ 3 years old, n = 22) averaged 47.9 kg ± 0.9 kg (F = 38.9 ± 1.3, M = 55.5 ± 1.3). Males averaged 30% heavier than females, similar to reports from other studies (Gay and Best 1995; Pierce and Bleich 2003). Subadult cougars (1.5–3 years old, n = 7) averaged 38.1 kg ± 2.4 kg (F = 32.1 ± 3.2; M = 44 ± 3.6). No significant difference in weight was detected between north and south rim cougars across all sex and age classes. Weights of cougars captured at Grand Canyon NP were within reported weights from other studies (Logan et al. 1986). Iriarte et al. (1990) reported that cougar body size is strongly influenced by the size of available prey.

Age at the time of capture was determined by visual inspection of tooth wear and gumline recession (Ashman et al. 1983; Laundré et al. 2000). Cougars from the south rim (n = 22) averaged 5.5 ± 0.7 years (M = 4.6 ± 0.9, F = 6.6 ± 0.9), and cougars from the north rim (n = 10) averaged 3.4 ± 0.4 years (M = 3.5 ± 0 .6, F = 3.3 ± 0.5). No significant age differences ($p > 0.05$) were detected in male cougars on the north and south rims, but female cougars on the north rim were significantly ($p = 0.019$) younger than south rim females. The young age structure of cougars on the north rim may be indicative of heavy hunting pressure on the North Kaibab NF. Turnover in adult individuals can be high in heavily hunted populations, where they are routinely replaced by subadult individuals.

5.10.5. Summary

The Arizona Game and Fish Department has not developed population estimates for cougars in Game Management Units (GMUs) near the Grand Canyon, but the department estimates around 2500–3000 animals throughout the state. Efforts to assess the cougar population within the analysis area are underway. In the meantime, assessments of mortality sources, prey base, range sizes, habitat availability, and body condition can all be indicative of overall cougar population health in Grand Canyon NP. Overall, a relatively high percentage of human-caused cougar mortalities (primarily hunting outside the park and roadkill events) in the region suggests that Grand Canyon NP may not necessarily be operating and functioning as a natural refugia for a large population of cougars. However, other indicators are more positive. The prey base for cougars throughout much of the park is fairly robust, and varies from the south to the north rims of the canyon. Unnaturally high densities of elk have modified the cougar-prey dynamics in the southern Grand Canyon region. On the north rim, the prey base for cougars trends toward more natural conditions. Small prey item kills are likely often undetected because consumption is generally more complete.

The size and boundaries of a cougar's territory depends on the density and distribution of available prey and of other cougars, jurisdictional management (namely in hunted populations of cougars), and natural and human-related barriers. Habitat located along the rims of the Grand Canyon itself appears to be particularly preferred and is regularly used for daybeds. Preferred cougar habitat found within Grand Canyon NP is primarily along the rims of the canyon, which is relatively small in area compared to the extensive amount of quality habitat found adjacent to the park; good-quality cougar habitat can be found both within the park and in surrounding jurisdictions. Adjacent lands outside the park are characterized both by heavy hunting pressure and more quality habitat and resources.

5.10.6. Data Needs

- It is currently impossible to adequately assess mountain lion abundance in the analysis area. Mark-recapture studies would be required for this.
- A better understanding of inner canyon-obligate mountain lions that may have a larger impact on bighorn sheep than estimated is also needed, as are abundance/density estimates.

5.10.7. Level of Confidence

The data sources used to evaluate mountain lions include telemetry data from 30 individuals as well as information derived from the wildlife literature. Assessments of habitat, prey base, mortality factors, and movement carry high confidence. Mark-recapture studies would help with abundance metrics.

5.10.8. Sources of Expertise

This section was prepared by Brandon Holton. Mountain lion habitat quality analysis was performed by Brett Dickson (Conservation Science Partners and Northern Arizona University). Abundance, survival, prey base, body condition, and seasonal movement data were provided by Brandon Holton, Grand Canyon National Park. Holton also authored an unpublished park report (2011) providing much of the information cited in this assessment.

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5.11. Wildlife: Desert Bighorn Sheep

5.11.1. Description



Information pertaining to the abundance and density of bighorn sheep in Grand Canyon is still relatively limited compared to other desert bighorn ranges in the desert southwest. Habitat quality and connectivity are impacted by human-caused disturbances. Epizootic pneumonia is currently of greatest concern (NPS photo).

Desert bighorn sheep (Ovis canadensis nelsoni) are considered a species of concern in the GGCLA, where they are distributed sparsely and largely confined to the inner canyon itself. Stressors include disease, mountain lion predation, disturbance from recreationists and overflights, and disrupted connectivity due to highways and other developments.

Desert bighorn declined precipitously in the late 1800s and early 1900s in a significant part of their historic range (Wehausen et al. 1987; Valdez and Krausman 1999). Transmission of disease from domestic sheep was one of the primary causes for this decline, along with overhunting (Wehausen et al. 1987; Valdez and Krausman 1999; Gross et al. 2000; Zeigenfuss et al. 2000; Singer et al. 2001). Bighorn sheep disperse between mountain ranges and canyons, often crossing highways and other anthropogenic barriers that are the cause of high mortality (Epps et al. 2005). Human recreation activities may affect survival and reproductive success as well (Papouchis et al. 2001; Etchberger et al. 1989). Finally, mountain lion predation can also significantly limit bighorn sheep populations (Kamler et al. 2002; Holl et al. 2004; Festa-Bianchet et al. 2006).

Since bighorn sheep typically occupy arid mountain ranges, the population in the analysis area is unusual in that it occupies an extensive deep canyon. Bighorn sheep within the park are patchily distributed throughout the Inner Canyon, from rim to river. Primary forage species for bighorn sheep include encelia (*Encelia farinosa*), acacia (*Acacia greggii*), black grama (*Bouteloua eriopoda*), desert globemallow (*Sphaeralcea ambigua*), blackbrush (*Coleogyne ramosissima*), and Mormon tea

(*Ephedra* spp.). There are aggregations of bighorn individuals near the Colorado River during the breeding season, although at other times, adult males may move to higher elevations while adult females tend to remain along the river. Higher elevations provide high-quality forage, but also higher risk of mountain lion predation and higher impact from overflights. Lower elevation provides easier access to water but also potential impacts from river recreationists. Habitats important for lambing include steep and rugged terrain that have protection from predation (Etchberger and Krausman 1999).

5.11.2. Indicators/Measures

- Habitat quality
- Connectivity
- Movements
- Population estimate
- Survival and mortality factors
- Genetic structure
- Forage availability
- Disease factors

5.11.3. Methods

Habitat Quality

Habitat quality analysis examines the probability of an individual being found in a particular site. Habitat quality was assessed and mapped spatially using telemetry data from 40 bighorn sheep individuals tracked in the western portion of the analysis area, and overlaying utilization data with topographic and vegetation data. The assessment of bighorn habitat quality and connectivity incorporates seven elements: abundance, habitat quality, lambing area, genetic diversity, mortality, seasonal movements, and forage availability. We used general linear mixed models (GLMMs) to relate probability values to topographic and vegetation covariates.

Connectivity

This indicator was developed using the habitat quality data to develop a resistance surface, and then employing Circuitscape to predict connectivity across that surface. Connectivity analysis estimated a probability of movement between pixels over a resistance surface.

Movements

Data sources are both high-and low-precision GPS and satellite locations of collared bighorn sheep monitored between 2010 and mid-year 2014, and historical and current observations of lambs along the river. This information is preliminary and limited in scope. Ewe lambing behavior and preferred lambing areas in Grand Canyon were inferred from studies of desert bighorn sheep in areas outside of Grand Canyon. Based on lambing behavior extrapolated from other studies, GPS locations of

collared ewes during the estimated lambing season and timing of lambs observed were used to predict potential lambing areas and parturition.

Population Estimate

Data sources are historical accounts of population estimates at Grand Canyon NP; the most recent 15 years of observations of bighorn sheep collected during river trips, and population information from Arizona Game and Fish Department (AZGFD); and American Indian tribes with lands within the analysis area.

Survival and Mortality Factors

Data sources are both high-and low-precision GPS and satellite locations of individually collared bighorn sheep monitored between 2010 and mid-year 2014. GPS satellite collars are equipped with mortality sensors that indicate when the collar (i.e., the animal) has stopped moving for over four hours. Mortality information is communicated through an animal-specific log transmitted daily or bi-weekly via satellite. In addition, all collars continuously broadcast radio signal that change pulse when mortality occurs. When mortality of an animal is detected, a mortality site investigation and field necropsy occurs to determine cause of death. This information is an estimate, does not reflect a trend, and is limited in scope.

Lamb-ewe Ratios / Lamb Recruitment

Data sources are direct observations of bighorn sheep ewes and lambs collected during river trips by Grand Canyon science and resource management personnel between 2010 and mid-year 2014. Lamb-ewe ratios are derived from spring trips (April-June), with estimated lamb recruitment derived from fall (September-October) trips.

Predation Impacts

Data sources include both high-and low-precision GPS and satellite locations of individually collared bighorn sheep and pumas monitored between 2010 and mid-year 2014, and 2003 and 2013, respectively. Impacts from predation by mountain lions are derived from mortality site investigations of collared bighorn sheep in Grand Canyon, and an overall assessment of prey composition of collared mountain lions in Grand Canyon.

Survival Rates

Data sources are high-and low-precision GPS locations of individually collared bighorn sheep monitored between 2010 and mid-year 2014. Animal survival is derived from animal disposition (alive or dead) of collared bighorn sheep; and annual survival rates (ASR) were calculated based on daily survival rates (Heisey and Fuller 1985) by grouping all animals from 2010 to midyear 2014.

Genetic Structure

Data sources are fecal samples non-invasively collected to obtain DNA, based on well-established techniques (Epps et al. 2005). Sampling areas were on the north and south sides of the Colorado River, distributed in upper, middle, and lower reaches, providing a geographic distribution designed to detect genetic mixing, not only across the river, but also along the river and up-down slope. Sampling began in 2011, and will continue over a period of at least 5 years. Genetic diversity is being assessed using neutral microsatellites that are highly variable and ideally suited for studies of

kinship analysis and gene flow, including population connectivity. Assessment of neutral genetic variation of samples is currently being analyzed at Oregon State University. This information is preliminary and limited in scope.

Forage Availability

Data sources are bighorn diet studies in the literature, observations of bighorn sheep foraging in Grand Canyon, and the Grand Canyon Vegetation Map produced in 2012.

Disease Factors

Data sources are biological samples collected from immobilized or deceased bighorn sheep to determine exposure to disease pathogens. Blood serum and nasopharyngeal samples were sent to NPS Wildlife Health Program personnel, and analyzed via the Colorado State University Veterinary Diagnostics Lab (VDL) or the Washington Animal Disease Diagnostics Lab (WADDL) at Washington State University to detect the presence of bacterial or viral pathogens (e.g. Mycoplasma ovipneumoniae [MYOV]). Additionally, information regarding disease exposure to bighorn sheep translocated to areas adjacent to the park is provided.

5.11.4. Condition and Trend

Table 25. Summary of bighorn sheep resource conditions and trends by indicator.

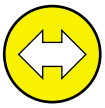
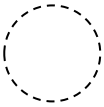
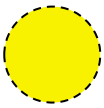
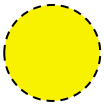
Indicator	Reference framework	Relative condition	Summary comments
Habitat quality	Relative to similar areas across the bighorn range, assessment of quantity of high-quality habitat and protection from predation/human disturbance		Bighorn prefer topographically complex habitat that is little disturbed by humans
Connectivity	Comparison with areas of high linkage between patches of high habitat quality		Highways and development disrupt connectivity
Movements	Comparison of telemetry data from 17 individuals with information derived from the wildlife literature		Collared individuals in the analysis area have been restricted to the canyon itself
Population estimate	Comparison with rough historical population estimates		No population estimate in park
Survival and mortality factors	Comparison with other desert bighorn populations across the West		Disease likely exerting more of an impact over predation; hunting not likely exerting strong impact
Genetic structure	Estimates of pre-dam population mixing		Dam construction has created permanent deep water in the Colorado River throughout the analysis area, preventing mixing

Table 25 (continued). Summary of bighorn sheep resource conditions and trends by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Forage availability	Dietary studies establishing nutritional needs		Climate change could impact future forage
Disease factors	Current scientific knowledge of desert bighorn sheep mortality/disease		Disease pathogens appear to be the primary cause of mortality

Habitat Quality

Habitat of high quality for bighorn sheep is mostly located below the canyon rim, with patches near the Vermillion Cliffs, the eastern edge of Lake Mead, and the town of Kaibab, Arizona.

Connectivity

According to our analysis (Figure 42), the region below the rim would be conducive to bighorn connectivity, except that, given the fact that no collared sheep have been detected crossing it, the Colorado River likely impedes connectivity across the landscape. Above the canyon rim, vegetation and topographic conditions are less conducive to movement, and movement is interrupted by highways larger than two lanes.

Movements

In Grand Canyon NP, bighorn sheep are distributed in low densities throughout the inner canyon between Lees Ferry and Lake Mead, and occupy habitat from the river to the rim. By all indications, the greatest densities of bighorn sheep occur along the river, where water is abundant and accessible year round. However, the river corridor is also the most easily surveyed region, and estimates may be biased accordingly. Aspect and radiant exposure most likely significantly influence how bighorn sheep orient in the canyon, while accessibility to quality forage and water certainly influences seasonal movement patterns and habitat selection of bighorn sheep occupying various regions of the inner canyon. Movements of collared bighorn sheep along elevation gradients within Grand Canyon have been restricted to between the canyon bottoms at river level to the Esplanade formation. Collared bighorn sheep have never traveled above the physiographic rim, nor have they have crossed the river.

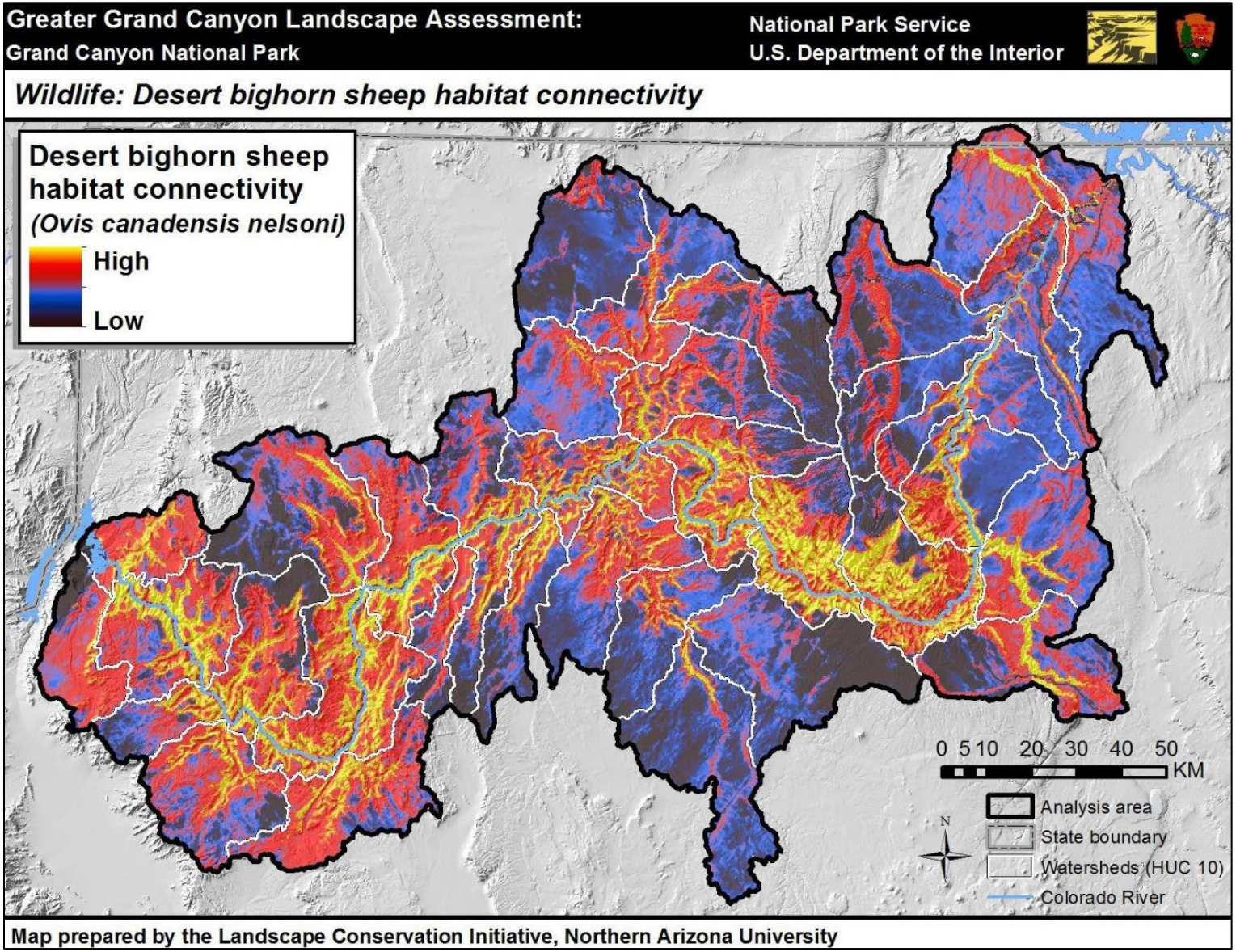


Figure 42. Desert bighorn sheep habitat connectivity in the Greater Grand Canyon Landscape Assessment area.

Multiple ewe subpopulations are the most basic demographic units within a larger desert bighorn population (Boyce et al. 1999). In Grand Canyon NP, ewes are more likely to restrict their movements to maintain year-round access to water, and to reduce predation risk from mountain lions. Bighorn sexes commonly occupy different habitats during much of the year (Wehausen 1980; Bleich et al. 1997). Outside of the fall breeding season, adult rams are more inclined to move longer distances and climb to higher elevations (i.e., Tonto and Esplanade formations) within the inner canyon, segregating into ram groups for most of the year. Desert bighorn sheep have been reported to have longer breeding seasons than Rocky Mountain bighorns (Hass 1997; Krausman et al. 1989), resulting in a relatively long and ill-defined lambing season. The primary lambing season in Grand Canyon NP likely occurs between February and May, with peak parturition perhaps in March-April. Observations of recently born lambs have occurred as early as mid-February and as late as June. Because lambing sites are generally used for short periods of time, these areas are poorly understood and often disregarded as critical habitat (Bangs et al. 2005). Short lambing episodes and steep terrain makes identifying lambing areas in Grand Canyon difficult.

Population Estimate

From 1972 through 1974, Guse (1974) estimated a population of 400-500 animals in the park itself, using observations obtained from commercial river runners, backcountry hikers, and park staff. At the present time there is no reliable population estimate. However, based on fecal pellet genetic analysis that began in 2011, preliminary information indicates that a population estimate today would likely exceed the 1975 estimate. Population estimates for bighorn sheep adjacent to the park vary with jurisdiction. The Hualapai Tribe, whose reservation borders the south-western boundary of the park, has periodic bighorn sheep survey information dating back to 1981. The most recent survey documented 232 bighorn (Hualapai 2014). No bighorn sheep population information is available for Navajo and Havasupai lands bordering the park. However, the AZGFD conducts annual surveys for bighorn sheep on BLM lands adjacent to the northern park boundary. Surveys indicated that bighorn sheep populations in bordering GMUs 12A, 12BW and 13A north of the park declined from 430 to less than 300 individuals between 1998 and 2006 (AZGFD 2009); 2014 surveys indicate further declines in adjacent GMU's north of GRCA.

Survival and Mortality Factors

Lamb-ewe Ratios / Lamb Recruitment.

Juvenile survival often has the greatest impact on population trajectories. Bighorn lambs are highly vulnerable to pneumonia. The critical survival range for lambs in Grand Canyon is likely within the two month period post parturition. From 2012-2014, fall lamb-to-100-ewe ratios in Grand Canyon averaged higher compared to long term averages across Arizona's desert bighorn sheep populations.

Predation Impacts

Predators can influence population dynamics and behavior of their ungulate prey (Brown et al. 1999). In Grand Canyon, pumas (*Puma concolor*), bobcats (*Lynx rufus*), coyotes (*Canis latrans*), and golden eagles (*Aquila chrysaetos*) are perhaps the most common predators of bighorn sheep. Wehausen (1996) asserted that bobcats and coyotes may be the most effective predators of lambs. However, no documented bighorn sheep mortalities in Grand Canyon have been attributable to golden eagles,

bobcats, or coyotes. Pumas are perhaps the only predator that can cause significant mortality and limit the bighorn sheep population. Puma predation is often thought to exacerbate the effects of disease and declining habitat quality, but predation alone can have substantial effects when either individual pumas specialize in killing bighorns or pumas turn to killing bighorns when other prey (typically mule deer [*Odocoileus hemionus*]) decline (Ross et al. 1997; Kamler et al. 2002; Holl et al. 2004; Festa-Bianchet et al. 2006). Predation by pumas on adult bighorns has been reported to affect bighorn sheep populations (Ross et al. 1997; Wehausen 1996; Kamler et al. 2002; Rominger et al. 2004,) and reduce lamb survival (Smith et al. 2014). In Grand Canyon, bighorn sheep comprised less than 1% of puma diets. The rough topography of the inner canyon constructs various levels of escape terrain fit for bighorn sheep, precluding less risky and more efficient hunting by pumas found on the comparatively gentler slopes of south and north rims. Although predation of bighorn sheep by pumas does occur in Grand Canyon, the population level effects on bighorn sheep are most likely negligible when compared to disease.

Survival Rate

Bighorn sheep generally have low intrinsic rates of population growth, and are vulnerable to rapid population reductions and slow population recovery rates (Geist 1975). Survival rates for bighorn sheep in Grand Canyon reported in this analysis are preliminary and limited due to a small sample size of mostly censored (alive or unknown disposition) animals. As such, a more general approach was employed, whereby survival for each collared animal was calculated based on a dynamic year determined by date of capture. Annual survival rates (ASR) were calculated based on daily survival rates (Heisey and Fuller 1985) by grouping all animals from 2010 to midyear 2014. Annual adult survival rate for 15 marked bighorn sheep was 0.89, similar to survival rates reported from other bighorn studies (0.70-0.88 in AZ, Kamler et al. 2002; 0.72-0.91 in CA, Hayes et al. 2000; 0.95 in NM, Rominger et al. 2004). Hayes et al. (2000) and Schaefer et al. (2000) reported declining desert bighorn populations in southern California with annual adult survival rates of 0.81 and 0.80 respectively.

Hunting

Hunting for bighorn sheep rams does occur on most lands adjacent to the park. Hunting on Navajo and Havasupai land is assumed to be limited. The level of bighorn sheep hunting by the Havasupai is unknown, but likely minimal. To the west and south of Havasupai lands, hunting is permitted through the AZGFD in Cataract Canyon; however, only one permit is issued per year. Hunting on Hualapai lands is strictly managed—the tribe only issues two guided hunt permits per year (Hualapai 2013). North of the park, AZGFD proactively manages bighorn sheep ram hunts within bordering GMUs. Hunting is permitting along the entire northern boundary of the park, but few permits are issued. Considering that only rams are legally taken during hunts, the population level impacts on bighorn sheep in Grand Canyon from hunting north of the park is likely minimal.

Genetic Structure

Grand Canyon NP is unique among desert bighorn populations in never having been subjected to direct translocations of bighorn sheep from other areas. However, desert bighorn sheep in Arizona outside of the park have been intensely managed by AZGFD, with multiple releases over the past few

decades in areas adjacent to the Grand Canyon. The degree of mixing between translocated and Grand Canyon bighorn sheep is currently unknown, but is being investigated. Within the park, over 1000 fecal samples from bighorn sheep have been collected, resulting in 500 genotyped samples, and identification of 239 unique individuals. Sampling efforts have been concentrated along the river corridor and short distances up major side canyons. Genetic differentiation is apparent through the river corridor, especially in the extreme eastern and western portions of the park. The Colorado River likely serves as a natural impediment to gene flow and connectivity between meta populations. In pre-dam conditions, seasonally low water along the Colorado River likely encouraged more genetic exchange. Consistent high flows of the Colorado River have likely created a formidable barrier, condensed seasonal movements of bighorn across the river, and potentially restructured the population in GRCA over the last 50 years.

Forage Availability

Bighorn sheep are generalist foragers and feed on a wide variety of plant species (Miller and Gaud 1989; Shackleton 1985), with diet composition varying with season and location (Bleich et al. 1997; Miller and Gaud 1989; Shackleton 1985). In Grand Canyon, the largest varieties of nourishing plants are found on talus slopes (Walters and Hansen 1978). The current availability of quality forage in Grand Canyon is likely sufficient to maintain a viable bighorn population in current low densities throughout the canyon. However, the effects of a drying environment, e.g. modifications to seasonal forage and water availability, will likely change the distribution and seasonal availability of preferred forage, and perhaps change the frequency of contact between bighorn sheep and other large herbivores in and around Grand Canyon NP. Identifying the spatial and temporal selection of preferred forage by bighorns is needed to better understand how changes in climate and/or park management (i.e., Backcountry Management Plan, Colorado Management Plan) may affect availability of or accessibility to seasonally important forage species.

Disease Factors.

Based on recorded mortality events in recent years, the primary threat to survival of bighorn sheep in Grand Canyon is respiratory disease. During 2000–2014, 35 nonpredation related bighorn sheep mortalities were confirmed from the upper reaches of the inner canyon (i.e., Hermit Shale) to the river bottom, but exact cause of death has generally been undeterminable due to the logistical constraints and carcass deterioration. For 65% of these mortalities, disease is suspected. A pneumonia epizootic has likely been occurring in the Grand Canyon population. It is however unclear whether pathogens are being maintained and transmitted among populations via bighorn sheep movements or whether the disease pathway is from contact with domestic sheep and goats.

Cattle (*Bos bos*), domestic goats (*Capra hircus*), and domestic sheep (*Ovis aries*) all occur or have occurred on jurisdictions adjacent to GRCA and periodically move into the park where they could potentially transmit epizootic diseases to bighorn sheep. Infectious Bovine Rhinotracheitis, Bovine Virus Diarrhea, Bovine Respiratory Syncytial Virus, Parainfluenza 3, Brucella oviso, Leptospirosis, Epizootic Hemorrhagic Disease, Bluetongue, and Anaplasmosis all pose a potential threat to bighorn sheep (Schommer and Woolever 2008) in Grand Canyon. Transmission from domestic sheep is widely accepted as the primary cause of fatal respiratory disease in bighorn sheep in general (e.g.

Toweill and Geist 1999; Valdez and Krausman 1999; Tomassini et al. 2009). In 2013 and 2014, bighorn infected with at least two types of nonnative bacterial pathogens in Grand Canyon were detected. Historic and current domestic sheep grazing on Navajo lands abutting the upper 65 miles (105 kilometers) of Grand Canyon NP has potentially served as a transmission route for infectious disease. On adjacent tribal lands, the prevalence of bighorn disease is relatively unknown, either because bighorn sheep do not occur near the ark (i.e., on Navajo lands) or testing has been limited or nonexistent (i.e., Havasupai and Hualapai lands). The AZGFD monitors bighorn herd health. In 2005, in response to observed mortality, the AZGFD completed a disease assessment of bighorns from adjacent GMU's 12A and 13A. Results indicated that the population decline in Kanab Creek habitat area was associated with the presence of *Mannheimia haemolytica* and *Mycoplasma ovipneumoniae* pathogens (Justice-Allen et al. 2011). The Kaibab National Forest 2014 revised Land Management Plan restricts grazing of domestic sheep and goats on the Tusayan and North Kaibab ranger district with the intent of preventing disease transmission in Kanab Creek and Grand Canyon NP.

5.11.5. Summary

Our spatial analysis allows examination of the distribution of areas of high bighorn habitat quality and connectivity by jurisdiction and by HUC 10 zone across the GGCLA. The break-down of these elements by jurisdiction appears in Table 26.

Table 26. Distribution of areas of high bighorn habitat quality and connectivity by jurisdiction across the Greater Grand Canyon Landscape Assessment area.

Indicator	BLM	USFS	Tribal	NPS	Private Lands	State Trust Lands	Other
Bighorn habitat quality	3.4±1.4	3.1±1.3	4.1±1.9	5.2±2.4	2.7±1.0	2.8±0.9	2.9±0.5
Bighorn habitat connectivity	4.0±1.5	3.5±1.5	4.6±1.9	5.6±2.2	3.3±1.0	3.2±1.0	3.1±0.6

Examining HUC10 zones, those with highest average bighorn habitat quality (Figure 43) include zones 10 (Shinumo Creek-Colorado River), 19 (Granite Park Canyon-Colorado River), and 9 (Bright Angel Creek-Colorado River), all of which exhibit habitat quality values above 5.5. Zones with the lowest average bighorn habitat quality include zones 20 (Bulrush Wash), 25 (Heather Wash), 26 (Upper Havasu Creek), and 1 (Water Holes Canyon-Colorado River), all of which exhibit habitat quality below 3.0.

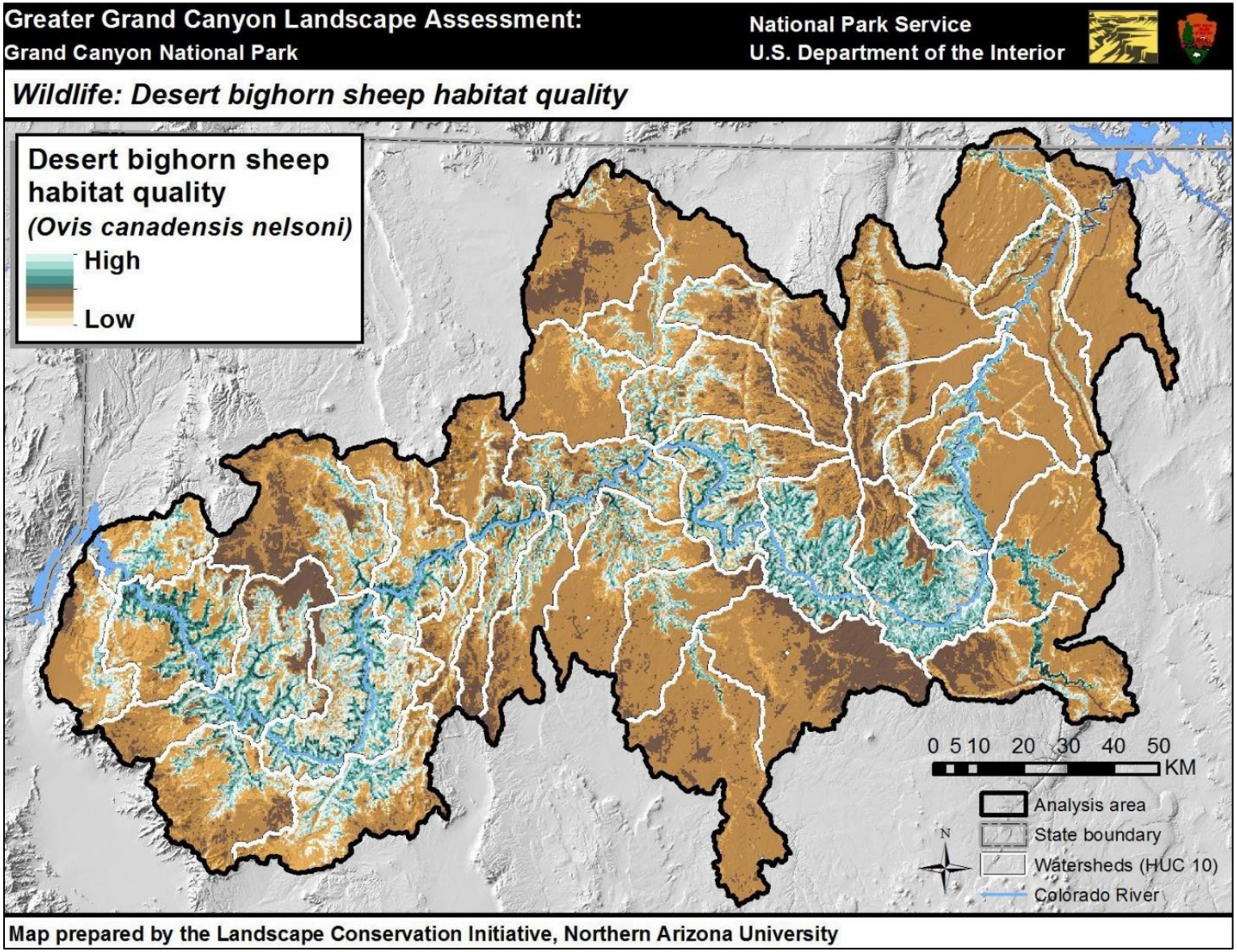


Figure 43. Desert bighorn sheep habitat quality in the Greater Grand Canyon Landscape Assessment area.

Although Grand Canyon NP contains one of the largest and most continuous, naturally persisting populations of desert bighorn sheep in North America (Bendt 1957; Allen 1961; Guse 1974; Wilson 1976; Walters 1979; Holton 2014), information about seasonal movements, habitat use, genetic and demographic structure, and disease exposure is incomplete. Feral burros (*Equus asinus*, since removed) were thought to have severely impacted Grand Canyon bighorn sheep (Bendt 1957; Walters and Hansen 1978), and backcountry human recreation is thought to be detrimental (cf., MacArthur et al. 1982; Krausman and Hervert 1983; Legg 1988; Stockwell et al. 1991; Papouchis et al. 2001; Thompson and Longshore 2007), yet no studies have addressed these effects. Moreover, bighorn sheep in Grand Canyon occupy an environment that is unique relative to most desert bighorn sheep range. The bulk of investigations have focused on desert bighorn sheep occupying arid mountain ranges with limited—largely point—water sources and near enough to other populations for effective dispersal and gene flow. By contrast, Grand Canyon bighorn sheep live in a highly lineated, comparatively isolated, very deep canyon with abundant free water along the bottom.

The bighorn sheep population in Grand Canyon is one of the most significant desert bighorn populations in the country; not only in terms of size, but potentially in genetic uniqueness. This population has never been subject to direct reintroductions of bighorn sheep from other areas. This is especially important given the recent die-offs (2012-2013) in the other desert bighorn stronghold, the Mojave National Preserve. Desert bighorn sheep in Grand Canyon are not only susceptible to potential disease transmission events from domestic and infected bighorn sheep, but can also be affected by habitat modifications due to climate warming and drying (e.g., Epps et al. 2004), which can alter bighorn distributions in the canyon and increase predation risk. Primary mechanisms that could potentially regulate or otherwise stress bighorn sheep populations in Grand Canyon include disease (e.g. Singer et al. 2001; Miller at al. 2011; Wehausen et al. 2011; Besser et al. 2012), precipitation (e.g. McKinney et al. 2001), forage quality (e.g. Krausman et al. 1989; DeYoung et al. 2000), and predation (e.g. Wehausen 1996; Ross et al. 1997; Logan and Sweanor 2001; Kamler et al. 2002).

5.11.6. Data Needs

- Identifying important lambing areas should be a high priority in conjunction with determining lamb survival to provide a better indication of potential stressors (i.e., human disturbance) that could affect lamb survival.
- No reliable population estimate exists for bighorn in the analysis area. Determination of juvenile survival and recruitment rates is required.
- A better understanding of the degree of genetic mixing between translocated and Grand
- Canyon bighorn sheep is needed.
- More precise assessment of forage selection is required in order to predict the likely impacts of climate change on forage availability.
- Because disease is a major cause of mortality for bighorn in the analysis area, understanding how pathogen transfer is occurring across the population is a critical need.

- Accurate assessment of surface water availability and quantity, availability of preferred forage, and finer-scale habitat suitability models including the influence of factors such as mountain lion movements, epizootic disease spread, and bighorn population genetic structure and diversity is required.
- A better understanding of the impacts posed by backcountry recreation is needed.

5.11.7. Level of Confidence

This assessment is based on data derived from collared bighorn sheep individuals, bighorn habitat requirements as understood in wildlife biology literature, and analysis of mortality factors. Assessment of habitat factors and movement patterns carries high confidence, but better population estimates, genetic profiles, and disease ecology are required to boost confidence in demographic factors.

5.11.8. Sources of Expertise

This section was prepared by Brandon Holton. Bighorn sheep habitat quality and connectivity analysis was performed by Brett Dickson, (Conservation Science Partners and Northern Arizona University). Other data were provided by Brandon Holton, Grand Canyon NP.

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5.12. Wildlife: Mule Deer

5.12.1. Description



Important stressors for mule deer in Grand Canyon NP include availability and distribution of water, livestock overgrazing, exotic plant species composition and distribution on the landscape, hunting (excludes inner canyon NPS lands), and poaching.

Factors that influence habitat quality and connectivity for mule deer include forage availability and sufficient concealment cover (to prevent predation) without closed canopy (which reduces forage). Fire and thinning treatments, coupled with predation, may therefore dictate mule deer populations (Photo: Mule deer in Grand Canyon National park, NPS photo).

Mule deer (*Odocoileus hemionus*) are found throughout much of western North America, ranging from British Columbia and Alberta in Canada to the north and to southern Baja and Zacatecas in Mexico to the south. Within this wide distribution, mule deer are found in a variety of habitats, varying from desert scrub to high-elevation conifer forests. This ability to inhabit a variety of ecosystems is demonstrated in Grand Canyon NP, where mule deer can be found on the north rim where the average elevation is 8,000 feet and also at the Colorado River, where the elevation is approximately 2,200 feet.

Ecologically, the mule deer serves as a large herbivore on the landscape. Compared to larger ruminants, such as elk, which can eat larger volumes of lower quality forage, mule deer are classified as concentrate selectors, searching for forage of the highest quality and digestibility (Hofmann et al. 1985). They also serve as important prey for mountain lions (*Puma concolor*), constituting 14% of the prey items documented at kill sites on the south rim and 92% on the north rim (Brandon Holton,

personal communication, 2015). Culturally, mule deer serve as an important food source, provide utilitarian services, and function in religious ceremonies with all tribes associated with the Grand Canyon. For example, in Navajo culture, all parts of the deer are used for religious ceremonies, food, or clothing (Arizona Game and Fish Department 1998).

Mule deer in the greater Grand Canyon landscape can be roughly divided into three populations: areas south of the south rim of the canyon (henceforth referred to as the south rim), areas north of the north rim (north rim), and within the canyon and the major tributaries (inner canyon). The Arizona Game and Fish Department (AZGFD) has collected some information regarding mule deer population trends for the north and south rim populations, but not for the inner canyon.

Although recent trends suggest a stable to increasing population of mule deer on the south rim, historical records suggest that mule deer were a much more common species 20–30 years ago. To better understand mule deer population trends and patterns, it would be valuable to investigate the role of elk in forage competition, as well as resource partitioning between elk and mule deer. Elk, as herbivores and shapers of vegetation communities, could affect the ecosystem as a whole.

5.12.2. Indicators/Measures

- Presence (deer distribution)
- Condition (population trends)
- Habitat quality
- Habitat connectivity

5.12.3. Methods

For both the north and south rim areas, this condition assessment draws heavily on annual fall aerial surveys and corresponding population model results conducted by the AZGFD. The south rim population estimate in this analysis is based on Game Management Units (GMUs) 9 and 10, and the north rim population is based on GMUs 12 and 13. However, there are currently no population model data points for mule deer in the inner canyon, which comprises a majority of Grand Canyon NP.

Presence

Generally mule deer are distributed throughout the area, although the diversity of habitat types and the distribution of water and forage are each important in the pattern of deer distribution.

Condition

The condition of the mule deer population in the area can be determined by examining whether numbers are decreasing, increasing, or remaining stable.

Habitat Quality

This analysis of habitat quality is based on nine habitat variables, for which five experts provided scores relating the variables to the likelihood of deer use of habitat, as well as providing weighted estimates to assess the relative importance of the variables. These variables included topographic position classes, NDVI, and average annual precipitation. Water bodies, highways with more than

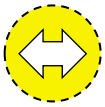
four lanes, and cliffs were considered occupancy barriers. The resulting map identified large areas, both north and south of the canyon, as high-quality habitat, with particular concentrations near the Vermillion Cliffs, the eastern end of Lake Mead, and Tusayan.

Habitat Connectivity

The habitat connectivity analysis (described below) transformed habitat quality variables and barrier variables into a permeability layer and identified high connectivity across the eastern portion of the analysis area (east of the canyon) and near Lake Mead (south of the canyon).

5.12.4. Condition and Trend

Table 27. Summary of mule deer condition and trend by indicator

Indicator	Reference framework	Relative condition	Summary comments
Presence	Distribution relative to historical distribution		Mule deer populations remain in historical areas of occupation.
Condition	Historical population sizes		Populations appear to be stable or increasing in most areas, but may have declined in recent decades on the south rim due to competition with introduced elk.
Habitat quality	Condition of index variables relative to historic conditions		Topographic position classes remain unchanged. Although precipitation has declined in recent decades, increased artificial water development has largely ameliorated this change. However, future climate change may reduce water availability.
Habitat connectivity	Historical population sizes		Increased fragmentation by road construction and other anthropogenic developments is reducing habitat connectivity over time.

5.12.5. Summary

Mule Deer Presence (Distribution) and Condition (Population Trend)

Distribution

South Rim

Mule deer are distributed throughout the southern portion of the greater Grand Canyon landscape. The south rim mule deer population can be divided into two regions related to game management units (GMU). Unit 10 encompasses portions of the Hualapai and Havasupai Indian Reservations. Unit 9 is a combination of Kaibab National Forest, Tusayan Ranger District, and open grasslands south to Hwy 180 and west from Valle to Cataract Canyon. For unit 9, aerial surveys and corresponding population modeling surveys suggest that the mule deer population is stable to

increasing. We have no data regarding mule deer populations in either the Hualapai or Havasupai Indian Reservations.

Inner Canyon

Mule deer are distributed throughout the inner canyon. However, no population estimates exist for inner canyon mule deer herds.

North Rim

Mule deer are distributed throughout the northern portion of the landscape. The north rim mule deer population can be divided into three regions according to GMUs as described by the AZGFD. Unit 12A is primarily the Kaibab Plateau, unit 12B includes much of the lowland east and north of the Kaibab plateau, and unit 13 includes all lands west of Kanab Creek. Aerial surveys and corresponding population estimates for regions 12B and 13 have been stable to increasing over a 1-year period. The population in the unit encompassing the Kaibab plateau was stable until 2010, when the population began to increase, reflecting the AZGFD's decision to manage the 12A unit deer herd for an annual 5–10% population increase.

Population Trend

South Rim

Population estimates for GMUs 9 and 10 derived over a 10-year period suggest that mule deer populations are stable to slightly increasing. We have no population estimate data within Grand Canyon NP to confirm this trend, but due to proximity the same trend is likely occurring within the park boundary. Park wildlife files document that management has been aware of wildlife-human interaction issues with mule deer along the South Rim within the park up to the early 1990s. Although several early NPS biologists published estimates of the mule deer population within the park, there were no data to confirm those estimates. Currently deer management in the south rim area is not an issue. There is a perceived smaller population of deer around the south rim, but there are no data to support this observation. Recent data suggest that the mule deer population in GMU 9 is stable to increasing, but long term (30-year) anecdotal evidence suggests that mule deer were much more common along the south rim than they are today.

One possible explanation for the perceived reduction in deer could be that elk are outcompeting mule deer for the best-quality forage, thus reducing fitness of adult deer as well as recruitment and survival of young. As concentrate grazers, mule deer need regular access to high-quality food and they are not able to process enough low-quality food to meet nutrient requirements. In areas with sympatric elk and mule deer populations, mule deer distributions have been inversely related to elk resource selection (Johnson et al. 2000).

Inner Canyon

The population of mule deer inhabiting the inner canyon is an unstudied and unmonitored population. With the exception of mule deer on Havasupai and Hualapai lands, it is also an unharvested population. Furthermore this population does not compete with any significant source of introduced ungulates. They may have competed with burros when they were present in the canyon, but have likely since recovered from any burro effects. Anecdotal evidence from conversations with inner

canyon rangers suggests that the population remains largely stable, but there is no quantitative evidence to confirm this. Management of deer in the inner canyon has mainly revolved around dealing with deer-human and deer-garbage interactions at Phantom Ranch, and to a lesser extent at Indian Garden (Grand Canyon NP Wildlife Department files). Deer have been euthanized in those locations. In conjunction with most wildlife in the inner canyon, mule deer distribution and abundance are likely strongly influenced by the presence of water on the landscape.

North Rim

The north rim area includes the Kaibab Plateau, the location of a famous long-term deer study. In 1904, the deer herd was estimated at approximately 4,000 individuals (Rasmussen 1941). Beginning in 1907 hunting was banned and an attempt was made to remove all predators from the plateau to increase the deer herd. By the 1920s the deer herd had expanded greatly and was estimated by Rasmussen to be approximately 100,000 individuals. This overpopulation led to a severe reduction in available food, winter starvation, and poor fawn recruitment. Hunting began in 1924, but it was not enough to control the population. By 1931, the population had dropped to approximately 20,000 animals due to starvation, disease, and malnutrition (Swank 1968). After this die-off the population rebounded and again surpassed the food supply. By 1954, biologists raised the alarm regarding the increased population, resulting in the offering of 12,000 permits to harvest deer on the Kaibab. Approximately 8,500 deer were harvested, but this was not enough to curtail a severe winter die-off. During the winter of 1954-55, 18,000 deer died due to starvation and malnutrition, an estimated 66% of the post-hunt deer herd (Swank 1968).

Today, the population of mule deer along the north rim is stable to increasing. The Kaibab Plateau is being managed for an annual increase of 5–10%, and areas within park boundaries should also witness a corresponding increase in the deer herd. Although there is no hunting within park boundaries, winters with adequate snow cover on the plateau induce migration of the mule deer to lower elevations off the plateau onto areas where deer are hunted. If concerns are raised from the increasing population of mule deer on the Kaibab Plateau, winters with snow pack should help keep the population from becoming too large.

Mule Deer Habitat Quality and Connectivity

Divided into 10 habitat quality levels, and based on natural breaks, just 3.2% of the land in the area emerges as the highest category of habitat quality (i.e., displayed as palest green in Figure 44). The three top categories together account for 24.0% of the land. By contrast, lowest habitat quality areas, most of which are located in the precipitously steep lands within the Grand Canyon, account for 35.2% of the land area. Total land area per mule deer habitat category is summarized by hectares and percentages in Tables 28 and 29.

Connectivity for mule deer across the greater Grand Canyon landscape is characterized in Table 29 and Figure 45. The canyon is a major barrier to connectivity between the north and south rims. There is however a major north-south corridor in the eastern section of the analysis area, east of the main canyon.

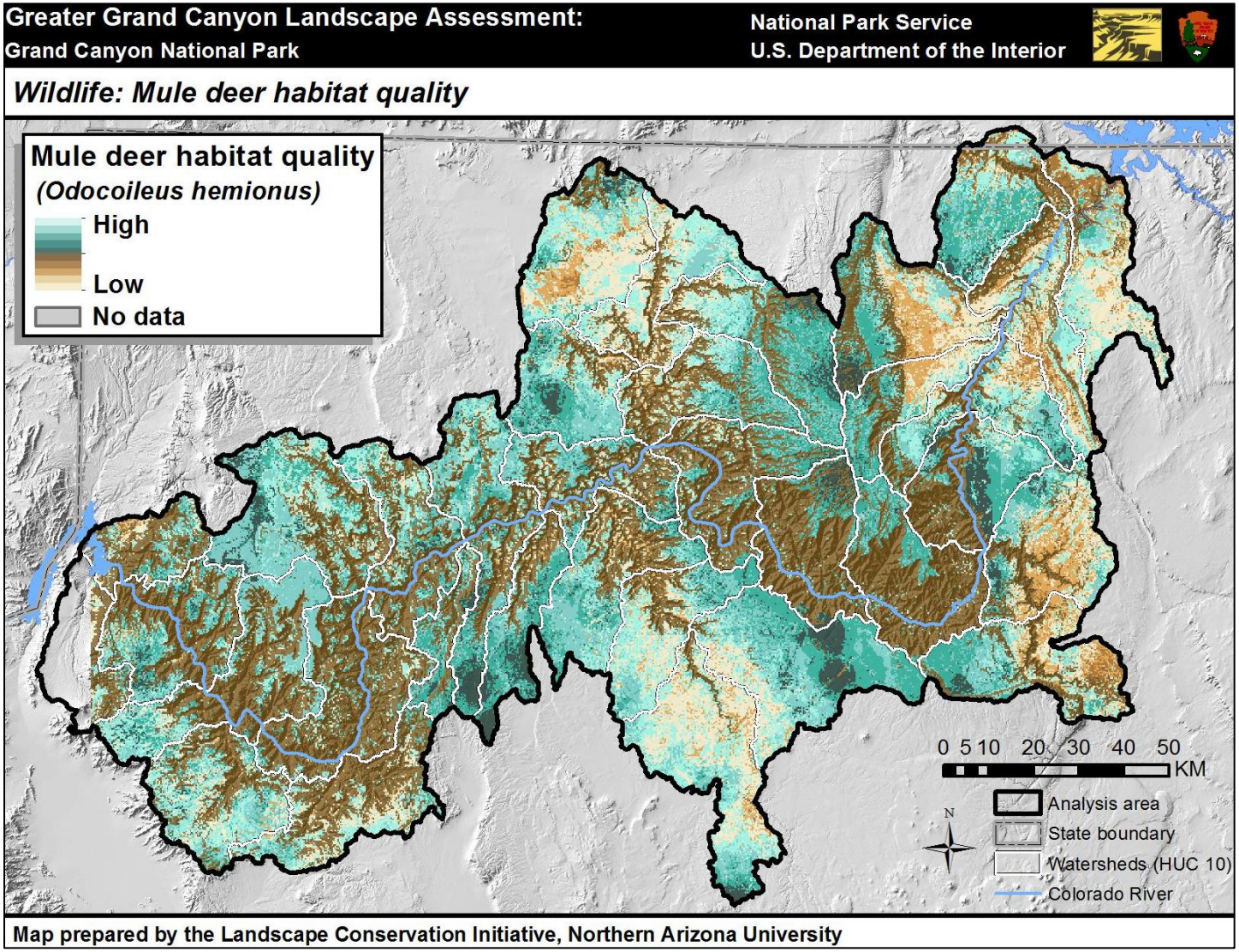


Figure 44. Mule deer habitat quality in the greater Grand Canyon landscape.

Table 28. Breakdown of the greater Grand Canyon landscape by mule deer habitat quality. Ten categories characterize habitat quality (lowest 1 and highest 10).

Habitat Quality	1	2	3	4	5	6	7	8	9	10
By hectares (in thousands)	789.3	20.7	44.9	110.3	202.3	255.3	279.0	260.1	206.2	72.2
By percentage	35.2	0.9	2.0	4.9	9.0	11.4	12.5	11.6	9.2	3.2

Table 29. Breakdown of the greater Grand Canyon landscape by mule deer habitat connectivity. Ten categories characterize habitat connectivity (lowest 1 and highest 10).

Habitat Connectivity	1	2	3	4	5	6	7	8	9	10
By hectares (in thousands)	751.6	373.7	535.3	265.1	168.5	78.7	38.7	19.4	6.8	1.2
By percentage	33.6	16.7	23.9	11.8	7.5	3.5	1.7	0.9	0.3	0.05

Habitat Quality and Connectivity

South Rim

The habitat in GMU 9 is in good condition. Over the past 10 years, the Kaibab National Forest has accomplished significant habitat improvements using controlled and prescribed burns in critical mule deer habitat. This, coupled with more reliable water sources, has resulted in improved habitat conditions throughout the unit.

North Rim

According to AZGFD, 10 new water sources on the 12AW winter range have been installed, and in cooperation with the AZGFD Game Branch and the USFS, the unit wildlife manager has developed a large-scale plan to address forage issues in GMU 12AW. Implementation of these habitat manipulations began in 2007 and if successful, this will ensure an increased level of browse availability for many years.

Forage conditions in the Warm Fire burn area continue to improve, with the footprint of the burn now providing excellent forage and very good cover. Winter precipitation in 12AE is below normal and may impact summer forage negatively. Meanwhile multiple projects have been completed or are ongoing in 12B that should positively affect the deer population. These conditions should continue to help increase the deer population in years to come.

All water catchments in GMU 13A were checked in accordance to the district water protocol in 2013. In 2010, eight mule deer waters were redeveloped in 13A, with several more scheduled for future years. Habitat conditions have improved over the past several years with a substantial amount of green-up seen in areas treated around the Mount Trumbull and Mount Logan areas. Four new waters were slated for redevelopment in the Mount Logan area in 2014.

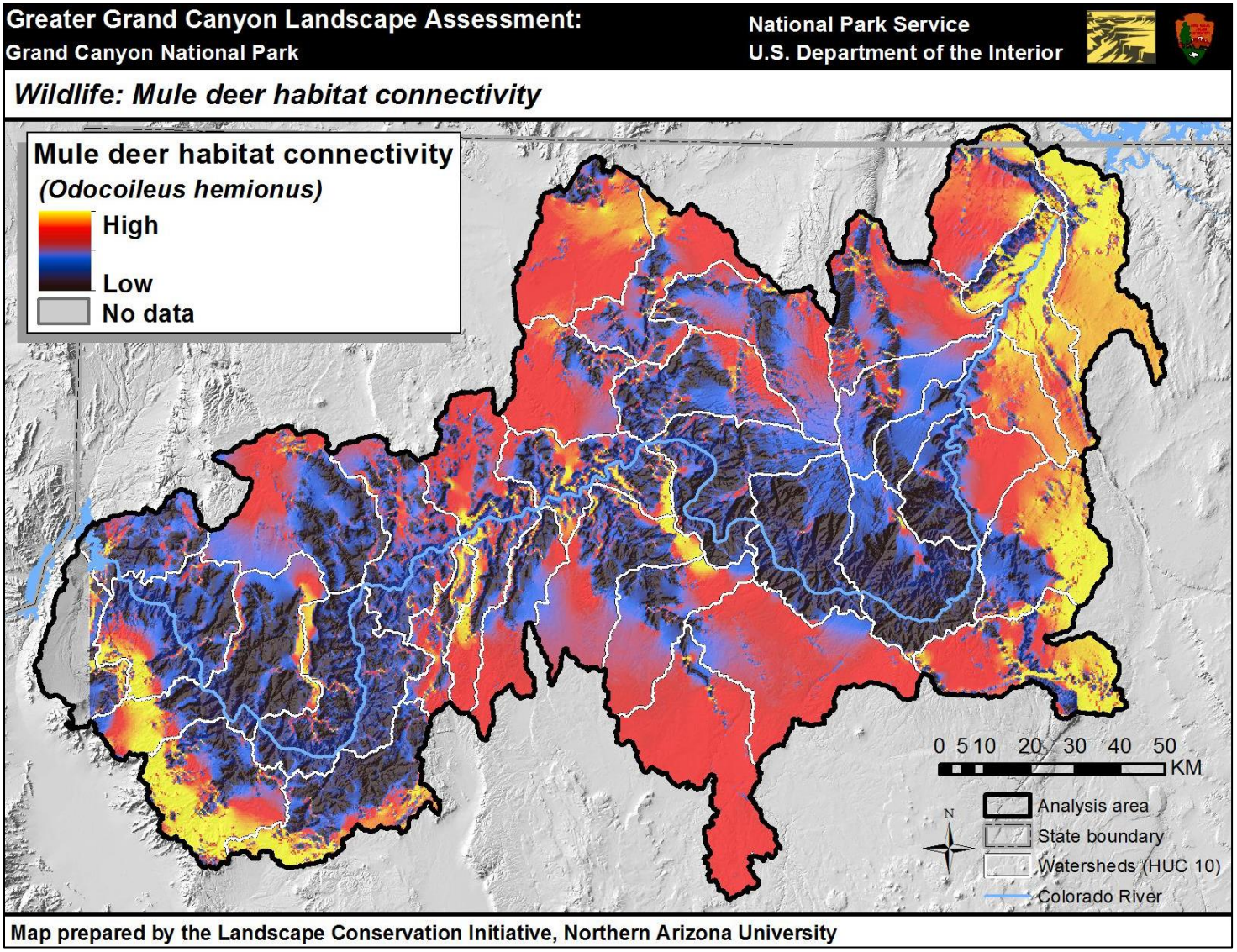


Figure 45. Connectivity for mule deer across the greater Grand Canyon landscape.

5.12.6. Data Needs

Little is known about the south rim mule deer population within the park along the GMU 9 boundary. Direct and indirect interactions between mule deer and elk on the south rim deserve study. It has been suggested that mule deer may be outcompeted by elk in this area for browse and grazing. Research investigating mountain lion prey use of the south rim identifies elk as an important alternative prey source and they may serve as a subsidizing prey source to inflate mountain lion populations in the area. Thus, there is potential for elk to not only affect mule deer populations directly through competition but also to serve as a food source to bolster predator populations. Understanding these dynamics is a critical research need.

The status of mule deer in the inner canyon is believed to be relatively stable, but there is no information to support this. Identifying techniques to establish baseline mule deer populations in the inner canyon would be a valuable addition to Grand Canyon NP's wildlife data.

It would also be valuable to determine whether the inner canyon population is relatively isolated from the south and north rim populations. For example, it is believed that mule deer on both the north and south rims migrate, however, they are believed to migrate away from the canyon. Whether or not there is mixing between the populations on the rims and the inner canyon would be valuable information from a management perspective.

A better understanding of the effects on mule deer of species interactions, invasive species, and climate change would be helpful to this assessment of mule deer and our ability to predict future conditions.

5.12.7 Level of Confidence

For habitat quality and connectivity assessment, information of variable importance has been derived from expert assessments, and is subject to the constraints imposed by the data needs listed above.

5.12.8. Sources of Expertise

This section was prepared by Cory Mosby, Wildlife Biologist, Grand Canyon National Park and Greg Holm, Wildlife Program Manager, Grand Canyon National Park. Tom McCall, Game Specialist, Arizona Game and Fish Department, Flagstaff provided trend data, Brandon Holton, Wildlife Biologist, Grand Canyon National Park provided predation data, and Brett Dickson, Conservation Science Partners provided habitat quality and connectivity modeling.

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5.13. Wildlife: Eagles

5.13.1. Description



Golden eagles, though likely not bald eagles, nest within the GGCLA area. While there is some limited data on golden eagles in the study area, there is not enough information to determine the overall condition (USFWS photo by Tom Koener).

In 1940, Congress passed the Bald Eagle Protection Act in an effort to provide protection for declining bald eagle populations (*Haliaeetus leucocephalus*). In 1962, the Act was amended to include golden eagles (*Aquila chrysaetos*), becoming the Bald and Golden Eagle Protection Act (BGEPA) (16 U.S.C. 668-668d, 54Stat. 250). Under the BGEPA, the U.S. Fish and Wildlife Service issues permits to take, possess, and transport bald and golden eagles for scientific, educational, and Indian religious purposes, depredation, and falconry (golden eagles). In addition to the BGEPA, golden eagles are protected by the Migratory Bird Treaty Act, Lacey Act, Airborne Hunting Act, Convention on International Trade in Endangered Species of Wild Flora and Fauna, and Arizona Revised Statute Title 17.

One of the 1962 amendments to the BGEPA authorizes the Secretary of the Interior to grant permits to American Indian tribes for traditional religious use of eagles and eagle parts and feathers; however, this activity is extremely rare within NPS units. The Hopi Tribe is one of the few American Indian tribes authorized to take live eagles for religious use. Typically, enrolled tribal members who want eagle feathers or other parts of the bird to practice their religion obtain them from the National Eagle Repository, operated by the U.S. Fish and Wildlife Service. The number of birds that Hopis have captured has ranged from two to 38 per year under previous permits. The Fish and Wildlife Service allowed the Hopi Tribe to take an unlimited number of birds between 1994 and 1996 but has capped the number at 40 each year since 1997. The golden eagle also plays a role in the religion of

the Navajo Nation, where the birds' feathers are used as sacred adornments to protect the wearer from harm, but killing of golden eagles is not condoned.

5.13.2. Summary

There is not enough data to support a condition assessment of golden eagles in the GGCLA area. The primary datasets available at this time are observation data collected by Grand Canyon NP and survey data from the AZGFD. We summarize that data here.

Grand Canyon National Park Data

There were 184 reported sightings of golden eagles in GRCA between 1982 and 2004 (Figure 46). These records include sightings of biologists specifically searching for nests and eagles, NPS staff, and park visitors. The records also include data from a November 2002 river trip, during which a trained biologist attempted to document all golden eagle nests and sightings. The biologist reported four adults (one pair) and five possible nests, but four of the five nests were listed as either red-tailed hawk (RTHA) or golden eagle (GOEA). In 2003, a proposal for more golden eagle work within the park was submitted, but there are no reports confirming that the study ever took place. However, there are observations from the year 2004 coded "GE nesting study"; whether they were pilot observations or part of the above-mentioned study is still unclear. The golden eagle is listed as "a rare to uncommon permanent resident." Although the surveys have been statewide, gaps remain, particularly within national parks and Tribal lands. According to AZGFD (Kenneth "Tuk" Jacobson, Raptor Management Coordinator, personal communication, 2015), there are about eight known and recently occupied breeding areas within 20 miles (32 kilometers) of the Grand Canyon NP to the south, six historically documented breeding areas to the north, and an additional 12 areas nearby with large eagle-sized nests where occupancy has not been confirmed. AZGFD suspects additional breeding areas on the lands of the Hualapai Tribe and within Grand Canyon NP, but has no data to date to confirm this.

West-wide Data

Transects were conducted by air between 2006-2010 and 2012 across four Bird Conservation Regions (BCR). Abundance across all BCRs, and trend for each BCR was calculated. For the Southern Rockies and Colorado Plateau bird region a negative trend in birds of all ages (trend coefficient of -0.014, 90% credible intervals -0.0945, 0.0637) and juveniles (trend coefficient of -0.3034, credible intervals -0.5543, -0.0590) was detected over the study period (Nielson et al 2014).

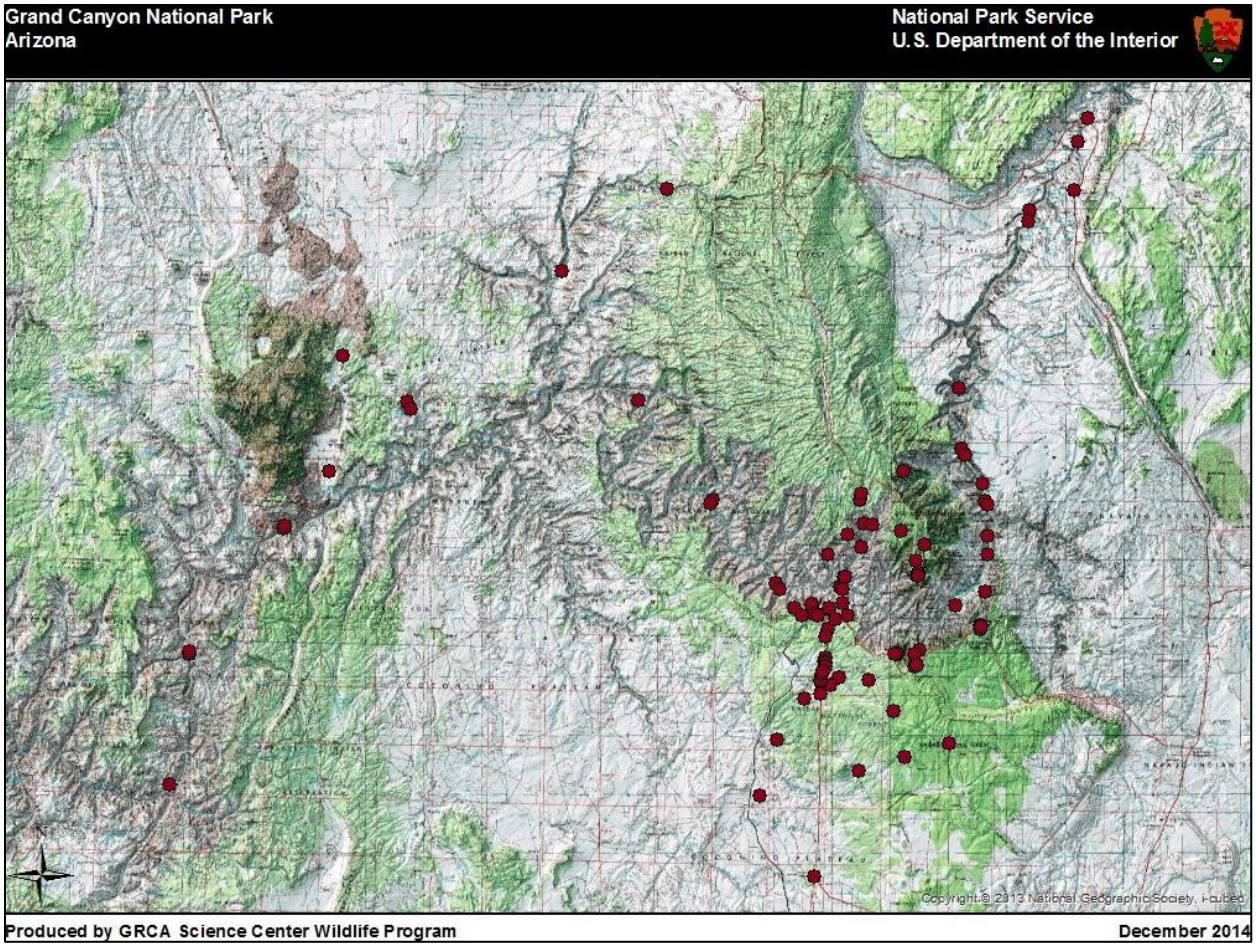


Figure 46. Coarse locations of reported sightings of golden eagles in Grand Canyon NP, 1982-2004. Sightings included biologists specifically searching for eagles, as well as sightings by NPS staff and park visitors.

5.13.3. Data Needs

- Nest surveys within the park would be valuable for determining the condition and trend of this species.
- Long-term monitoring of known nests in the GGCLA study area to determine reproductive success and possibly marking eagles to determine long-term survival of individuals and dispersal of juveniles would also be valuable.

5.13.4. Sources of Expertise

This section was prepared by Greg Holm.

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5.14. Wildlife: California Condor

5.14.1. Description



Today's non-captive population of California condors is a result of nearly two decades of recovery efforts resulting in the establishment of managed populations in California, Arizona, and Baja, Mexico. The Grand Canyon, situated in the heart of the Arizona/Utah population, provides not only immense landscapes for natural foraging, but also critical habitat for nesting (Photo: condor soaring over the Grand Canyon, courtesy of The Peregrine Fund by C. Parish).

The California condor has been an off-and-on resident of the Grand Canyon ecoregion since the end of the last glacial period. Radiocarbon-dated condor remains collected from caves within the Grand Canyon suggest that the species existed in the canyon from the Middle Pleistocene epoch up to 10,730 B.P., but disappeared from the region in coincidence with a large-scale extinction of land-dwelling, mammalian megafauna, the primary food source of the condor (Emslie 1987). Total extinction was averted in the early 1980s by a captive keeping and breeding program, but for a brief time between 1987 and 1992, the California condor was, in fact, extinct in the wild (Walters et al. 2008).

With a nearly 10-foot wingspan, the California condor (*Gymnogyps californianus*), a globally rare and conservation-dependent species, is the largest North American member of the Cathartidae family. These new-world vultures are a long-lived monomorphic avian scavenger characterized by delayed maturation and a low reproductive rate. The condor, which reaches sexual maturity between 6 and 8 years of age, is usually not successful in producing viable young until the third attempt, or eighth year. Given their low annual contribution to population growth, adult survival has to exceed 92% for population stability, making population recovery from relatively new anthropogenic causes of death, such as lead poisoning, challenging.

While other members of the cathartid family are thought to be increasing in numbers and expanding in range in some parts of North America, the California condor has historically existed in low numbers, until recent years as a result of intensive reintroduction and management (Kiff 2000).

Both fossilized and non-fossilized remains of condors have been recovered from numerous caves within the Grand Canyon, suggesting occupation from the mid to late Pleistocene epoch, but evidence is sparse for recent occupation, outside of the recent historic population in the Pacific Coast region (Emslie 1987; Kiff 2000). Without specimens or more detailed accounts, the matter of whether or not the species has occurred east of the California Sierra Nevada in historical times is subject to disagreement. At most, condors could only have been exceedingly rare outside of the Pacific Coast region within the past century (Kiff 2000).Isotopic evidence supports the hypothesis that condors have gone through two major dietary shifts: one from Pleistocene to historical times, transitioning in diet from land-dwelling mammals to sea-going mammals; and another from historical to modern times, with land mammals (including domestic stock) now dominating the condor diet (Chamberlain et al. 2005). More recently, changes in land management practices have resulted in increasing food sources of domestic stock and wild ungulates, allowing reintroduced populations of condors to reoccupy parts of their historic and prehistoric range, including the Grand Canyon. Today, reintroduced and wild-hatched condors feed exclusively on carrion, either proffered by managers at the Vermilion Cliffs release site or non-proffered/naturally occurring carcasses found within the Grand Canyon ecoregion. Recently released, inexperienced condors are more likely to take advantage of carrion provided at the release site. Large carcasses are generally preferred, but condors have been documented feeding on a variety of sizes and types of carcasses.

Today's population of more than 70 individuals in the Grand Canyon ecoregion is a product of reintroduction and reproduction in the wild (Woods and Heinrich 2007). Eleven of 25 wild-hatched young remain in the population. Two of these are of breeding age, and one produced viable offspring in 2014, initiating the beginning of an F2 wild-hatched population. Figure 47 displays the recorded locations of 20 individual condors in the Grand Canyon ecoregion in 2014. These relocations, or recorded time-stamped GPS coordinates, are collected up to 17 times per day for each individual.

Following initial releases from captive breeding facilities in 1996, condors from the Vermillion and Hurricane Cliffs release sites began showing interest in the South Rim of the Grand Canyon some 50 miles (80 kilometers) south of the release area. Since 1997, condors have been continuous visitors and residents within the boundaries of the national park, producing and fledging young in nearly every year since 2003. Condors continue to be a popular and sought-after attraction by visitors at the Grand Canyon throughout the year. Thus, both condors and visitors will require continued management. Despite efforts to manipulate behavior of reintroduced condors, their innate lack of fear for humans and the public's desire to get close to wildlife sometimes results in close encounters where condors might be approached and/or fed. Efforts to identify at-risk birds and to reduce encounters with humans and human-related structures have been in place since 2002 (Cade et al. 2004).

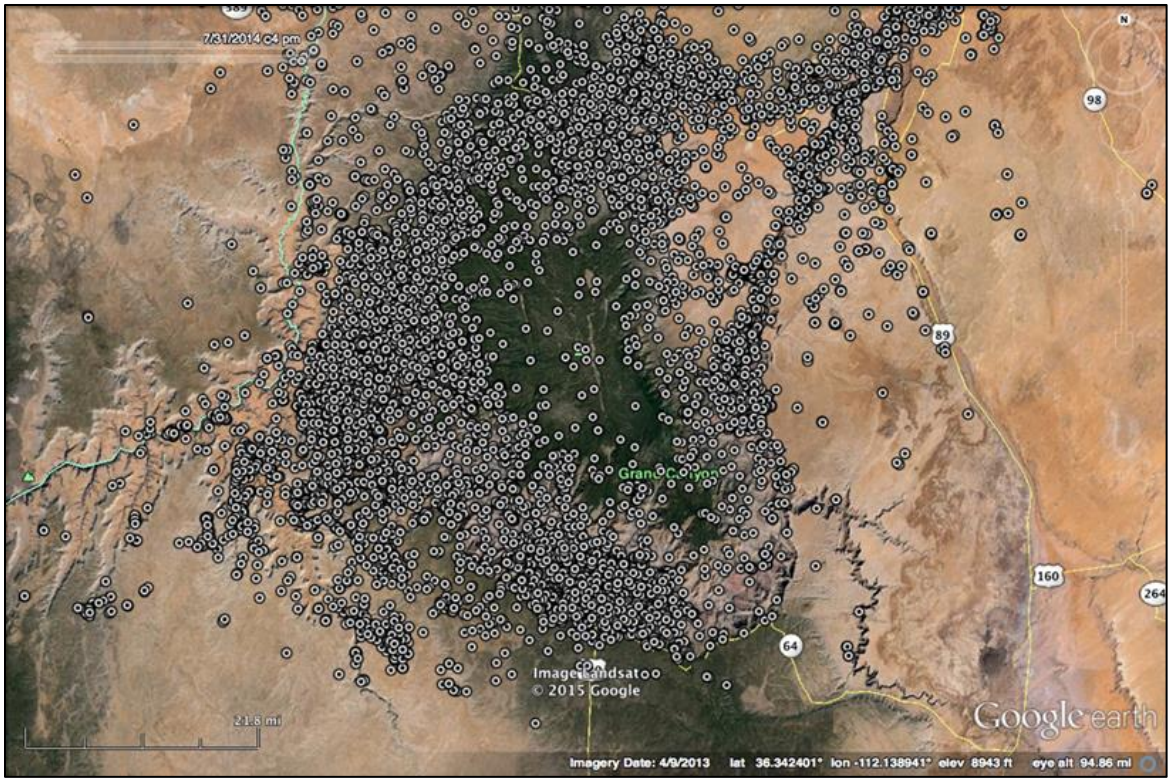


Figure 47. Recorded locations for 20 individual condors in the Grand Canyon ecoregion in 2014. Time-stamped GPS locations are recorded up to 17 times per day for each condor.

5.14.2. Indicators/Measures

- Population integrity

5.14.3. Methods

For this analysis, condor population integrity was assessed by determining the population size (year-round inhabitance in the park). This information was derived from tracking of individual condors using very high frequency (vhf) and Global Positioning System (GPS) telemetry by National Park Service (NPS) and the Peregrine Fund (TPF) biologists.

5.14.4. Condition and Trend

The condor is globally endangered. Throughout its range, the species remains at risk from environmental contaminants such as micro-trash and lead in the form of fragments and/or pellets from ammunition, and, in rare cases, paint. The population in the analysis area includes reintroduced and wild-bred individuals, present in the region since 1997. Table 30 summarizes condor condition and trend in the analysis area.

Table 30. Summary of California condor resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Population integrity	Historical population in the analysis area		Although reintroduction efforts have reestablished a population in the analysis area, environmental contaminants remain a significant threat and ongoing management is essential.

5.14.5. Summary

The condor, a rare species throughout its recorded history, has shown an encouraging increase in numbers during the past decade as a result of a vigorous captive breeding and release programs (Kiff 2000). Continued captive-production will be necessary as long as manageable threats, such as lead poisoning from ammunition residues and the presence of micro-trash, continue to threaten both juvenile and adult survival (Walters et al. 2010; Johnson et al. 2014). Efforts by hunters to reduce lead on the Kaibab Plateau (Sieg et al. 2009), the initial foraging area for released birds, have had encouraging results, with 80–90% participation annually, but exposure levels and lead-caused death persist at unsustainable levels for condors. This may be in part due to the condor's expanding range into southern Utah, or the ubiquitous nature of lead still available within the landscape as has been suggested for the southern California flock (Finkelstein et al. 2014). Despite mitigation, ranging from voluntary programs to ammunition bans throughout the condor's current range, nearly 60% of all diagnosed condor deaths continue to be from lead poisoning. Without further lead reduction, the condor will remain a conservation-dependent species.

5.14.6. Data Needs

- Social science research to develop new, more effective ways to work with shooters to reduce the availability of lead-based ammunition in carcasses available to scavengers, thus addressing the primary threat to condors today.

5.14.7. Level of Confidence

Condors in Grand Canyon ecoregion are a closely studied population and the level of confidence for this analysis is high.

5.14.8. Sources of Expertise

This assessment was prepared by Chris Parish, The Peregrine Fund.

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5.15. Wildlife: Mexican Spotted Owl

5.15.1. Description



Although Grand Canyon NP and the North Kaibab National Forest have surveyed for Mexican spotted owls over the past 30+ years, field efforts have been largely focused on compliance-based surveys in forested habitat. Inner-canyon inventory and monitoring surveys have also occurred, but not under a scientifically rigorous monitoring design. As a result, owl site occupancy, extinction, and re-colonization rates are largely unknown. Understanding the dynamics of Grand Canyon NP's MSO metapopulation and how it is linked to the larger regional population would help guide land management practices (NPS photo).

Mexican spotted owls (*Strix occidentalis lucida*; hereafter MSOs) are nocturnal avian predators that primarily consume rodents, birds, and insects (Block et al. 2005). MSOs are of special concern to the National Park Service in part due to their specialized habitat requirements (USDI 1995; Willey 1995); evidence that MSO populations are declining in the Southwest (Seamans et al. 1999); their status as a threatened species (USDI 1995); and because as a top-level predator, they may have a fundamental role in the proper functioning of ecosystems (Forsman et al. 1984; Franklin et al. 1990; USDI 1995).

The MSO was listed as a threatened species in 1993 by the U.S. Fish and Wildlife Service (Cully and Austin 1993). A recovery plan for MSO was completed in 1995 (USDI 1995) and a revised recovery plan was completed in 2012 (USFWS 2012). Two primary reasons were cited for the original listing of MSOs: historical alteration of its habitat as the result of timber-management practices and catastrophic wildfires, and increased risk of stand-replacing wildfire, currently identified as the greatest threat to the species (USFWS 2012). In northern Arizona, MSO habitat use departs strongly from the classic use of late seral, "old growth" forests found in the South (Willey and Van Riper 2000). In Grand Canyon NP, these owls use the myriad tributary canyons of the Colorado River to nest and hunt in the steep rocky habitat distinctive of the Colorado Plateau province.

Critical habitat designated by the USFWS in 2004 includes protected lands in the greater Grand Canyon ecoregion under critical habitat unit CP-10. Critical habitat within the GGCLA area totals 917,757 acres, with 682,646 acres in Grand Canyon NP. Within the GGCLA area, all sites identified as occupied MSO territories at some point (termed protected activity centers, or PACs) are within Grand Canyon NP. Protected habitats include all known PACs. Recovery habitat has been designated on the north rim of the canyon within the mixed-conifer forest (~ 26,868 acres).

Surveys in the park for MSOs have been inconsistent. They were initially conducted above the canyon's rim, from 1991 until 2001, when a 2-year concerted effort began to survey for MSOs in the interior canyonland. The canyonland surveys located 34 previously unknown MSO PACs (Willey 2002). The large majority of these occurred in the upper reaches of large tributary canyons in steep, rugged rocky canyon terrain located below the main canyon rims (Figure 48). Overall, the initial canyonland surveys covered approximately half of the suitable MSO breeding habitat predicted within the park. Based on these data, it has been speculated that a population of more than 200 MSOs could be present (Willey 2002).



Figure 48. Typical rocky inner-canyon habitat used by MSOs in Grand Canyon National Park (NPS photo).MSO inventory/compliance surveys on the canyon's north rim have been conducted annually from 1991 to 2012 (except 2011), and have covered a total of 160,383 acres (Table 31, Figure 49). The North Kaibab National Forest has conducted inventory/compliance MSO surveys since 1989, covering a total of 62,097 acres (Table 32, Figure 49). All surveys conducted in north and south rim forested habitat have detected zero breeding MSOs. From 2003 through 2012, monitoring of MSO PACs in Grand Canyon NP was limited and additional inventories of canyonland habitat did not occur. In 2013 and 2014, there was an increase in survey effort for both the inventory of canyonland habitat and the monitoring of PACs, resulting in the discovery of 15 additional PACs (Bruner et al. 2013, 2014). Currently 55 MSO PACs are officially recognized by park biologists and the USFWS (Table 33); all core nesting areas are located within the inner canyon (Bowden 2008; Bruner et al. 2014).

Table 31. Acreage of Mexican spotted owl fire compliance surveys on the north and south rims, 1991–2012.

Year	North Rim (acres)	South Rim (acres)
1989	–	–
1990	–	–
1991	10,500	57
1992	8,895	13,220
1993	15,000	0
1994	15,000	0
1995	13,889	0
1996	13,889	0
1997	7,037	0
1998	14,620	0
1999	15,157	NA[A]
2000	11,866	0
2001	12,714	NA
2002	7,197	NA
2003	5,195	0
2004	2,998	1,755
2005	6,462	3,432
2006	10,500	1,874
2007	8,895	0
2008	15,000	0
2009	15,000	0
2010	13,889	0
2012	13,889	0
2013	–	–
Total	**160,3832**	**7,118**

[A] Based off pre-2014 identified mixed-conifer forest which equaled 64,600 acres. In 2014, the North Kaibab National Forest ground-truthed true mixed-conifer habitat as defined in the 2012 MSO Species Recovery Plan and identified 54,617 acres of mixed-conifer habitat.

Table 32. Acreage of Mexican spotted owl fire compliance surveys on the North Kaibab National Forest, 1989–2013.

Years	North Kaibab MSO Survey Area (acres)	% of Total MSO Habitat Surveyed[A]
1989–1995	39,074	60.49%
1996–1999	21,180	32.79%
2000–2003	34,544	53.47%
2004–2013	45,440	70.34%
Total[B]	**62,097**	**96.13%**

[A] Based off pre-2014 identified mixed-conifer forest which equaled 64,600 acres. In 2014, the North Kaibab National Forest ground-truthed true mixed-conifer habitat as defined in the 2012 MSO Species Recovery Plan and identified 54,617 acres of mixed-conifer habitat.

[B] Total acreage includes areas surveyed multiple times.

Table 33. Occupancy and Survey History of Mexican Spotted Owl Protected Activity Centers in Grand Canyon NP, 1990–2015.

PAC Name	Area (acre)	'90s	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15
150 Mile	762	1998-P	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
209 Mile Canyon	643	–	–	S	–	–	–	–	–	–	–	–	–	–	S	–	–
Atoka	984	–[A]	–	S[B]	–	S	–	–	–	–	–	NR	–	–	–	–	–
Bass	1234	–	NR[C]	S	–	–	–	NR	–	–	–	–	–	–	NR	S	–
Boucher	651	–	P[D]	–	–	–	P3[E]	P	P1	P1	P2	–	–	–	P	–	S
Bright Angel	660	–	NR	S	S	P3	P2	P4	P3	P	P2	–	P2	P	P	P	P2
Cape Royal E	1113	–	P	–	–	S	–	--	–	–	–	–	P2	–	–	P	S
Cape Royal W	671	–	–	S	–	–	–	--	–	–	–	–	–	–	–	–	S
Cottonwood	933	–	NR	–	–	–	–	--	S	–	–	–	–	P2	S	–	–
Cremation	999	–	P	S	S	P1	P2	P3	S	P	P2	NR	–	P2	S	S	NR
Desert View	666	–	–	S	S	–	–	NR	–	P	P	NR	–	–	NR	NR	S
Dragon	1040	1992-S	–	–	S	NR	–	--	–	S	NR	–	–	–	NR	–	–
Forster	740	1999-P	P2	–	–	–	–	P	–	–	–	–	P	–	NR	–	–
Fossil	2720	–	NR	–	–	–	–	--	–	–	–	–	–	–	–	P	–
Gallaway	2734	–	NR	–	–	–	–	--	–	–	–	–	–	–	–	S	–
Grandview	675	–	P	NR	S	P1	P2	P	P	P	P2	S	–	–	NR	P	P
Grapevine	664	–	S	NR	NR	NR	–	NR	P	P	P1	P2	–	–	P	–	NR
Hermit	684	–	NR	S	NR	NR	NR	NR	–	–	–	–	–	NR	S	NR	NR

[A] – = Not surveyed

[B] S = Single

[C] NR = No response

[D] P = Pair

[E] # = Number of juvenile

Table 33 (continued). Occupancy and Survey History of Mexican Spotted Owl Protected Activity Centers in Grand Canyon NP, 1990–2015.

PAC Name	Area (acre)	'90s	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15
Horn Creek	814	–	NR	–	S	–	–	P	–	–	–	–	–	–	S	S	P
Indian Hollow	1577	–	–	–	–	–	–	–	–	–	–	–	–	–	P1	–	–
Kanab Creek	740	1999-S	NR	NR	–	–	–	–	–	–	–	–	–	–	S	–	–
Kanab Spring (Jump Up Canyon)	957	90s-S	–	–	–	–	–	–	–	–	–	–	–	–	P1	–	–
Kwagunt 1	956	–	–	P	–	S	–	–	–	–	–	–	–	–	S	–	–
PAC Name	Area (acre)	'90s	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15
Kwagunt 2	606	–	–	S	–	–	–	–	–	–	–	–	–	–	NR	–	–
Kwagunt 2	606	–	–	S	–	–	–	–	–	–	–	–	–	–	NR	–	–
Lipan Point	739	–	NR	S	S	S	–	S	–	NR	NR	–	–	–	S	P	NR
Manzanita Creek	711	–	S	–	S	S	–	–	–	–	–	–	–	NR	NR	NR	NR
Matkat	947	1998-S	–	–	–	–	–	–	–	–	–	–	P	–	–	NR	–
Monument Creek	1795	–	NR	NR	S	–	–	NR	–	–	–	–	–	–	P	S	NR
Mount Hayden	655	–	S	NR	–	NR	--	NR	–	–	–	P1	–	–	–	NR	–
Nankoweap South	697	–	–	S	–	–	–	–	–	–	–	–	–	–	–	NR	–
North Clear Creek	1652	–	–	NR	–	–	–	–	–	–	–	–	–	NR	–	P	–
Papago Point	631	–	NR	S	S	S	–	P1	P1	P	P2	S	–	–	NR	–	–

[A] –Not surveyed

[B] S = Single

[C] NR = No response

[D] P = Pair

[E] # = Number of juvenile

Table 33 (continued). Occupancy and Survey History of Mexican Spotted Owl Protected Activity Centers in Grand Canyon NP, 1990–2015.

PAC Name	Area (acre)	'90s	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15
Pipe Spring	778	–	P	S	S	–	–	P2	–	P	P1	–	–	P	–	P	P
Red Canyon	745	1998-S	P	NR	S	P	S	P2	S	P	P2	P1	P2	NR	S	–	P
Redwall Canyon'	1129	–	–	NR	–	–	–	–	–	–	–	–	–	–	P1	–	–
Royal Arch	2751	–	–	–	–	–	–	–	–	–	–	–	–	–	–	P	–
Ruby	734	–	–	S	–	–	–	NR	–	–	–	–	–	–	S	S	–
Salt Creek	646	–	P	–	–	–	–	NR	–	–	–	–	–	–	S	NR	S
Scotty's Hollow	1825	–	–	–	–	–	–	–	–	–	–	–	–	–	–	P2	–
Serpentine	991	–	–	NR	–	–	–	NR	–	–	–	–	–	–	P	S	–
Sinking Ship	667	1998-S	P	P	S	NR	–	–	–	–	–	–	–	–	–	–	–
Slate Creek	684	–	P	–	–	–	–	P1	P1	P2	P2	–	–	–	P	S	–
Specter	678	–	–	S	–	–	–	–	–	–	–	–	NR	–	NR	–	–
Spring Canyon	956	–	–	P	–	–	–	–	–	–	–	–	–	–	P	–	–
Transept	754	–	NR	P	NR	NR	–	–	–	–	–	–	–	NR	NR	NR	–
Travertine	762	–	NR	S	NR	–	S	–	–	S	–	–	–	–	S	–	–
Tuckup East	633	–	P	–	–	–	–	–	–	–	–	–	–	–	S	–	–
Tuna Creek	711	–	–	–	–	–	–	–	–	–	–	–	–	–	P	–	–
Turquoise	690	–	S	NR	–	–	S	P	–	–	–	–	–	–	P	P	–

[A] –Not surveyed

[B] S = Single

[C] NR = No response

[D] P = Pair

[E] # = Number of juvenile

Table 33 (continued). Occupancy and Survey History of Mexican Spotted Owl Protected Activity Centers in Grand Canyon NP, 1990–2015.

PAC Name	Area (acre)	'90s	'01	'02	'03	'04	'05	'06	'07	'08	'09	'10	'11	'12	'13	'14	'15
Walhalla	654	–	P	–	–	–	–	–	–	–	–	–	–	–	–	NR	–
Wall Creek (Cottonwood Camp)	1032	–	NR	–	NR	–	–	–	–	–	–	–	–	–	NR	–	NR
Walthenberg	872	–	S	NR	–	–	–	–	–	–	–	–	–	–	NR	–	–
Woolsey Butte[14]	1693	–	NR	–	–	–	–	–	–	–	–	–	–	–	S	S	P

[A] – = Not surveyed

[B] S = Single

[C] NR = No response

[D] P = Pair

[E] # = Number of juvenile

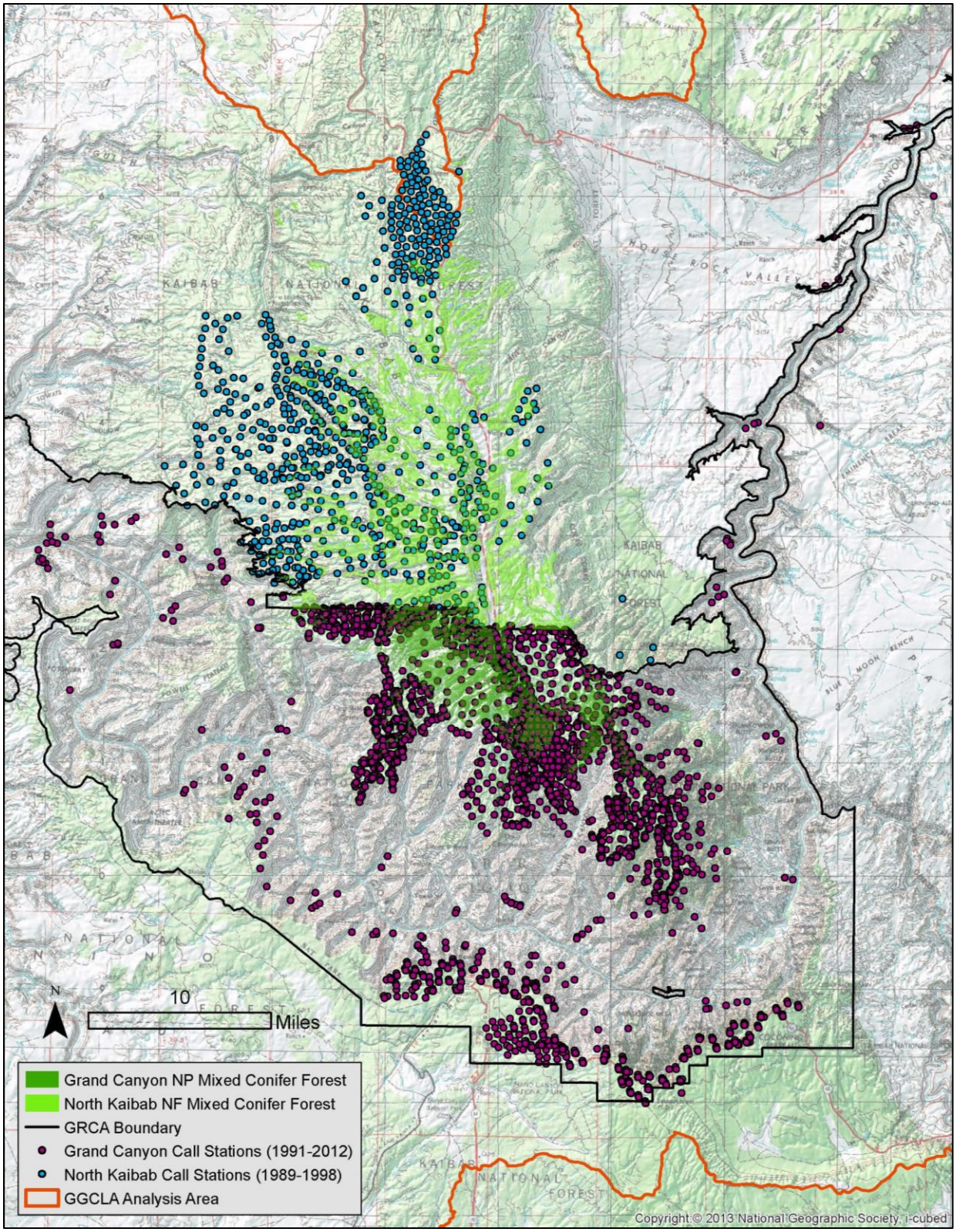


Figure 49. North Kaibab Plateau mixed-conifer forest and Mexican spotted owl inventory/compliance survey call stations, North Kaibab National Forest and Grand Canyon National Park, 1989–2012.

5.15.2. Indicators/Measures

- Presence (protected activity center occupancy)

5.15.3. Methods

Since 1991, Grand Canyon NP has employed several MSO survey methods, depending on the survey objective and the survey location. Many of the MSO surveys conducted employed variations to the recommended survey protocol specified in the MSO Recovery Plan (USDI 1995; USFWS 2012) largely due to the logistical difficulty of surveying in the remote backcountry of Grand Canyon NP.

Presence (PAC occupancy)

Overall, Grand Canyon NP MSO presence/absence surveys can be divided into the following three goal categories:

- Inventory: surveys conducted in an area that had never been previously surveyed, or in an area that had been previously surveyed, but in which MSOs had not been detected.
- Monitoring: surveys conducted in previously identified MSO territories (i.e., PACs) or where a single MSO had been previously detected.
- Compliance: surveys conducted within or adjacent to a proposed project area that is within MSO habitat.

Common methods across each type of survey include the following data points:

- Time of year: surveys were conducted between March 1 and August 30.
- Time of day: surveys were conducted between sunset and sunrise.
- Predators: surveyors discontinued calling when a potential owl predator was detected; surveyors either moved on to another calling station out of earshot of the predator or returned at a later time to the calling station.
- Weather: surveyors did not call for owls during inclement weather such as rain, snow, or at wind speeds greater than 24 kilometers per hour.

Beyond these commonalities, slight variations in survey methods have occurred in different habitat types and different survey goal categories.

Forested Plateau Habitat

Designated calling stations were used to locate owls by aural detection of owl response to recorded calls played over mechanical speakers. Survey points were placed every 800 meters throughout forested plateaus and drainage rims throughout the survey unit/project area. The four-note location call is the most common call used by male spotted owls, and was the primary call used during surveys. Contact calls and the bark series were also used during each survey. Surveyors spent at least 15 minutes at each calling station.

Inner Canyon Habitat

Sites were surveyed using two methods: a potential core area visit or use of a parabolic dish from the rim of the canyon. For potential core area visits, surveyors backpacked into side canyons of the Grand Canyon in order to access potential breeding habitat. At each potential core area survey site, calling routes were established that systematically traversed suitable patches of MSO habitat identified by the GIS model. Along each calling route, calling stations were placed every 0.5 to 1.0 km. For parabolic dish surveys, surveyors used parabolic dishes with a microphone preamp from the rim of the canyon in order to amplify potential owl calls coming from deep within the canyon (Figure 50). In all cases, calling stations were located with the intent to obtain complete coverage of the survey area. Four-note and bark series calls were mimicked periodically until an owl was detected or 1 hour had elapsed. The methods were the same as for inventory/compliance surveys. However, for monitoring surveys, the surveyors hiked directly to an established nest/roost site or the center of an established PAC to begin surveying.



Figure 50. Use of a parabolic dish from the rim of the canyon.

North Kaibab National Forest Methods

Surveys followed USDA Forest Service "Spotted owl inventory protocol interim directive number 2" (USDA 1990) and methods described by Forsman (1983).

5.15.4. Condition and Trend

Table 34. Summary of Mexican Spotted Owl resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Presence (PAC occupancy)	Historic occupation of MSOs in PACs, as well as MSO densities in other canyon areas in the Southwest.		Anecdotally, MSO populations are particularly high in the Grand Canyon relative to similar habitats elsewhere in the Southwest. Surveys conducted for 25 years show no evident decline in occupation over that time. However, surveys have been performed inconsistently and there are many missing data points.

Presence (PAC occupancy)

The current condition and trend of MSO populations in the GGCLA area is generally unknown due to the inconsistent survey efforts and incomplete inventory of all potential habitat. Unverified assumptions regarding the Grand Canyon MSO population claim that Grand Canyon NP likely hosts the largest population of canyon-dwelling MSOs in North America. It is also hypothesized that Grand Canyon NP MSOs move around a fair amount within the canyon, perhaps using different parts of side canyons at different seasons or shifting territory boundaries in response to prey populations. Such movements may make determining actual MSO population size for the Grand Canyon area challenging.

There are multiple stressors that may be or will be having an effect on MSOs in the GGCLA area, many of which are influenced by and interrelated to each other. These stressors include the following:

- Model-based predictions of the effects of climate change include, but are not limited to hotter and drier climates in the U.S. Southwest (Archer and Predick 2008). Climate change impacts on MSOs include shifts in distribution of the owl and/or major prey species, possibly along elevational or latitudinal gradients; effects on demographic rates and changes in coevolved interactions (e.g. prey-predator relationships); direct loss of habitat due to increased fire severity, bark beetle outbreaks, and direct warming of habitats; increased population, or range expansion of species that are direct competitors; and reductions in population size, which in turn can alter vegetation communities and prey populations. Climate change will influence the severity of other stressors, mentioned below, including fire management, water development, and insects and disease.

- Both the potential for stand-replacing fire and fire suppression may directly and indirectly affect MSO forest habitat, including the alteration of vegetation structure, soil, and watershed conditions. In Grand Canyon NP, severe fires and/or the cumulative effects of multiple prescription treatments (e.g., thinnings) may also affect MSO inner-canyon habitat. Hotter and drier climates will increase susceptibility of forests to large-scale, stand-replacing fires.
- Introduced species or native-species infestations can pose risks to MSOs when they are exacerbated by unnatural stand conditions, drought, climate change, or other factors. Insects and disease outbreaks may increase in frequency, extent, intensity, and duration if climates become hotter and drier (Lynch 2003; Seager et al. 2007). Heavy die-off from insects and disease will also increase the potential for stand-replacing wildland fires.
- Land development threatens foraging and wintering habitat by creating habitat fragmentation, disrupting dispersal corridors, inhibiting gene flow, altering prey habitat, increasing competitive and predator species, and altering grazing patterns by wildlife and domestic ungulates.
- Water development effects can range from site-specific habitat loss or degradation to habitat fragmentation through inundation and altered hydrological function, disruption of migration corridors, and inhibited gene flow across larger landscapes. Stock tanks allow both domestic and wild ungulates to expand their geographic range, which may affect the habitat of owls and their prey. Dams have inundated habitat and influence the structure and function of riparian ecosystems (Poff et al. 1997). An increase in non-native tamarisk increases soil salinity and thus conveys a competitive advantage to tamarisk over native cottonwoods and willows. An increase in tamarisk and a decline in native vegetation may have implications for owl habitat quality. Development of water that occurs outside Grand Canyon NP boundaries (e.g., drilling wells) has the potential to negatively impact surface water (seeps, springs, and streams) in the inner canyonlands of Grand Canyon NP.
- Creation of long-term facilities such as wind turbines, utility lines, mines, pits, well pads, roads, and pipelines may increase the risk of MSO collision with structures, increase noise disturbance, and fragment habitat.
- Activities such as canyoneering, hiking, camping, OHV use, rock climbing, and biking that occur in or near PACS or dispersal corridors may disturb breeding pairs and/or juveniles or negatively alter their preferred habitat.
- Noise from Grand Canyon NP air tour operations may potentially disturb nesting MSOs.
- Grazing by both domestic and wild ungulates may alter vegetation communities and prey populations, degrade riparian communities, and reduce available surface water.

5.15.5. Summary

MSO populations within forest habitats have received considerable attention over the past decade (Ganey and Balda 1989; Ganey et al. 1999; Ganey et al. 2005). In contrast, our knowledge of the owl's ecological fundamentals in rocky canyon habitat of the Colorado Plateau is quite limited (Rinkevich and Gutiérrez 1996; Willey 1998; Willey and Van Riper 2007). The lack of adequate knowledge and the potential for population declines (Seamans et al. 1999) highlight the need for further research in the Colorado Plateau Ecological Management Unit (Andersen and Mahato 1995; USDI 1995). It is believed, but not proven, that the study area hosts a source population of MSOs. Understanding the dynamics of Grand Canyon NP's MSO metapopulation and how it is linked to the larger regional MSO population is a critical data need, and filling that need would help us to better understand the life history of the canyon-dwelling MSOs, as well as helping to guide land management practices.

As indicated above, there are many stressors that affect or have the potential to affect MSOs in the GGCLA area. Many of these stressors can be monitored if the above-mentioned data needs are investigated. For example, if a dispersal study discovered that MSOs were using the North Kaibab Forest as a dispersal corridor, then stressors that may negatively affect habitat on the North Kaibab Forest could be better mitigated. In Grand Canyon NP, the presence of a steep elevational gradient allows MSOs to potentially shift their local distribution in response to climate change impacts in their canyon habitat. The potential warming and drying trends of climate change may begin to "push" the owls out of canyon habitat and into the forested plateaus of both canyon rims. Understanding why MSOs are not currently using these forested habitats may help guide future forest management practices to better support breeding MSOs.

5.15.6. Data Needs

- Determine, via genetic sampling and/or telemetry, the dispersal patterns of Grand Canyon MSOs.
- Determine the relatedness of MSOs in Grand Canyon to surrounding forest-dwelling and canyon-dwelling MSOs.
- Identify and investigate dispersal habitat and determine if this habitat is a sink (e.g., North Kaibab forest).
- Determine the MSO occupancy status and population size in Grand Canyon NP.
- Study abundance and diversity of small mammal communities in rocky-canyon habitat with and without owls, and what key habitat features are important to sustaining a robust prey base for MSOs.
- Conduct a comparative study of North Kaibab Forest's MSO recovery habitat and forested habitat that support breeding MSOs in order to determine potential limiting factors on North Kaibab MSO populations (e.g., prey, shelter, climate, water, predation, competition).

5.15.7. Level of Confidence

Although Grand Canyon NP has recently increased their survey effort within identified potential canyon habitat, there are still many other areas that could be surveyed. At this point, assumptions about placement of PACs on the landscape and the associated habitats within them are based only on the sample of PACs we have identified to date. Also, inconsistent survey methods and efforts make comparisons between PACs tenuous at best.

5.15.8. Sources of Expertise

This section as prepared by Janice Stroud-Settles, a former wildlife biologist at Grand Canyon National Park, Greg Holm, wildlife program manager at Grand Canyon National Park, and Angela Gatto, wildlife biologist on the North Kaibab National Forest.

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5.16. Wildlife: Northern Goshawk

5.16.1. Description



Northern goshawks are widespread in the forest–dominated vegetation communities within the GGCLA area. A variety of forest structural characteristics in the region provide goshawks with dense mature cover for nesting, open forests for foraging, and adequate forest openings and conditions important to their prey. Intensive demographic studies of goshawks on the Kaibab Plateau have provided key information to guide forest management in the region. However, although the Kaibab Plateau has distinct climatic and vegetative characteristics due to its relatively high elevation, it comprises only a fraction of the analysis area, and generalizations about the suitability of habitat for northern goshawk across the greater analysis area should be made with caution. Research on the Kaibab Plateau indicates that goshawk reproduction may be in slight decline. Implementation of a systematic and efficient goshawk inventory program (e.g. Woodbridge and Hargis 2006) would provide an assessment of occupancy at the GGCLA scale without the need for intensive local nest area monitoring (Photo by Martha de Jong-Lantik, creative commons license CC BY-NC-ND 2.0).

The northern goshawk (*Accipiter gentilis*, hereafter, goshawk) is a species of particular interest to multiple resource management agencies in the analysis area. Declining goshawk populations on the Kaibab Plateau (Crocker-Bedford 1990) prompted the USFS to convene a multi-disciplinary task force to develop habitat management guidelines. The resulting management recommendations for the northern goshawk (MRNG) in the southwestern United States (Reynolds et al. 1992) were officially adopted into the 11 forest management plans in Arizona and New Mexico in 1996 and again in 2006 (USDA 2006). The revised 2014 Land Management Plan for the Kaibab National Forest (USDA 2014) does not explicitly reference the MRNG but does incorporate findings from goshawk and habitat research to establish desired conditions in the ponderosa pine and frequent fire mixed conifer vegetation types that support foraging, nesting, and dispersal.

The goshawk was unsuccessfully petitioned for listing under the Endangered Species Act (Goad 2005) but remains a USFS sensitive species in the region. The most recent USFS restoration-focused management framework for southwestern forests likewise incorporates practices to maintain goshawk habitat (Reynolds et al. 2013). USFS researchers have collected extensive long-term demographic and ecological data from the goshawk population on the Kaibab Plateau; these data can be assessed in the context of ecosystem processes (e.g., predator-prey interactions, climate change) to enhance analyses of overall forest health.

In the Southwest, goshawks prey on medium-sized birds and mammals such as rabbits (*Sylvilagus* spp.), tree squirrels (*Sciurus* and *Tamiasciurus* spp.), ground squirrels (*Spermophilus* spp.), chipmunks (*Tamias* spp.), woodpeckers (*Colaptes*, *Leuconotopicus*, *Melanerpes*, and *Sphyrapicus* spp.), jays (*Aphelocoma* and *Cyanocitta* spp.), thrushes (*Catharus*, *Myadestes*, *Turdus* spp.), and grouse (*Dendragapus obscurus*; Reynolds et al. 2006). Goshawks nest in stands of mature trees with high canopy cover (Crocker-Bedford 1990; Ward et al. 1992; Beier and Drennan 1997). There is substantial support for the hypothesis that goshawks prefer to forage in dense, mature forests (Drennan and Beier 2003; Greenwald et al. 2005; Reynolds et al. 2006; Beier and Drennan 1997), but some prey species are typically more abundant in forests with more open canopy structure. Prey abundance has been shown to correlate positively with goshawk reproductive success (Salafsky et al. 2005, 2007).

Within the analysis area, the Kaibab National Forest (North Kaibab and Tusayan Ranger Districts) is managed under its Land Management Plan to provide multiple goshawk nest areas per territory and a mosaic of forest size and structure classes that includes habitat attributes specific to goshawk hunting strategies (e.g., adequate canopy base height for subcanopy flight space and abundant perches). Forest openings, snags, and woody debris are also important habitat elements for goshawk prey species (Reynolds et al. 2012). The MRNG describe a set of conditions in which mature stands are maintained in the 12 hectares nest area (NA) and the surrounding 170 hectares post-fledging family area (PFA), with a much more open forest in the remainder of the 2430 hectares home range, or foraging area (FA).

5.16.2. Indicators/Measures

- Habitat quality
- Demographics

5.16.3. Methods

Habitat Quality Model

Previous efforts have identified forest structural characteristics important to the goshawk in portions of the analysis area (La Sorte et al. 2004; Tuten et al. 2015) and elsewhere in northern Arizona (Beier et al. 2008). Others have estimated habitat occurrence by modeling habitat at the landscape scale (Dickson et al. 2014) but still do not cover the entire region. Our objective was to generate a classified model of habitat quality across the analysis area

We obtained data documenting goshawk detections, including nest locations, from Grand Canyon NP. Two nest locations within the boundary of the Outlet Fire of 2000 were omitted from the dataset; although these nests were successful in 1992 and 1996, the fire severely impacted available nesting habitat. The remainder of the data documented nest locations (n = 81) or individual detections (n = 35) between 1992 and 2011. The data on nest activity and/or success were incomplete and were therefore not included in our analysis. When planning restoration or silviculture projects in goshawk habitat, the management approach is primarily to designate nest areas around known nest locations and to maintain alternative nest sites with the appropriate forest structural characteristics. We therefore conducted our analysis using the MRNG-specified nest area (12 hectares); each pixel in the analysis was summarized by the mean and/or standard deviation of a surrounding 12 hectares circular area.

We created buffer areas representing NA, PFA, and FA habitat surrounding goshawk nest locations. We created buffers of FA size around individual detections, but did not include any NA or PFA. These buffer areas were used as training samples in a supervised multivariate maximum likelihood classification model (Richards 2013) to determine where current conditions may be best described as NA, PFA, or FA. To bolster the relatively small amount of NA training data available to the classification from the known nest locations, we supplemented the NA buffers with additional regions representing high predicted territory occurrence from Dickson et al. (2014). The lowest predicted probabilities from the model were used to delineate training data representing low-quality habitat (LQ). We considered LQ habitat to be vegetated but with insufficient structure to constitute a permanent part of a home range. Additional training data for unsuitable habitat (UNS; developed lands or lower-elevation and unforested or sparsely vegetated cover) was generated using pixels described by the Landfire existing vegetation type layer (www.landfire.gov) as developed, barren, or sparsely vegetated. Classes were predicted using a priori probabilities proportional to the areas sampled in each class of training data (Hagner and Reese 2007).

For our final model, NA, PFA, FA, LQ, or UNS areas were dependent on the following variables:

- Total aboveground biomass, obtained from the National Biomass and Carbon Dataset (NBCD, Kellndorfer et al. 2012). In a subset of the analysis area, NBCD was a good predictor of quadratic mean diameter, as predicted by previous custom-derived forest structure data (Dickson et al. 2014). We therefore found the NBCD data to be an appropriate surrogate for forest size and age class. Biomass was summarized by mean; high biomass is more appropriate for goshawk nesting and may be preferred for foraging.
- Percent tree canopy cover, obtained from the National Land Cover Database (NLCD, Jin et al. 2013). Canopy was summarized by both mean and standard deviation. High mean canopy cover indicates homogeneity of forest cover. High standard deviation of canopy cover indicates more forest openings, important for some prey species.
- Distance from forest/woodland cover. Landfire Existing Vegetation Type (EVT) was used to derive data representing upland forest/woodland cover types. Goshawks nest only in forest/woodland cover and are highly adapted to forage in similar cover types.

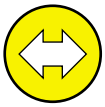
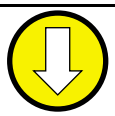
- Standard deviation of slope, derived from Landfire elevation data. We used these data to derive this metric of topographic roughness due to their good classification at multiple scales and ease of computation (Grohmann et al. 2010). Nest sites tend to be located in areas of relatively gentle topography as compared to the remainder of the home range (Reich et al. 2004).

Demographics

This assessment was completed through a review of peer-reviewed studies and agency reports.

5.16.4. Condition and Trend

Table 35. Summary of Northern Goshawk resource condition and trend by indicator.

Indicator	Reference framework	Trend	Summary comments
Habitat quality	Presence of mature forest stands for nesting and a variety of forest structural stages for foraging.		Habitat is diverse and appropriate for all goshawk life stages; forest management planning considers goshawk habitat conditions.
Demographics	Number of nesting pairs, young hatched and successfully fledged.		Reproduction is variable but stable to declining over the past 20 years.

Habitat quality model. Our habitat model was able to distinguish between all five habitat classes (UNS, LQ, FA, PFA, and NA) with an acceptable amount of overlap between the classes. The mean value of each predictor in each class, and range within 1 standard deviation of the mean, is shown in Table 36.

Table 36. Mean (±1 standard deviation) values for five predictor variables in unsuitable (UNS), low-quality (LQ), foraging area (FA), post-fledging family area (PFA), and nest area (NA) classes of goshawk habitat quality. All predictor variables were geographically summarized at the scale of a 12 hectares goshawk nest area by mean (biomass, canopy, and distance from forest) or standard deviation (canopy variability, slope variability) before use in our habitat model.

Variable	Biomass (kg/m^2)	Canopy (%)	Canopy variability	Distance from forest (km)	Slope variability
UNS	0.3 (0.0–1.1)	2.0 (0.0–4.8)	1.2 (0.0–2.5)	19.3 (8.9–29.7)	4.6 (0.0–9.6)
LQ	1.9 (0.2–3.6)	9.9 (3.6–16.2)	3.8 (1.6–5.9)	2.0 (.7–3.3)	7.8 (2.5–13.1)
FA	5.4 (2.7–8.1)	20.0 (11.7–28.2)	7.0 (3.3–10.7)	0.08 (0.0–0.22)	3.5 (0.6–6.5)
PFA	10.0 (8.0–12.0)	36.7 (30.8–42.6)	10.5 (8.3–12.7)	0.007 (0.0–0.028)	4.6 (2.6–6.5)
NA	12.5 (11.4–13.5)	41.7 (38.3–45.1)	6.9 (4.7–9.1)	0.004 (0.0–0.016)	3.7 (2.3–5.2)

Our predictions indicate that high-quality goshawk habitat in the analysis area (i.e., NA or PFA) is likely to be found in forests dominated by ponderosa pine, aspen-mixed conifer, and spruce-fir. FA habitat was commonly found in forested areas, though not as restricted, and also occurred in pine-oak, pinyon-juniper, and grasslands or rangelands in close proximity to forested cover. Small areas of FA and most LQ habitat were predicted in low-elevation pinyon-juniper woodlands or shrublands (Figure 51). The classification predicted 4.2% of the GGCLA area as goshawk NA or PFA. Another 7.8% was FA, and 12.8% was LQ habitat. The remaining 75.2% of the GGCLA area was considered UNS. The majority of the NA was located in the North Kaibab district of Kaibab National Forest (KNF). Forests located in the Tusayan district of KNF, surrounding the Uinkaret Mountains south of Mount Trumbull, and the Pine Spring/Aubrey Cliffs region of the Hualapai Indian Reservation were predominantly classified as FA with some areas of PFA. Most habitat with PFA-like conditions was found on USFS-administered lands of the Kaibab Plateau, and Kaibab Plateau forests within Grand Canyon NP were more likely to be NA.

Overall, areas of higher habitat quality are concentrated in forested vegetation. Within these core areas, heterogeneity of NA, PFA, and FA habitat is relatively high on the Kaibab Plateau, especially when compared to the vast regions of UNS habitat found in the majority of the analysis area. Forests elsewhere in the analysis area were classified more as homogeneous FA. The varied vegetative structure may benefit goshawks by providing suitable habitat conditions for nesting goshawks and a full suite of preferred prey species (Reynolds et al. 2006).

Demographics

The Kaibab Plateau has been the focus of an intensive multi-year goshawk ecology study conducted by the USFS Rocky Mountain Research Station. This effort has resulted in studies describing the demography (Reynolds and Joy 2006; Wiens et al. 2006a), prey resources (Salafsky et al. 2005, 2007; Wiens et al. 2006b), ecological and habitat associations (Gatto 2002; La Sorte et al. 2004; Reich et al. 2004; Salafsky et al. 2007), genetics (Bayard de Volo et al. 2013), and effective research methods (Reynolds et al. 2006, among others).

Goshawks will readily switch between alternate prey species; the presence of a diverse prey base favors goshawk reproduction, but makes it difficult to assess the importance of any single species. Some individual prey species may contribute greatly to goshawk diets in terms of predation rates and biomass, but show no relationship with reproduction (Salafsky et al. 2005). Salafsky et al. (2007) assessed the abundance of four major prey species on the Kaibab Plateau and found that goshawk productivity was higher in years of higher total prey density. Weather conditions can directly affect goshawk reproduction by reducing foraging activity, causing hypothermia, and freezing eggs (Squires and Kennedy 2006). However, it is the synchronous declines in many prey species due to broad climatic factors (e.g., drought conditions resulting in low cone crop production) that have a stronger influence on goshawk reproductive success (Salafsky et al. 2005; Keane et al. 2006).

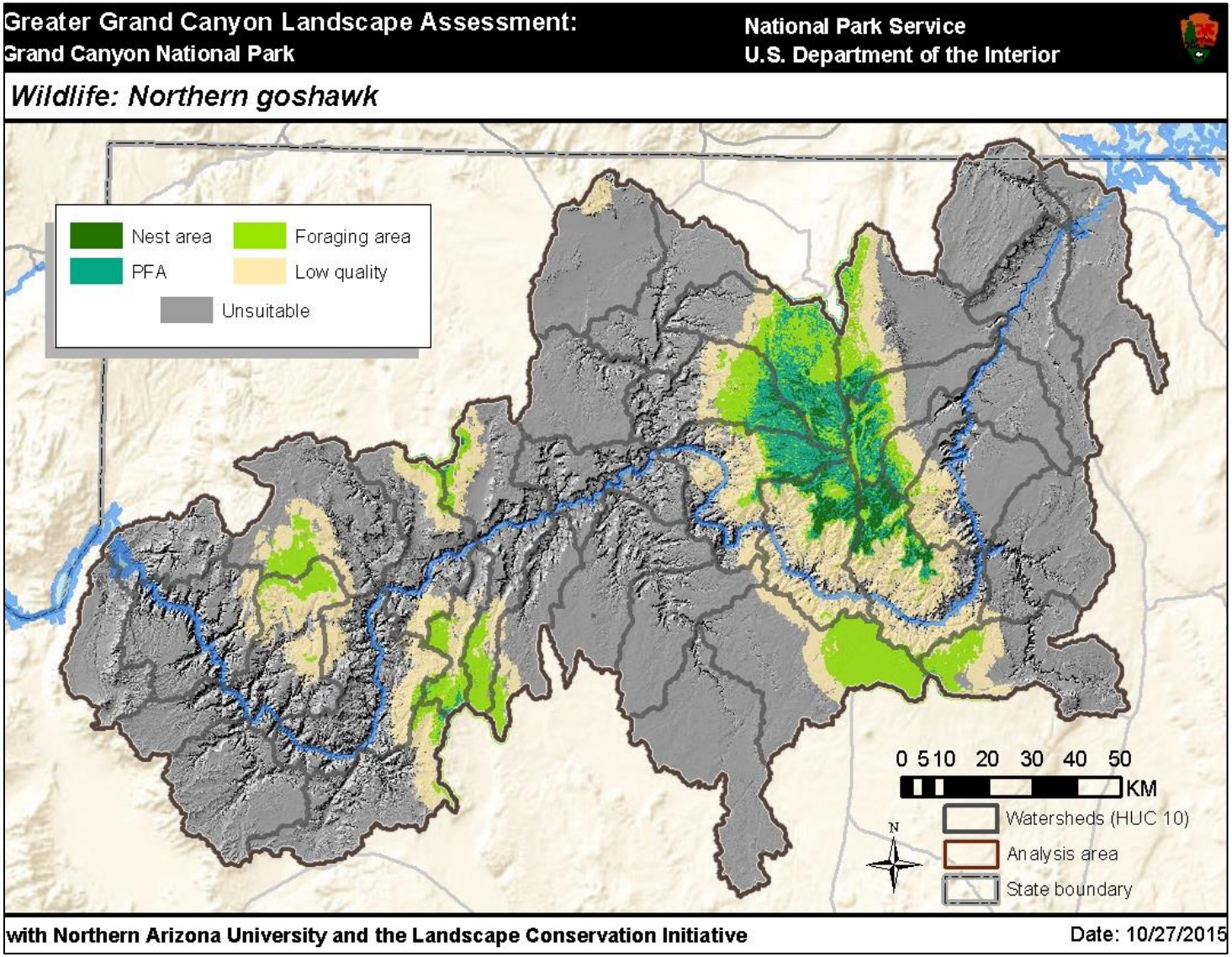


Figure 51. Goshawk habitat quality model identifying nest areas (NA), foraging areas (FA), post-fledging family areas (PFA), areas of low goshawk habitat quality (LQ), and areas of unsuitable goshawk habitat quality (UNS).

Nevertheless, a comprehensive synthesis for the entire analysis area has not yet been produced. Partial analyses show that on the Kaibab Plateau from 1991 to 1996, nest productivity was in the lower range of values reported elsewhere in North America (Reynolds and Joy 2006). Territories on the Kaibab Plateau were frequently occupied by the same pair throughout their reproductive lives, and were reoccupied within 1–3 years of being vacated. The population of breeding individuals appeared stable over time. Territories were spaced regularly throughout the forested areas on the Kaibab Plateau, which suggests that all available nesting habitat was occupied (Reich et al. 2004).

Additional research suggests that the Kaibab Plateau has been densely populated by goshawks (Reich et al. 2004). The annual number of breeding pairs has been variable and had indicated a slight but statistically significant overall decline from 1991 to 2005. Breeding success has also been variable. As of 2014, the USFS considered the goshawk population to be widespread across the Kaibab National Forest, with a stable number of active territories. Reproduction is likely dependent on precipitation, which is highly variable, and resultant forest productivity (Foster et al. 2010).

It is important to consider that goshawk population trends identified on the Kaibab Plateau may not be representative of the entire analysis area, especially since the Kaibab Plateau includes a larger, more continuous expanse of forest-dominated vegetation than most other suitable areas in the region (e.g., the south rim of Grand Canyon National Park, Mount Trumbull Wilderness).

In the analysis area, goshawks are subject to stressors specifically associated with forest management and fire ecology. These processes alter the distribution of tree size classes, patterns of forest openings, overall tree density, canopy cover, and understory composition. Habitat components important to goshawk prey species are likewise affected (Reynolds et al. 2006). Climate change may alter forest conditions through drought-induced plant mortality and disruption to ecosystem processes (Hanson and Weltzin 2000). Long-term changes in temperature and precipitation due to climate change have resulted in an increase in wildfire activity (Westerling et al. 2006) and may cause geographic shifts in vegetation communities (Kelly and Goulden 2008). In addition to the direct effects on goshawk habitat components, changes to forest structure from human activity or wildfire may increase interspecific competition with other raptor species better adapted to more open forest conditions (Gatto et al. 2005).

5.16.5. Summary

Forested areas within the GGCLA area provide a diverse set of habitat conditions that meet the needs of breeding and foraging goshawks. However, it remains unclear how this diversity affects reproductive success at local (i.e., territory) and regional (i.e., analysis area) scales. Although the status of the goshawk population on the Kaibab Plateau is highly variable and thought to be declining, little is known about the status of populations elsewhere in the analysis area.

5.16.6. Data Needs

- Systematic, long-term monitoring of goshawk populations (and associated habitat characteristics) across all potential habitat in the analysis area.

- Goshawk occupancy and abundance over large spatial extents could be more efficiently assessed through the bioregional monitoring protocol described in USFS GTR WO-71 (Woodbridge and Hargis 2006). This regional approach to data acquisition and monitoring avoids the relatively resource-intensive challenges associated with local-scale nest monitoring, while maintaining a statistical ability to assess changes in goshawk population status. The design maximizes efficiency through the integration of stratified sampling, standardized data-collection protocols, and centralized analysis and reporting (Hargis and Woodbridge 2006).

5.16.7. Level of Confidence

Our habitat quality model represents a reasonable, contemporary prediction of the distribution of key attributes that meet the ecological and life history requirements of goshawks. These attributes are also relevant to resource managers tasked with developing habitat prescriptions that incorporate concern for goshawks and their prey. Nevertheless, refinements to our model could be made to incorporate other environmental variables, including measures of prey abundance and/or availability and considerations for effects of climate change on precipitation patterns. Further refinement could be made to incorporate actual nest locations from areas other than the Kaibab Plateau. Our confidence in the assessment of demographic trends over the entirety of the analysis area is moderate, considering that each of the peer-reviewed studies and agency reports that we examined were products of data collected solely within Kaibab National Forest.

5.16.8. Sources of Expertise

This section was prepared by Christopher Ray, MSc, in cooperation with Brett Dickson, PhD, and Luke Zachmann, MSc (Conservation Science Partners, Inc). Goshawk nest locations and detection data were provided by Grand Canyon National Park.

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5.17. Wildlife: River Avifauna

5.17.1. Description



Riparian habitats cover just a small area of the Southwest but contain high avifaunal diversity. In the Grand Canyon, avifaunal numbers are thought to have increased since dam construction due to the increase in riparian habitat. Post-dam surveys have not identified a long-term trend in avifaunal richness. More continuous efforts to monitor the southwestern willow flycatcher have detected declines since the 1990s. Photo: Blue-gray gnatcatcher (Photo by Kelly Colgan Azar, creative commons license CC BY-ND 2.0.).

The Grand Canyon is home to an impressive diversity of birds, with 362 species identified in the region (Gatlin 2013). The riparian vegetation, marsh habitat, and food sources available on the Colorado River offer important resources to species that nest in the river corridor and many others that migrate through or use the river as winter habitat. Less than 1% of the land area in the western United States consists of riparian vegetation; however, more breeding birds occur in riparian habitat than in any other habitat type in the Southwest (Knopf et al. 1988). Furthermore, riparian habitats host more land birds than any other habitat in the Southwest (Rich et al. 2004), indicating the important role played by riparian habitats in bird diversity in the Grand Canyon region and across the West.

Waterfowl and shorebirds share a direct connection to the river, songbirds and raptors are associated with the river corridor for nesting, migration, and foraging, and several species of concern occur in the river corridor. The threatened bald eagle (*Haliaeetus leucocephalus*) hunts along the Colorado River, the California condor (*Gymnogyps californianus*), managed as endangered inside Grand Canyon NP, nests in the canyon walls high above the river, and the passerines, which feed upon invertebrates from the river, in turn, are food for the peregrine falcon (*Falco peregrinus*; Holmes et al. 2005). The southwestern willow flycatcher (*Empidonax trailli extimus*), a species listed as

endangered in 1995, is known to nest in small numbers at a few sites in the riparian vegetation of the Colorado River corridor.

Prior to the construction of Glen Canyon Dam, the old high-water zone was home to species that included Apache plume (*Fallugia paradoxa*), mesquite (*Prosopis glandulosa*), and cat claw acacia (*Acacia greggii*), but dam operations have brought dramatic changes to riparian vegetation in the river corridor. A new high-water zone was created along the banks of the river with a vegetation community that consisted primarily of tamarisk (exotic, *Tamarix chinensis*) and coyote willow (*Salix exigua)*, as well as rushes and grasses.

Although the first detailed surveys of river avifauna were not conducted until after the construction of Glen Canyon Dam, it is thought that river avifauna numbers have increased since dam construction (Brown et al. 1986; Carothers and Brown 1991; Stevens et al. 1997), likely due to the increase in riparian vegetation (Sankey et al. in preparation). Waterfowl, too, are thought to have increased below the dam due to an increase in food sources (Brown et al. 1986). Birds are considered a good indicator of ecosystem change due to their habitat selectivity and quick response times to ecosystem change resulting from climate variability, nonnative species, changing food sources, and human disturbances (Spence 2004). In a dammed ecosystem, riparian vegetation and subsequent responses by birds are affected by variable flow levels and timing of water discharge. A number of monitoring efforts have addressed river avifauna as part of broader studies of river dynamics, dam management, riparian vegetation, and faunal responses on the Colorado River.

5.17.2. Indicators/Measures

- River avifaunal richness by reach
- Southwestern willow flycatcher, habitat availability, presence, and nesting

5.17.3. Methods

Avifaunal richness. We used existing data from the Grand Canyon NP Research, Monitoring and Mitigation Program (RM&MP) to assess avifaunal richness in the GGCLA analysis area. In order to provide a landscape-level interpretation of the site data that had been collected and analyzed through the CRMP RM&MP efforts described in this section, species richness was also calculated by river reach.

The RM&MP was developed to monitor and adaptively manage the effects of the 2006 Colorado River Management Plan (CRMP) recreational use levels on park resources (Kearsley and McMaster 2011). The resources monitored included river avifauna, soil, vegetation, and campsite impacts. The RM&MP data, collected from 2007 to 2011, were analyzed to assess management and trends. Avifaunal data were analyzed to assess detection probabilities, to calculate occupancy probabilities, and to estimate species richness across use levels, hydrological zones, and sites (Zachmann et al. 2012; Horncastle et al. in review).

Between 2007 and 2011, surveys were conducted once per year in April or May at sites located between Lee's Ferry and Diamond Creek in the Colorado River corridor. Crews conducted 615 point counts (Horncastle et al. in review). Data were collected for bird species based on both direct

sightings and auditory cues, and estimates were made of distance from birds. The number of point counts per site depended on the site size, and usually was one or two. Community estimates were calculated using the EstimateS software application to determine avifaunal richness by hydrological zone, use level, year, and site type (camp and control), using Simpson diversity and jackknife richness estimators. Welch's t-test was used to compare differences in diversity and richness across the other variables. In order to assess trends over the 5 years, one-way ANOVA and Tukey HSD tests were performed to determine differences in richness over the period of the data (Horncastle et al. in review).

Southwestern willow flycatcher. We used monitoring data collected by Grand Canyon NP from 2010 to 2012 to address condition and trend of the endangered southwestern willow flycatcher in the GGCLA analysis area. Grand Canyon NP used surveys to assess suitable breeding habitat and southwestern willow flycatcher presence at 25 sites from 2010-2012 between Lee's Ferry and Pearce Ferry (Stroud-Settles et al. 2013), and were supplemented with sound monitoring in areas where the species had previously been observed, or in suitable habitat. Historical data collected using different methodologies since 1982 were compiled by applying a single set of residency and reproductive rules to make inferences about general population trend over time.

5.17.4. Condition and Trend

Table 37. Summary of River avifauna resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Avifaunal richness by reach	Pre-Glen Canyon dam avifaunal richness		In general, the post-dam increase in riparian vegetation is thought to have led to an increase in river avifauna. No trend has been found in existing survey data.
Southwestern willow flycatcher presence and nesting	Reference condition: Pre- Glen Canyon dam Desired condition: Habitat abundance in levels similar to 2000		Southwestern willow flycatcher historically had limited breeding habitat in the Grand Canyon. Post dam construction, habitat temporarily increased; however drought and tamarisk beetles have led to declines in habitat and subsequently southwestern willow flycatcher nesting and presence in the canyon since the 1990s. Thus, Southwestern willow fly catchers are in decline compared to desired conditions.

<u>Avifaunal Richness</u>

In total, 72 species from 10 dietary guilds were detected during the RM&MP spring point count surveys. The most common bird species identified were blue-gray gnatcatcher (*Polioptila caerulea*), common yellowthroat (*Geothlypis trichas*), house finch (*Carpodacus mexicanus*), Lucy's warbler

(*Oreothlypis luciae*), and yellow warbler (*Dendroica petechia*). The number of species observed in a given year ranged from 35 to 41. Annual mean jackknife richness estimates ranged from 36.59 to 42.33 over the study and annual mean Simpsons diversity ranged from 6.74 to 8.66 (Horncastle et al. in review; Zachmann et al. 2012). Diversity and richness differed significantly between years; 2007 and 2008 had the highest diversity and 2010 had the highest richness (Table 38). Although some inter-annual variability was detected in avian occupancy estimates, no trend, either increasing or decreasing, was found over the 5-year period at either the species or guild level. At the reach level, avifaunal richness varied, with the highest richness found in reaches 4 and 10 (Table 39, Figure 52). These also had the highest number of survey samples collected.

Table 38. Species richness estimates by year in Grand Canyon NP. Bold *F*-values are statistically significant based on $\alpha = 0.05$ and |*F*-crit| of 3.09. Table summarized from Horncastle et al. (in review).

Variable	# Sites	# Species	Jack 1 Mean	Jack 1 SE	F	Simpson Mean	Simpson SE	F
2007	56	37	38.60	2.58	**41.99**	8.66	0.66	**65.96**
2008	51	39	40.11	2.88	–	8.39	1	–
2009	58	35	36.59	2.11	–	6.74	0.47	–
2010	56	41	42.33	2.62	–	7.88	0.71	–
2011	50	36	37.02	3.28	–	7.05	0.89	–

Table 39. Species richness estimates by river reach in Grand Canyon NP. Data provided by Horncastle et al. and re-analyzed by river reach.

Reach	Name	Samples	Jack 1 Richness	Jack 1 SD	Simpson Diversity	Simpson SD
1	Permian Section	4	32.89	4.77	10.58	0.74
2	Supai Gorge	6	29.46	3.67	8.73	1.05
3	Redwall Gorge	8	32.67	3.29	10.95	0.93
4	Lower Marble Canyon	10	46.69	5.01	8.56	1.1
5	Furnace Flats	9	32.81	3.84	6.65	0.71
6	Upper Granite Gorge	9	19.84	2.83	4.95	1.35
7	Aisles	5	28.14	4.25	8.83	1.49
8	Middle Granite Gorge	9	26.24	3.2	5.45	0.72
9	Muav Gorge	6	22.67	3.07	4.38	0.52
10	Lower Canyon	18	50.46	3.88	6.97	0.41
11	Lower Granite Gorge	3	25.85	3.45	10.66	2.02

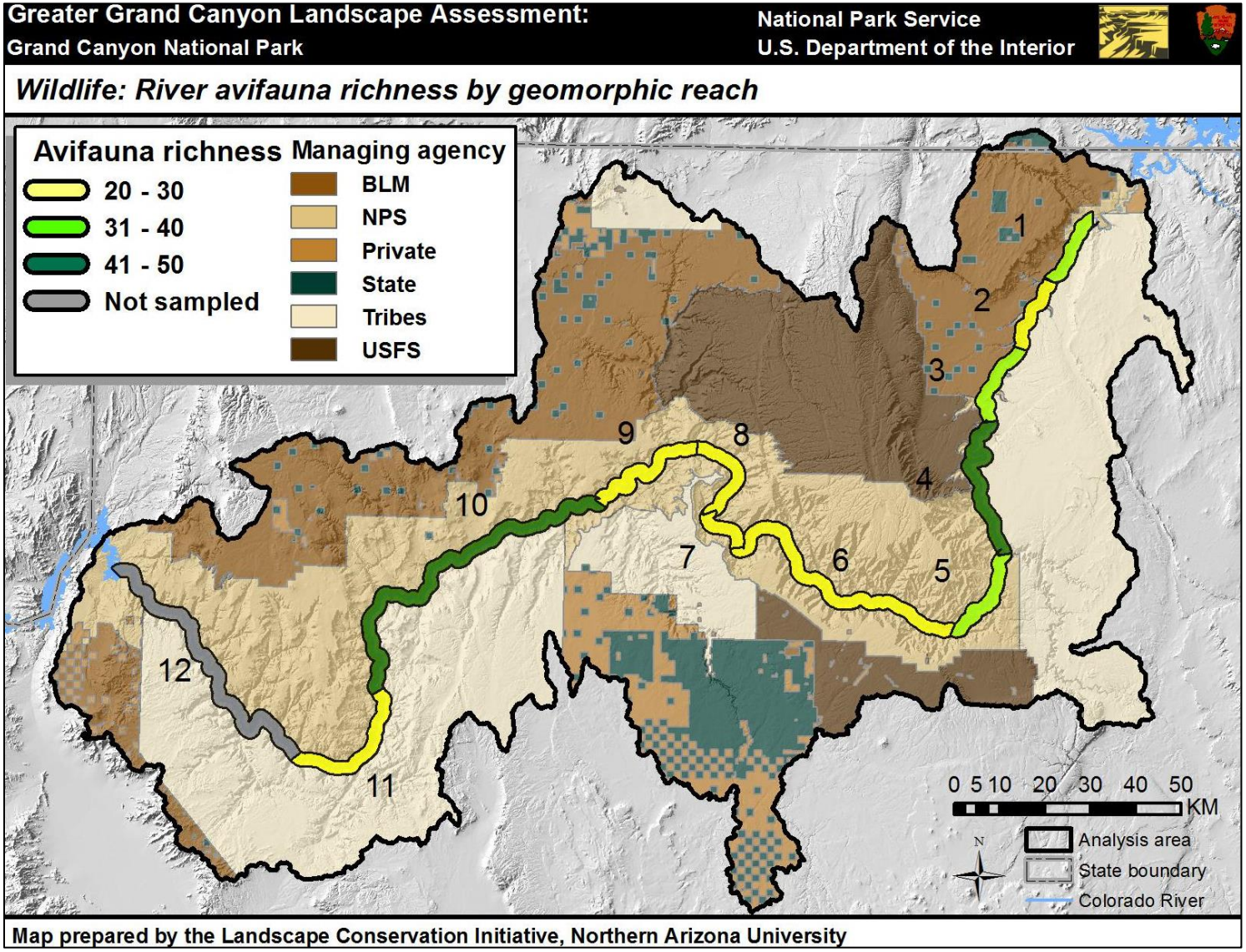


Figure 52. Number of species of avifauna per reach.

Southwestern Willow Flycatcher

Ten southwestern willow flycatcher detections occurred over the 2010–2012 survey study conducted by Grand Canyon NP. All detections were single occurrences; no breeding attempts were verified. Because Southwestern willow flycatcher abundance has been tracked since 1982 using various methodologies, methodological differences among datasets make statistical trend analysis unrealistic, but inference suggests that southwestern willow flycatcher populations in this area are in decline (Table 40). The Lee's Ferry to Phantom Ranch river section has been most consistently sampled, and it shows a decrease in breeding pair detection since the 1990s.

Table 40. Total number of observed adult breeding pairs and nests of the southwestern willow flycatcher along the Colorado River in Grand Canyon NP in 3-year increments, 1982–2012. Table from Stroud-Settles et al. (2013).

	Lee's Ferry–Phantom Ranch			Phantom Ranch–Diamond Creek			Diamond Creek		
Years	*Adult*[A]	*Pair*[B]	*Nest*[C]	*Adult*	*Pair*	*Nest*	*Adult*	*Pair*	*Nest*
1982–1984	10	3	4	ns[D]	ns	ns	ns	ns	ns
1985–1987	33	9	9	ns	ns	ns	ns	ns	ns
1988–1990	ns	ns	ns	ns	ns	ns	ns	ns	ns
1991–1993	17	6	6	1	0	0	3	0	0
1994–1996	36	6	11	3	0	0	1	0	0
1997–1999	10	3	3	0	0	0	56	20	9
2000–2002	9	2	2	3	0	0	63	26	9
2003–2005	5	2	2	0	0	0	4	1	1
2006–2008	1	0	0	ns	ns	ns	11	2	2
2009–2012[E]	6	0	ns	5	1	ns	2	0	ns

[A] Total number of adult southwestern willow flycatchers observed.

[B] Total number of breeding pairs observed (1 pair = 2 adult southwestern willow flycatchers).

[C] Total number of nests found, including re-nests (nest rebuilt after first or second nest failed/destroyed).

[D] No survey conducted.

[E] 2012 surveys were lumped with the 3-year increment of 2009–2011; no detections were made in 2012 along the entire stretch of river.

Before dam construction, regular scouring by flooding limited southwestern willow flycatcher breeding habitat in the Grand Canyon, though some cottonwood-willow gallery forests provided breeding habitat (Stroud-Settles et al. 2013). Between dam construction and about 2001, breeding was at its prime due to the abundance of habitat, primarily nonnative tamarisk, and the water levels in Lake Mead. Although they do not provide a historical reference point, the conditions during this time period are considered desirable for southwestern willow flycatcher habitat, particularly due to the overall loss of riparian habitat throughout the southwestern United States (Stroud-Settles et al. 2013; Stroud-Settles personal communication, 2016). Since 2001, drought has affected water levels and

southwestern willow flycatcher has decreased due to the tamarisk beetle defoliation of the tamarisk-dominated southwestern willow flycatcher breeding habitat. As such, southwestern willow flycatcher habitat in the canyon and the number of detections have decreased (Stroud-Settles et al. 2013; Stroud-Settles personal communication, 2016).

5.17.5. Summary

In addition to the 2007–2011 RM&MP survey efforts reviewed above, monitoring of river avifauna was conducted from 1996 to 2000 (Spence 2004) and 2001 to 2003 (Kearsley et al. 2006). Although the season of the surveys differed between these efforts, as did specifics of data collection and analysis, the number of species identified in the spring RM&MP effort (74) falls within the range of species found in spring and summer surveys (54–117) conducted earlier (Spence 2004; Kearsley et al. 2006). In addition, the studies share a similar list of most common species. No trend was detected in the 2007–2011 RM&MP data. Consistent with this, other monitoring efforts conducted post dam construction have seen little change in the river avifauna community; species common in the 1980s are still considered common today, although Bell's vireo and the song sparrow have expanded breeding ranges (Holmes et al. 2005). It has been calculated that a survey time frame of 10–15 years would be needed in order to monitor the trends for many bird species on the river (Spence 2004).

The RM&MP survey analysis found that vegetation volume is an important influence on avian species richness and diversity—species richness increases with total vegetation volume (Zachmann et al. 2012; Horncastle et al. in review). Other studies have also suggested that patch size, volume of woody species, and locations of patches are major factors affecting avifaunal abundance and richness (Holmes at al. 2005). Vegetation density is also thought to play an important role, with breeding birds found most often in the densest vegetation patches, perhaps because of shade or food availability (Kearsley et al. 2006).

At a landscape scale, richness tends to vary by river reach; however, reach-level richness could have been influenced by several non-biological factors, including the number of samples collected in each reach and the size of each reach. Furthermore, the number of campsites and controls sampled within a given reach varied, and because there were differences in the bird species composition between campsites and controls, it is expected that site type and number influenced the reach-level richness estimates. A number of other factors and patterns have been identified regarding reach-level variability in bird richness and diversity. The elevation drop and ecotone shifts along the Colorado River corridor lead to habitat shifts, and subsequent shifts in community composition. Other research has found the highest abundance, richness, and diversity of breeding birds in the lower reaches of the river, where habitat patches are larger and more contiguous (Sogge et al. 1998). In contrast, winter waterbird presence decreases with distance from the dam (Spence 2004).

Limited data on southwestern willow flycatcher numbers prior to dam construction suggest that they were uncommon breeders along the Colorado River. Surveys conducted since the 1980s show that their numbers have declined since 2000, and nesting flycatchers have not been confirmed since 2007, though formal nest surveys have not been conducted since 2007 (Stroud-Settles et al. 2013). The presence of southwestern willow flycatcher breeding pairs and non-residents trends downward, particularly in the Lee's Ferry to Phantom Ranch river section. Varying hydrological conditions have

affected the quality of southwestern willow flycatcher habitat as dam operations, climate, human water use, and increased water-consuming vegetation all affect water availability for flycatcher habitat. In addition, the increased distribution of the tamarisk leaf beetle has increased defoliation of tamarisk-dominated sites, which are used by southwestern willow flycatchers for nesting (Stroud-Settles et al. 2013). The southwestern willow flycatcher survey work suggests that the Grand Canyon does not contain extensive stands of dense riparian habitat suited to breeding flycatchers, and that many habitat patches do not contain slow moving water and consistent soil moisture, suggesting that existing habitat is marginal and will decline with future hydrological projections and increased range of tamarisk beetle. Repeat surveys have concluded that nesting territories are confined to a small number of sites, most of which now are experiencing declines in key habitat components. Southwestern willow flycatcher presence will likely continue at reduced rates from previous decades, with the Grand Canyon providing essential habitat for migrating flycatchers, but limited nesting habitat in the canyon (Stroud-Settles et al. 2013).

Threats to river avifauna include presence of the nonnative brown-headed cowbird (*Molothrus ater*), which practices brood parasitism on passerine nests, including the southwestern willow flycatcher (Brown 1994; Stroud-Settles et al. 2013). Visitor presence and associated impacts are hypothesized to affect birds found on the river corridor in differing ways, some positive and some negative, depending on their sensitivity to disturbance and reliance on habitat that might be impacted by camp sites. Analysis of the 2007–2011 RM&MP data showed that omnivore ground foragers were more abundant at campsites and nectivores were significantly less abundant at campsites compared to controls; however this may have been due to the presence of tamarisk for nesting at control sites rather than visitor impacts (Horncastle et al. in review). Habitat loss in riparian areas, such as the impact of tamarisk defoliation on southwestern willow flycatcher habitat, is another threat (Stroud-Settles et al. 2013). Because many birds are migrants, stressors outside of the GGCLA analysis area such as habitat loss, forage, climate, and disturbance may also be affecting bird populations (Holmes et al. 2005; Spence 2004).

5.17.6. Data Needs

Collecting additional site level-information on vegetation type and other habitat type variables during RM&MP surveys would help improve understanding of the drivers of difference between sites, and its connection to visitor use levels. This could include dominant vegetation and patch size, slope, and elevation (Zachmann et al. 2012). Migrant and wintering bird surveys could also expand the data set beyond breeding birds. Due to inconsistent efforts in monitoring avifauna, long-term trends cannot currently be determined; longer and more consistent surveying efforts using standardized methods would improve the ability to detect trends. Southwestern willow flycatcher monitoring has occurred more consistently due to the species' listed status, however survey methods continue to vary; consistent and standardized survey methods would permit statistical assessment of trends.

5.17.7. Level of Confidence

The RM&MP surveys had a high confidence for detecting common species and low confidence for detecting the full possibility of richness due to small sample size. The low sample frequency means that estimates could reflect lower numbers than are actually occurring.

5.17.8. Sources of Expertise

This section was prepared by Sasha Stortz. Valerie Horncastle, Luke Zachmann, Jesse Anderson, Brett Dickson, Todd Chaudhry, Greg Holm, Jill Rundall, and Janice Stroud-Settles provided data, analysis, and expertise.

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5.18. Wildlife: Northern Leopard Frog

5.18.1. Description



Construction of Glen Canyon Dam on the Colorado River altered conditions in and around the river, reducing water temperature and altering the natural hydrological regime. This, combined with the nonnative fish introductions, made the Colorado River unsuitable for northern leopard frogs, and has likely led to their functional extirpation within the GGCLA. The observed decline of northern leopard frogs across the Southwest has led to efforts to preserve the species' genetic diversity and maintain refugial populations within the GGCLA. At House Rock Valley Wildlife Area, northern leopard frogs have successfully been established in non-traditional habitat. These refugial populations could serve as source populations for future reintroductions of northern leopard frogs into historically occupied habitat (USDOT photo by Liz Domingue).

The northern leopard frog (*Lithobates pipiens*) is widely distributed across North America, from Washington State, east to New York, and north to Hudson Bay. Arizona represents the southwestern extent of the range. Two genetically distinct populations have been identified within this range—an eastern and a western haplotype, with the Mississippi River and the Great Lakes dividing the two (Hoffman and Blouin 2004). Since the 1980s, amphibian declines have been observed throughout much of the western United States (Hammerson 1982; Corn 1994; Kimberling et al. 1996; Muths et al. 2012). In the Southwest over the past 40 years, northern leopard frogs have also exhibited a marked decline (Corn and Fogleman 1984; Clarkson and Rorabaugh 1989; Sredl 1998).

Historic surveys found northern leopard frogs widespread, but not abundant, along the main river course and perennial side canyons of the Colorado River, in what is now Glen Canyon National Recreation Area in northern Arizona (Eaton 1935; Woodbury 1958; Sredl 1998). Two records exist in Grand Canyon NP, one at Ribbon Falls (Sredl 1998) and a second at Cardenas Marsh (Tomko 1975). Outside of Grand Canyon NP but within the GGCLA, northern leopard frogs have been documented upstream from Lee's Ferry at Horseshoe Bend (Drost and Sogge 1995) and at one

location just outside of the park boundary in Kanab Creek (S. MacVean, AZGFD, personal communication, 2015). In Marble Canyon, northern leopard frog occurrence was sporadic, presumably due to lack of suitable habitat (C. Drost, USGS, personal communication, 2015). In other parts of the GGCLA study area, historical records of northern leopard frogs are limited to a handful of disjunct occurrences. In 2014, a single adult leopard frog was observed in the drainage below Robbers Roost Spring (G. Holm, personal communication, 2015). Photos confirmed that the individual was a northern leopard frog, but its haplotype has not been confirmed and no frogs have been observed in the Robbers Roost drainage since the initial sighting.

Construction of Glen Canyon Dam in 1963 resulted in the fragmentation of northern leopard frog habitat along the Colorado River in Glen Canyon (Drost et al. 2008). Similarly, effects were exhibited in Grand Canyon NP, further fragmenting and altering suitable habitat. Extensive surveys of Glen Canyon and Grand Canyon NP areas from 2003 to 2008 revealed that northern leopard frogs were extirpated, or likely extirpated, from 67% of their previously known sites in Glen Canyon. No northern leopard frogs were found in Grand Canyon NP (Drost et al. 2008), suggesting that the species was likely extirpated from the park (Persons and Nowak 2006).

Currently, the northern leopard frog is listed as "sensitive" by the U.S. Forest Service, a "species of special concern" by the state of Arizona, and a "threatened" species by the Navajo Nation. In 2006, the western population of the northern leopard frog was petitioned for listing as a federally threatened species (Nichols 2006). However, in 2012, the U.S. Fish and Wildlife Service's 12-month finding on the petition was that listing the species was not warranted, as the species is common throughout most of its range, and genetic differences between the eastern and western population are not markedly different (U.S. Fish and Wildlife Service 2009).

Amphibians are thought to be sensitive to changes in both terrestrial and aquatic habitat due to their dual life histories, highly specialized physiological adaptations, and specific microhabitat requirements (Bury 1988; Blaustein et al. 1994; Stebbins 1997). They are therefore considered to be valuable indicators of environmental quality (Lannoo 2005). Within the GGCLA area, the extirpation of the northern leopard frog could be viewed as an indicator of poor overall aquatic ecosystem health.

5.18.2. Indicators/Measures

- Presence of the species
- Condition of the population

5.18.3. Methods

To determine presence of the species, we looked at previous surveys in the park and surrounding areas. The first concerted effort to survey for northern leopard frogs in Grand Canyon NP and much of the GGCLA was started in 2003. From 2003 to 2007, the U.S. Geological Survey, led by Charles Drost and assisted by Utah State University staff and volunteers from multiple agencies, conducted surveys for northern leopard frogs in Canyonlands NP, Glen Canyon National Recreation Area, and Grand Canyon NP. Field surveys consisted of diurnal surveys, which included visual surveys for adult frogs, eggs, and their larvae; and nocturnal surveys, which were conducted by spotlight in an

effort to observe frogs when most active. In total, 329 surveys at 220 sites were conducted in the Grand Canyon NP and Glen Canyon regions during 2003–2007, consisting of nearly 1,200 observer hours.

Total survey time and area covered were estimated to determine catch effort. In addition, relative population size in different areas was estimated (Crump and Scott 1994).

In 2006, the Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and U.S. Geological Survey began work to establish refugial populations of northern leopard frogs in the House Rock Valley Wildlife Area (HRWA). This population was to serve as a source population for future introductions and reintroductions to the Colorado River and some of its tributaries in northern Arizona, including Grand Canyon NP. From 2006 to 2008, egg masses were collected from Ribbon Canyon, Utah, which is within the greater Grand Canyon landscape. They were raised to late-stage tadpoles in Flagstaff, Arizona, and then released into stock tanks in the HRWA. In 2012, five egg masses were collected from the HRWA and translocated directly into Soap Creek Tank in the Vermillion Cliffs area. In 2013 two egg masses were collected from Davis Gulch, Utah, and also translocated into Soap Creek Tank.

In 2013, a GIS model was developed for Grand Canyon NP to predict suitable habitat for northern leopard frogs (Figure 53). Variables were chosen based on recommendations by subject matter experts and literature review. Stream flow (permanent or intermittent), stream gradient, vegetation type, presence of nonnative predators (crayfish and trout), the presence/absence of beaver, and historical locations were identified as the most pertinent variables in predicting suitable habitat. The model was restricted to Grand Canyon NP east of Separation Canyon. The resulting model, which was reviewed by local specialists Charles Drost, Susi MacVean, and Shaula Hedwall, identifies the following water sources in the national park as potential habitat sites: Bright Angel Canyon, Phantom Canyon, the Transept, Clear Creek Canyon, Unkar Creek, Lava Canyon, Kwagunt Creek, Nankoweap Canyon, Crystal Creek, Shinumo Creek, White Creek, Crazy Jug Canyon, Tapeats Creek, Deer Creek, Kanab Creek, and Flint Creek.

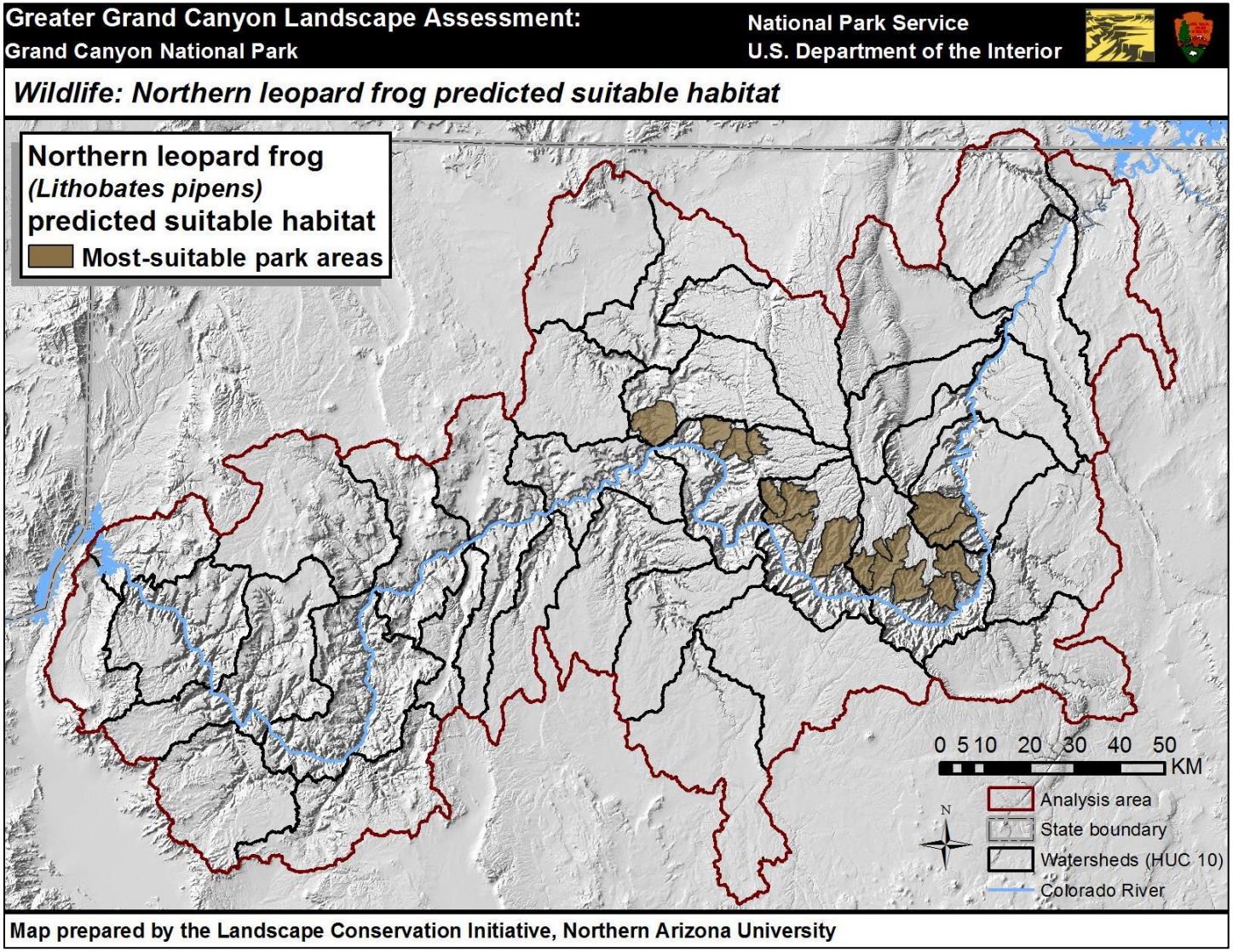


Figure 53. Predicted suitable habitat for northern leopard frogs.

5.18.4. Condition and Trend

Table 41. Summary of northern leopard frog resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Presence	Historical surveys		Recent survey efforts have detected no leopard frogs in Grand Canyon NP and very few in the GGCLA. Possible future reintroductions could occur, since refugial populations are reproductive.
Condition	Potential for future population reestablishment		Established refugial populations in HRWA are reproductive and potential reintroduction sites are being surveyed. However, at least one attempted reintroduction was unsuccessful.

Prior to the survey work initiated in 2003, northern leopard frogs were observed sporadically in the analysis area. In 1973, five adult northern leopard frogs were observed at the outflow of Cardenas Creek where a small marsh community had formed along the Colorado River (Tomko 1976). Since this observation, the marsh area has disappeared and the population was declared extirpated by 2008. In 1989 a single adult northern leopard frog was observed at Ribbon Falls, but no individuals have been observed since. This population is considered extirpated. In 1993, northern leopard frogs were observed in Kanab Creek north of the Grand Canyon NP boundary in the Kaibab National Forest. Subsequent surveys within national forest and downstream in NPS lands did not observe frogs. This population is also considered extirpated.

Later, the extensive surveys conducted by Drost and others from 2003 to 2008 provided evidence of strong declines in northern leopard frog populations and possibly complete extirpation of the species within Grand Canyon NP. In 2003, two adults were observed at Horseshoe Bend immediately below the dam within Glen Canyon and one adult and one egg mass were observed there in 2004. No frogs were observed after 2005, and the population is considered extirpated (Drost et al. 2008).

The translocation of populations to HRWA has been largely successful in establishing a robust refugial population. The last translocation of frogs to HRWA occurred in 2009. In 2014, the population had grown to more than 600 adults and metamorphs, with natural reproduction. Furthermore, natural dispersal into unoccupied areas was observed in 2014. Currently the population has grown to the point to where AZGFD managers feel that this population is now ready to serve as a source population for translocations.

At Soap Creek, tank egg masses were successfully transferred directly to the tank from the collection site at Davis Gulch and hatched without assisted rearing facilities. In 2014, three to four egg masses

were observed at Soap Creek Tank, an indication of natural reproduction, and a minimum of 28 adults and more than 1,000 juveniles were observed.

In 2012, a genetic analysis of the HRWA population was conducted to determine if the population still resembled the source population (Ribbon Canyon) and if there was evidence of inbreeding depression. Although the HRWA population showed reduced genetic diversity compared to the source population, it had captured the majority of the diversity found in the source population. However, to increase the genetic diversity of the HRWA populations, additional egg masses were collected from Ribbon Canyon and released into the HRWA population. All three refugial tanks at the HRWA were genetically similar. It was decided that tadpoles or adults should be periodically moved between tanks to prevent genetic divergence.

The genetic analysis indicated that allelic richness was identical among the refugial tanks, suggesting that all three tanks should be maintained as important refugia. This will reduce risk of catastrophic loss should something happen to one of the tanks, and permit higher effective population size and minimized genetic drift.

Validation of the habitat quality model began in 2014, with plans to continue field validation in 2015. This entails visiting high-ranking sites and evaluating the quality of potential habitat. Results will be used to evaluate potential reintroduction options.

In 2014, an NPS wildlife biologist observed a northern leopard frog in the Robbers Roost drainage during unrelated field work. Photos were taken and submitted to subject matter experts for review and it was confirmed to be a northern leopard frog. Three subsequent trips were made to the drainage in which the frog was originally observed, but no northern leopard frogs were seen.

5.18.5. Summary

Before the construction of Glen Canyon Dam, historical evidence suggested that northern leopard frogs were widespread along the Colorado River drainage in southern Utah and northern Arizona until approximately Marble Canyon (Theimer et al. 2011). From this point downstream into Grand Canyon NP, populations were likely disjunct. Changes in stream morphology after dam construction limited occurrence of the side pools and complex vegetation essential for northern leopard frog development. Limited marsh habitat along the Colorado River did provide historical habitat. Larger tributaries also likely provided limited amounts of suitable habitat, and past surveys that found northern leopard frogs in Kanab Creek and Bright Angel Creek further support this idea. Although the frog was likely historically limited in abundance, pre-dam conditions within the GGCLA likely supported isolated populations of northern leopard frogs in the Colorado River and some of its tributaries.

After construction of Glen Canyon Dam, the altered hydrology and decreased water temperature, combined with the introduction of predatory rainbow (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) and crayfish (Astacoidea), rendered the Colorado River unsuitable for northern leopard frogs and cut off tributary streams from other suitable habitat, creating habitat islands. Trout were both

actively brought into tributary streams and naturally dispersed into these waters. This combination of factors has likely led to the functional extirpation of northern leopard frogs within the GGCLA.

The observed decline of northern leopard frogs across the Southwest has led to efforts to preserve genetic diversity and maintain refugial populations within the GGCLA. At the HRWA, northern leopard frogs have successfully been established in non-traditional habitat created from artificial water sources in the form of cattle stock tanks and concrete tanks fed by a spring piping system. Currently this population is expanding. Natural reproduction and dispersal into uninhabited water tanks has been observed. At Soap Creek Tank, located at the base of the Vermillion Cliffs, an additional refugial population has been established; this introduction has also demonstrated that eggs masses can be transported directly to introduction sites without being raised in controlled facilities until metamorphosis. The success of these two populations has demonstrated successful translocation and introduction of northern leopard frogs, and they could serve as source populations for future reintroductions of northern leopard frogs into historically occupied habitat.

A GIS model created by Grand Canyon NP staff identified multiple areas that could potentially serve as suitable habitat for reintroduction efforts. Field surveys resulting from the model output have identified suitable northern leopard frog habitat in tributary streams (Figure 53). Although some factors that have been identified as stressors to northern leopard frogs (such as habitat changes from damming the Colorado River) cannot be managed, Grand Canyon NP has shown success in limiting trout populations in the Havasu, Bright Angel, and Shinumo tributary streams. Portions of both Bright Angel and Shinumo Creeks have been identified as suitable habitat for reintroduction efforts.

If successfully implemented, reintroduced populations would help maintain genetic diversity and bolster populations of northern leopard frogs in the Southwest. The presence of suitable habitat in tributary streams, the ability to control nonnative predators, and a viable source population of northern leopard frogs together provide a unique opportunity to reintroduce this species to the Grand Canyon NP portion of the GGCLA.

5.18.6. Data Needs

A habitat quality model has been developed to guide reintroduction efforts, but validation of that model (i.e., field-checking of sites for suitable habitat elements) is necessary before reintroduction planning can commence.

5.18.7. Level of Confidence

Extensive surveys for northern leopard frogs were conducted until 2007, indicating with a high degree of confidence that leopard frog populations are functionally extirpated from the GGCLA. However, no comprehensive surveys have been conducted since then. As the recent discovery of a single leopard frog in Robbers Roost illustrates, it is possible that additional populations occur in the GGCLA that have not yet been discovered.

5.18.8. Sources of Expertise

Charles Drost, U.S. Geological Survey; Cory Mosby, National Park Service; John Spence, National Park Service; Lisa Gelczis, U.S. Geological Survey; Shaula Hedwall, U.S. Fish and Wildlife Service;

and Susi MacVean, Arizona Game and Fish Department all contributed to this assessment and review.

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5.19. Wildlife: Invertebrates

5.19.1. Description



The Grand Canyon has high invertebrate species richness potential due to its position at the intersection of four biomes and its complex topography and unique refugial habitats, such as caves, springs, streams, riparian areas, isolated plateaus, and escarpments. Much of this richness has not been documented, and both basic research and synthesis of existing data are needed. By contrast, the Colorado River is considered to be depauperate in invertebrate richness, in part due to Glen Canyon Dam operations. Insufficient information exists to evaluate condition or trend of invertebrate assemblages in most habitat types in the GGCLA area. Photo: the Kanab ambersnail, photographed at Vasey's Paradise (USGS photo by Roy Averill-Murray).

Geophysical diversity is a major driver of species richness and diversity (Rosenzweig 1995; Coblentz and Riitters 2004; Anderson and Ferree 2010). Invertebrate species diversity in Grand Canyon NP is driven by both geography and geophysical diversity. The Grand Canyon region is located at the intersection of four biomes (Madrean, Mohavean/Sonoran, Intermountain, and Cordilleran; Stevens 2012), resulting in the convergence of multiple ecosystem types and support of a variety of habitats. The elevation range, topographic complexity, and geologic diversity of the region influence variation in local climate and ecosystems, resulting in a wide variety of landforms, microclimates, soils, and in turn, species distributions. Taxa of both North American (Nearctic) and South American (Neotropical) origins persist here, and species are generally distributed across elevational gradients that reflect their origin, with neotropical and nearctic species found at lower and higher elevations, respectively (Stevens 2012).

Species occurrence records and studies from which the species richness estimates in Table 41 were derived document more than 900 invertebrate species in the Grand Canyon ecoregion. Most collections have been made on the canyon rims and along rivers, streams, springs, and canyon bottoms that are accessible by trail or from the Colorado River corridor. Species richness is documented to be highest in aquatic and riparian habitats, in part because these habitat types yield the highest species richness per area sampled, and in part because the increased sampling effort in those habitats results in better documentation relative to species that primarily occupy upland habitats or have belowground-dependent life stages (with the exception of robber flies, for which some information on biogeography is known; Scarbrough et al. 2012).

The information provided in Table 42 is likely only a small proportion of the total number of species, given the lack of information for most taxonomic groups. For example, good estimates of invertebrate species richness exist only for Mollusca, the insect orders Odonata (dragonflies and damselflies), Lepidoptera (butterflies), aquatic Hemiptera (true bugs), selected Diptera (midges), selected Hymenoptera (Ammophila wasps, ants, and bees), and insect families including Cicindelinae (tiger beetles), Asilidae (robber flies), and Culicidae (mosquitoes). For all other groups, species richness information is only partially complete, and studies have been too limited in scope to draw broad diversity conclusions. Overall patterns of richness of the few taxa that have been studied indicate that area-adjusted species richness is generally highest at lowest elevations and generally drops off at elevations above 2500 meters (Stevens 2012; Stevens and Menke 2014).

Table 42. Taxa richness estimates of major invertebrate groups in the GGCLA area for which information is available. Sources for richness estimates are provided, and relative (to the regional species pool) species richness estimates (Stevens 2012) are provided where available. This table is modified from Stevens (2012). Unless specified, the study extent includes the Grand Canyon ecoregion, which roughly encompasses the GGCLA study extent.

Phylum	Subphylum	Class/Subclass	Order	lower taxonomic	Estimated Species Richness	Relative Species Richness	Source	Study Extent
Platyhelminthes	–	–	–	–	59	High	Spamer & Bogan 1993a, 1993b	GRCA & vicinity
Nematoda	–	–	–	–	59	High	Spamer & Bogan 1993a, 1993b	GRCA & vicinity
Mollusca	–	–	–	–	59	High	Spamer & Bogan 1993a, 1993b	GRCA & vicinity
Annelida	–	Oligochaeta	–	–	18	–	Wetzel 2009	Colorado River in GRCA
	–	Hirudinea	–	–	10	–	L. Stevens, unpub. data	–
Arthropoda	–	–	–	–	~10,000	–	L. Stevens, unpub. data	–
	Chelicerata (spiders, scorpions)	–	–	–	>350	–	L. Stevens, unpub. data	–
	Myriapoda (centipedes, millipedes)	–	–	–	>10	–	L. Stevens, unpub. data	–
	Crustacea (shrimp, crayfish, copepods)	–	–	–	>12	–	L. Stevens, unpub. data	–
Hexapoda (insects)	–	Insecta	Odonata (dragonflies, damselflies)	–	89	High	Stevens & Bailowitz 2009	–
	–	Insecta	Aquatic Hemiptera (true bugs)	–	89	High	Stevens & Polhemus 2008	–
	–	Insecta	Lepidoptera (butterflies)	–	140	High	Garth 1950; L. Stevens, unpub. data	–
	–	Insecta	Orthoptera (grasshoppers, crickets)	–	90	–	L. Stevens, unpub. data	–
	–	Insecta	Plecoptera (stoneflies)	–	8	–	L. Stevens, unpub. data	–
	–	Insecta	Trichoptera (caddisflies)	–	109	Moderate	Blinn & Ruiter 2006, 2009; L. Stevens, unpub. data	Arizona
	–	Insecta	Coleoptera (beetles)	tiger beetles	44	Low	Stevens & Huber 2004	–
	–	Insecta	Coleoptera (beetles)	darkling beetles	143	–	L. Stevens, unpub. data	–
	–	Insecta	Diptera (true flies)	midges	38	Low	Sublette et al. 1998	Colorado River in GRCA
	–	Insecta	Diptera (true flies)	mosquitoes	18	Low	Stevens et al. 2008	–
	–	Insecta	Hymenoptera (bees, ants, wasps)	bees	350+	High	Stevens et al. 2007	–
	–	Insecta	Hymenoptera (bees, ants, wasps)	thread-waisted wasps	35	High	Stevens & Menke 2014	–
	–	Insecta	Blattodea (cockroaches, termites)	termites	2	Low	Jones 1985	GRCA

These studies also suggest that species richness of tiger beetles, mosquitoes, and termites is low relative to the regional species pool, whereas relative species richness of more mobile invertebrate taxa that have been well studied is high (Table 42). Overall, nearly 20% of all invertebrate species that are well studied in the region are locally rare, and nearly 10% of them are regionally endemic (Stevens 2012).

5.19.2. Indicators/Measures

- Aquatic invertebrate richness – Colorado River
- Aquatic invertebrate richness – tributary streams
- Aquatic invertebrate richness – springs ecosystems
- Cave invertebrate richness
- Terrestrial invertebrate richness

5.19.3. Methods

Information for this assessment was summarized from peer-reviewed studies, agency reports, and the Grand Canyon research permit database.

5.19.4. Condition and Trend

Table 43. Summary of invertebrate richness condition and trend by indicator.

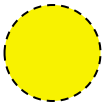
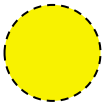
Indicator	Reference framework	Relative condition	Summary comments
Aquatic invertebrate richness – Colorado River	Invertebrate species richness and composition in comparison to that in undisturbed hydro-geomorphically similar rivers and streams in the region		Several common aquatic insect taxa are anomalously absent from the Colorado River. There have been no specific studies of long-term trend, but current and decades-old studies indicate a gradual downward trend due to increasing dominance of highly competitive, productive species that are favored by dam operations.
Aquatic invertebrate richness – tributary streams	Invertebrate species richness and composition in comparison to that found in undisturbed hydro-geomorphically and thermally similar streams in the region		Species richness is naturally low in some GRCA tributary streams relative to other streams in AZ, but may be naturally limited by water quality, flow variability, and the harsh physical settings in which these habitats exist. More hydrologically stable streams may have higher than expected richness. Insufficient information exists to assess trend.

Table 43 (continued). Summary of invertebrate richness condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Aquatic invertebrate richness – springs	Invertebrate species richness in comparison to that found in undisturbed springs of the same type (Springer and Stevens 2009) and flow volume		Information on the condition of aquatic biodiversity at Grand Canyon springs is available and indicates fair to good ecological condition in inner canyon springs and fair to poor condition in springs above the rim. Springs invertebrates are not monitored, so no trend information is available.
Cave invertebrate richness	Invertebrate species richness in comparison to that found in undisturbed caves of similar size, setting, and microclimate		There are several peer-reviewed papers on cave invertebrates, indicating that caves are generally low in richness but high in endemism. However, insufficient information exists to assess the condition or trend of this indicator.
Terrestrial invertebrate richness	Invertebrate species richness and community composition in comparison to that found in undisturbed habitats with similar vegetation and soils		The terrestrial invertebrate community in the park is composed primarily of native species, with relatively few known terrestrial nonnative invertebrate species. However, few monitoring data have been compiled, so there is no assessment of trend for this indicator.

Invertebrate Richness in Aquatic Ecosystems

Aquatic habitats are among the better-studied habitat types with respect to invertebrates in Grand Canyon NP (Kearsley et al. 2005). Numerous studies have examined macroinvertebrates and zooplankton in the Colorado River in Grand Canyon over the past several decades (e.g., Haury 1991; Blinn et al. 1995; Stevens et al. 1997; Cross et al. 2013, and many others); thus, invertebrate richness in the river has been moderately well characterized. With the exception of two highly productive taxa (Gammarus and New Zealand mud snail) found just between Glen Canyon Dam and Lees Ferry that are largely absent downstream, macroinvertebrate taxa richness is fairly constant throughout the canyon (Cross et al. 2013), although with much turnover among, for example, Chironomidae species (Sublette et al. 1998). Overall, the macroinvertebrate assemblage in the Colorado River is considered to be depauperate (Kennedy et al. 2013).

Several taxonomic groups expected to occur in cold-water streams in the region, particularly the Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) insect orders, are conspicuously absent (Stevens et al. 1997; Cross et al. 2013; Kennedy et al. 2013). There are no

recent published studies that address long-term trends; however, current characterizations of the macroinvertebrate assemblages are consistent with earlier studies in the 1990s (e.g., Blinn et al. 1995; Stevens et al. 1997), suggesting that changes are occurring slowly, if at all. Richness is limited in part by the existence and operations of Glen Canyon Dam, but the mechanisms by which this is occurring are still unclear (Blinn et al. 1995; Stevens et al. 1997; Haden et al. 2003; Cross et al. 2011, 2013; Kennedy et al. 2013). Low aquatic insect species richness in the river could be attributed to (1) naturally low richness in swift, canyon-bound river segments, (2) sensitivities of insect taxa to the river's thermal regime, and (3) hydropeaking operations causing exceptional drift and damage to eggs through flushing or desiccation.

There are 768 tributaries to the Colorado River in Grand Canyon NP (Webb et al. 2000); however, only 29 of these are classified as perennial streams (NHD 2011). Several quantitative assessments of macroinvertebrate richness have been completed in 21 perennial tributaries in the park (Table 5.15.3). Many of these have involved repeated sampling, but none have sufficient long-term data to infer trend. Some tributaries have much greater aquatic invertebrate richness, compared to the Colorado River in Grand Canyon NP (Oberlin et al. 1999; Lawson et al. 2007; Stumpf and Monroe 2014; Whiting et al. 2014). As compared to benchmarks established for warm-water streams by the Arizona Department of Environmental Quality, macroinvertebrate assemblage condition (based on several metrics, one of which is species richness) appears to be naturally poor at some sites (Lawson et al. 2007). Lawson et al. concluded that the disturbance-prone nature of some sites in Grand Canyon may result in lower richness for invertebrates, as compared to other streams in the state, and thus state-level benchmarks may not be good indicators of impairment in Grand Canyon streams.

Richness of tributary sites is related to streamflow stability and can vary greatly at a single site, depending on the occurrence of flash floods (Oberlin et al. 1999; Lawson et al. 2007; Stumpf and Monroe 2014). In high snowpack years, significant scouring can occur, reducing macroinvertebrate richness. Because north rim tributaries drain higher-elevation watersheds, with more snow runoff, richness is generally lower relative to south rim tributaries (Lawson et al. 2007). Other factors that may also limit macroinvertebrate richness in streams include habitat limitations due to the prevalence of bedrock, fine sediments, travertine deposits (Lawson et al. 2007), watershed size (relates to both flow stability and influence of upstream land uses; Oberlin et al. 1999), and predation by nonnative fish (Whiting et al. 2014). A distinctive decrease in aquatic invertebrate species richness occurs with distance upstream into the Grand Canyon in both the Colorado River and its tributaries, and further upstream into the Colorado Plateau (Stevens and Polhemus 2008; Stevens and Bailowitz 2009; Stevens 2012), indicating that regional biogeographic processes also influence aquatic invertebrate richness in this complex landscape (Table 44).

Table 44. Perennial tributary streams in which quantitative or semi-quantitative aquatic macroinvertebrate samples have been collected. Note that only years in which one or more sampling events occurred are shown. In some cases, repeated samples were not collected at the same site, were collected using different methods, were collected at different times of year, or were collected following a flood, suggesting that data are insufficient to infer trend. x = Oberlin et al. 1999; y = Lawson et al. 2007; z = Stumpf and Monroe 2014.

Tributary	1991	92	93	94	96	97	2005	06	09	10	11	12	13
Paria River	x	y	x	x	x	–	–	–	–	y	–	–	–
Vasey's Paradise	x	–	x	x	x	–	–	–	–	–	–	–	–
Nankoweap Creek	x	y	x,y	x	x		y	y					
Little Colorado River	x	–	x	x	x	–	–	–	–	–	–	–	–
Clear Creek	–	–	–	–	–	–	y	–	–	–	–	–	–
Bright Angel Creek	x	y	x,y	x,y	x	y		y	y	z	z	z	z
Garden Creek	–	–	–	–	–	y	–	–	–	z	z	z	z
Monument Creek	–	–	–	–	–	–	y	y	–	–	–	–	–
Hermit Creek	–	–	–	–	–	–	y	y	y,z	z	z	z	z
Crystal Creek	–	–	y	y	–	y	y	y	y	–	–	–	–
Shinumo Creek	–	–	–	–	–	–	–	y	y	–	–	–	–
Royal Arch Creek	–	y	y	y	–	y	y	y	y	–	–	–	–
Tapeats Creek	x	y	x,y	x,y	x	y	–	y	y	–	–	–	–
Deer Creek	–	–	–	y	–	y	y	y	y	–	–	–	–
Kanab Creek	x	y	x,y	x,y	x	y	y	–	y	–	–	–	–
Havasu Creek	x	y	x,y	x,y	x	y	y	y	–	–	–	–	–
National Creek	–	–	y	y	–	y	–	y	–	–	–	–	–
Matkatamiba Creek	–	y	–	–	–	–	y	–	–	–	–	–	–
Spring Canyon Creek	x	y	x,y	x,y	x	y	y	y	y	–	–	–	–
Three Springs Creek	–	–	y	y	–	y	y	–	–	–	–	–	–
Diamond Creek	x	–	x	x	x	–	y	–	–	–	–	–	–

In contrast to streams that are hydrologically less stable, several studies suggest that hydrologically stable springs and streams, particularly waters with low ion concentration, may have relatively high richness (Oberlin et al. 1999). A number of locally endemic species have been identified in these habitats. For example, (1) at least one undescribed endemic stonefly species exists in North Canyon, with another potentially in Thunder River; (2) the federally endangered Kanab ambersnail occurs at Vasey's Paradise and has been translocated into Royal Arch Creek springs; (3) the only breeding

population of masked clubskimmer dragonfly (Libellulidae: Brechmorhoga nr. pertinax) in the USA occurs in spring-fed streams in central Grand Canyon (Stevens and Bailowitz 2009); (4) the Arizona wetsalts tiger beetle (Cicindela hemorrhagica arizonae) only occurs in warm, spring-fed perennial streams from Soap Creek (River Mile 11) downstream to above Diamond Creek (River Mile 225); (5) the only population of the Tyloborus utahensis millipede in Arizona occurs in Deer Creek; and (6) a potentially new waterbug species may occur only in Inner Gorge and Warm (Medicine or Vulcans Well) Springs (Stevens 2012). Aquatic Hemiptera species turnover is high among springs in the Grand Canyon, with many species occurring at just one to a few sites (Stevens and Polhemus 2008). Given their relatively high species richness, large number (~900), and very limited sampling, inventories of unsampled springs and seeps have the potential to greatly expand the number of aquatic invertebrate species documented in the park.

Similarly, limited sampling of cave habitats (15 of an estimated 1,000 caves have information on invertebrates) suggests high species turnover among sites (Wynne et al. 2007; Wynne and Voyles 2013). Although arthropod richness at a given cave is generally low, especially at sites that lack water (Peck 1980; Pape 2014), the potential for discovery of new and/or endemic species is high. For example, Wynne et al. (2007) identified 37 arthropod species in 15 caves in the canyon, only four of which are known to be cave-adapted. Wynne and Voyles (2013) sampled 54 arthropod species in seven caves in the Grand Canyon–Parashant National Monument, reporting that nearly 17% of the species identified were new (6 species), or potentially new (3 species) to science, including two new genera (Wynne and Voyles 2013). These studies underscore the need for further study of these ecosystem types to enhance understanding of invertebrate richness in the park.

Invertebrate Richness in Terrestrial Ecosystems.

Except for butterflies and skippers and Mollusca, terrestrial invertebrates are relatively less well studied than aquatic species in Grand Canyon NP. Of the insect taxa for which there is species richness information in Table 41, only a few are truly terrestrial (i.e., they do not have aquatic-dependent life stages), including bees, wasps, butterflies, tiger and darkling beetles, grasshoppers, and most crickets. These represent only a small sample of all terrestrial invertebrate groups. One of the most comprehensive quantitative arthropod studies in the park illustrates this point. Kearsley et al. (2005) collected arthropods at 34 sites along the Colorado River riparian corridor over 3 years using a variety of methods to collect ground-dwelling, plant-dwelling, flying, and nocturnal arthropods. They identified 1,122 taxa in total, including at least five taxa that are new to science and only known to occur in the Colorado River corridor, and an additional six taxa that are not yet described (Kearsley et al. 2005). In spite of its spatial limitation, this study provides evidence of the enormous invertebrate richness of the region.

Review of the Grand Canyon research permit database reveals that additional research studies and collections of ants, butterflies, beetles, moths, spiders, and other terrestrial taxa have been completed by outside researchers, but the park does not have that information in usable form, nor has the information been published in many cases. Through the Museum of Northern Arizona in Flagstaff, L. Stevens has been updating the NPS invertebrate collections database to help fill this information gap.

Amidst all of these studies, there is little evidence of nonnative invertebrate species occurrences in the park.

Soil ecosystems are another source of likely high but largely unexplored invertebrate richness in the analysis area. Soils can harbor high levels of invertebrate biodiversity, but with the exception of Young (1999) and Kearsley et al. (2005), these habitats have not been well studied in the Grand Canyon. Soil biodiversity in mesic areas has been likened to the high levels found in coral reefs, and every major animal phylum with the exception of two is represented in soils at the global scale (Hole 1980). Desert soil crusts typically contain several types of invertebrate taxa in the top few inches of soil, the most numerous of which include microinvertebrates such as mites, nematodes, springtails (Collembolans), and tardigrades (Belnap and Lange 2003). Even the water film on soil crusts can support a surprising diversity of microfauna (Bamforth 2004). Although few studies of soil invertebrates have been conducted in Grand Canyon NP, studies in the Chihuahuan, Mojave, and Colorado Plateau deserts have revealed distinctive soil faunas that vary across gradients of soil temperature, precipitation, soil texture, plant assemblages, and biological soil crust development (Darby et al. 2007, 2010).

5.19.5. Summary

The geophysical diversity of Grand Canyon NP and its position near the convergence of the Nearctic and Neotropical zoogeographic regions promotes regionally high invertebrate richness for many types of taxa, and high proportions of rare and endemic taxa. More than 10,000 invertebrate taxa are likely to occur in the park (Stevens 2012), and it is certain that many species have yet to be documented. Several collections of invertebrates by park and outside researchers have been conducted, but the data have not been thoroughly compiled or published.

Aquatic and semi-aquatic invertebrate richness appears to be influenced by flow variability and ion concentration, with high variation among perennial streams and springs. The aquatic macroinvertebrate assemblage of the Colorado River itself is well characterized at coarse taxonomic resolution, and is known to be depauperate, in part due to the existence and operations of Glen Canyon Dam.

Terrestrial invertebrate faunal richness is well described for relatively few taxa, and few detailed studies of fossorial (burrowing) and soil invertebrates have been published. Springs and caves represent potential “hotspots” for the occurrence of new undescribed and/or endemic invertebrate species, but these habitats are not well sampled.

5.19.6. Data Needs

Several information gaps exist related to invertebrate diversity:

- The specific mechanisms causing reduced aquatic invertebrate richness in the Colorado River should be studied, and whether potential management solutions can generate an upward trend in riverine aquatic invertebrate diversity should be explored.
- Given the high natural disturbance potential in tributaries (e.g., due to high slope angles and flood potential) in Grand Canyon, macroinvertebrate species richness benchmarks established

for the state of Arizona may not be good indicators of impairment or condition. Thus, appropriate metrics that have greater capacity to distinguish natural from anthropogenic stressors in Grand Canyon tributaries are needed.

- A wealth of data related to invertebrate occurrences has been collected by outside researchers. For example, L. E. Stevens has collected more than 80,000 specimens in the study area. He has reported the identities of all species resolved in his collections to the park, and continues active publication of the results of that work. Despite this, the state of knowledge of invertebrate diversity in the park remains relatively low. Any data that have been collected but not processed or turned over to the park should be sought and processed. In addition, increased support for invertebrate biodiversity investigations would help to enhance knowledge of these taxa.
- Aside from studies on the Colorado River and its tributaries, and on Grand Canyon springs, few studies have quantitatively or systematically inventoried invertebrates in a manner that allows inferences to be made about overall richness at a given location or for particular habitat types. Systematic and comprehensive inventories across a variety of soil types, vegetation types, stream types, cave types, and spring types would greatly enhance the park's ability to establish reference conditions and, in turn, evaluate condition and trend.
- Sampling of springs and cave ecosystems has the potential to expand the number of species known in Grand Canyon NP; however, given the potential sensitivity of these ecosystems to human disturbance and the need to collect invertebrates for identification (as well as the need to study them in vivo), there is a need to ensure that these habitats are not altered by visitors, park staff, or the scientists studying them.
- Grand Canyon is relatively free of nonnative invertebrates; however, many potential invading alien taxa occur all around the park. For example, two species of nonnative crayfish that exist both north and south of the canyon can have significant adverse impacts on streams they invade (Martinez 2012). As yet, crayfish are not firmly established in Grand Canyon NP, but their colonization of the park is likely to have dire impacts on its many nearly pristine tributaries. Similarly, quagga mussel, New Zealand mudsnail, and other aquatic and terrestrial species threaten the park's native assemblages. Assessment of the present status of nonnative species and the upcoming threats may help the park prepare for the inevitable arrival of these unwanted, ecologically influential taxa.
- In addition, a strategic information management plan for archiving and reporting upon invertebrate distribution data for Grand Canyon NP should be developed.

5.19.7. Level of Confidence

As it is based on several peer-reviewed studies, confidence in the quality of information on aquatic invertebrate richness in the Colorado River is moderately high. However, all recent studies have only identified riverine Diptera to the family level, and have otherwise pooled taxa that play very different ecological roles. Insufficient monitoring data presently exist to assess the condition or trend of aquatic invertebrate richness in tributary streams, and suitable reference or desired conditions have

not been identified by the NPS. The condition and trend of other invertebrate indicators cannot be assessed due to lack of sufficient data or support for such work. NPS planning, museum curation capacity, guidance on methodological approaches, and information management capacity for providing relational analysis among taxa and physical variables is warranted.

5.19.8. Sources of Expertise

This section was prepared by Christine Albano, Conservation Science Partners, and Larry Stevens, Museum of Northern Arizona. The literature review was completed in consultation with Ted Kennedy (USGS; GCMRC; Colorado River ecology), Jeri Ledbetter (MNA; springs and invertebrate occurrence data), Stephen Monroe (NPS Inventory and Monitoring Program; water quality), Patti Spindler (Arizona Department of Environmental Quality; water quality), and Jut Wynne (NAU; cave invertebrates).

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5.20. Fisheries: Native Fish Species

5.20.1. Description



The Grand Canyon used to host eight species of native fish, but only five persist (the endangered humpback chub, endangered razorback sucker, bluehead sucker, flannelmouth sucker, and speckled dace). Currently the humpback chub population is stable, but lacks population redundancy. Razorback sucker spawning was documented in the analysis area in 2014, after the species had been considered extirpated for two decades. Nonnative species are present in all waters and dominate in most areas. Stressors to native fish include dam construction and operation, nonnative species, fire, and flooding (NPS photo by Brian Healy).

Grand Canyon NP is an important native fish refuge, providing habitat for endemic Colorado River fishes, including 5 of 8 native species that have remained within the park following the introduction of nonnative fish and the construction and operation of Glen Canyon Dam. The candidate roundtail chub (*Gila robusta*), endangered Colorado pikeminnow (*Ptychocheilus lucius*), and endangered bonytail chub (*Gila elegans*) have all been extirpated from the analysis area. However, Grand Canyon NP hosts the largest remaining endangered humpback chub (*Gila cypha*) population, and the endangered razorback sucker (*Xyrauchen texanus*) was discovered spawning in the lower reaches of the Colorado River in 2014 after being considered extirpated for decades. Other native species within the analysis area include bluehead (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), and speckled dace, all of which thrive in many areas of the park.

Improvements in populations of humpback chub and native razorback suckers have been observed in the Colorado River, but trends in tributary populations remain variable, and high densities of nonnative species such as brown trout (*Salmo trutta*) in Bright Angel Creek may limit native fish distribution and abundance. The region's native suckers, in particular, have suffered range-wide

declines, and until recently razorback sucker were known to reproduce naturally only within Lake Mead. As a whole, the resistance and resilience of the aquatic ecosystem to disturbance has been compromised by dam construction and operations, as well as nonnative species. Following completion of Glen Canyon Dam in the 1960s, a recreational fishery was established for nonnative rainbow trout (*Oncorhynchus mykiss*) downstream of Glen Canyon Dam, just upstream of Grand Canyon NP. This fishery remains important economically to the local community, despite potential stress to endangered and native fishes downstream. The NPS Comprehensive Fisheries Management Plan (NPS 2013) provides an extensive overview of aquatic resources for the Glen Canyon National Recreation Area downstream of Glen Canyon Dam, and the waters within Grand Canyon NP.

5.20.2. Indicators/Measures

- Relative abundance/dominance of native and nonnative fish
- Endangered fish abundance and distribution
- Rare/high-risk nonnative fish species captures
- Catch-per-unit effort of large-bodied fishes (trout, common carp, native suckers)

5.20.3. Methods

Relative Abundance/Dominance in Native and Nonnative Fish

Fisheries data collection in tributaries and the mainstem Colorado River has been focused on monitoring trends in Endangered Species Act listed fish species, feasibility studies of management actions, or evaluating the effectiveness of management actions in meeting NPS policy direction or goals and the objectives of the NPS Comprehensive Fisheries Management Plan (NPS 2013). Monitoring and sampling plans were developed to assess specific measurable objectives, and may or may not have been designed to sample all species in a specific tributary to determine an overall condition and trend in the fisheries community. Fish species vary in their susceptibility to specific sampling methods. For example, rainbow trout are not effectively sampled with passive sampling gear such as hoop nets, but are effectively sampled using electrofishing. Humpback chub are sampled effectively with hoop nets, but not with electrofishing in the Colorado River. Thus, sampling methodology and effort has varied spatially and temporally.

Nevertheless, some trend information is available for some fish species in the Colorado River, Little Colorado River, Bright Angel Creek, Shinumo Creek, and Havasu Creek. Since the 1990s, the Little Colorado River has been sampled by the U.S. Fish and Wildlife Service (USFWS), Arizona Game and Fish Department (AZGFD), U.S. Geological Survey (USGS), and others, using hoop nets for the purpose of assessing trends in endangered humpback chub. Bright Angel, Shinumo, and Havasu Creeks have been sampled since 2009 or 2010 by the NPS for the purpose of removing trout (Shinumo, Bright Angel Creeks), monitoring humpback chub translocations (Shinumo and Havasu Creeks), or determining effect of mechanical trout control on native and nonnative fish populations (Shinumo and Bright Angel Creeks).

The current condition of the fish community in Bright Angel Creek is described using NPS electrofishing three-pass depletion data collected between the mouth of Bright Angel Creek and an

area upstream of Roaring Springs (~ 16 km) between October 2012 and February 2013. The current condition of the fish community in Shinumo Creek can be assessed using NPS hoop netting and minnow trap data collected in September, 2014. Trends can be assessed using electrofishing and netting data from June 2010 through September 2014. Current condition and trend of fish abundance in Havasu Creek can only be assessed using mark-recapture hoop netting and minnow net data from the NPS boundary to the mouth of Havasu Creek at the Colorado River (~ 5.6 km). Research by Van Haverbeke et al. (2013) provides the most long-term, comprehensive trend analysis for native species trend and fish community composition data in the Little Colorado River. Colorado River fisheries data have been collected by a variety of agencies, universities, and researchers for several decades. The U.S. Geological Survey–Grand Canyon Monitoring and Research Center (USGS-GCMRC) has maintained a comprehensive fisheries database of data collected from within Grand Canyon NP, as well as the reach of the Colorado River from the Glen Canyon Dam to Lees Ferry (River Mile 0.0). The database consists of data collected for specific research studies, or monitoring species of interest (e.g., rainbow trout in Glen Canyon, endangered humpback chub), so effort and gear types varied by location and through time, limiting interpretation of the data to establish a trend.

Endangered Fish Abundance and Distribution

Grand Canyon harbors the only Lower Colorado River Basin humpback chub population, and is directly connected to Lake Mead, which was the only reproduction site for razorback sucker before the 2014 discovery of spawning within the lower reaches of the Colorado River. USGS-GCMRC, USFWS, and NPS have focused hoop netting and trammel-netting efforts on quantifying trends in humpback chub aggregation populations. In addition, the humpback chub population estimation methodology described above for the Little Colorado River (Van Haverbeke et al. 2013) and Havasu and Shinumo Creeks (Healy et al. 2014; NPS unpublished data) was also used to quantify the current condition and trend in endangered humpback chub populations in Grand Canyon NP. Razorback sucker abundance and distribution is assessed using catch information collected by AZGFD from the Colorado River, as well as reports developed by NPS and Bureau of Reclamation cooperators (Bio-West, Inc., and Aquatic Southwest Ichthyological Researchers).

Rare/High-Risk Nonnative Fish Species Captures

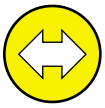
The USGS-GCMRC provided an unpublished dataset of all fish captures using all gear types and from all locations, from their central fisheries database with records dating from 1978 to 2013. A high number of captures of rare and high-risk nonnative fish in the Colorado River from a particular area, such as near a tributary mouth, was assumed to signify a potential source.

Catch-Per-Unit-Effort of Large-Bodied Fishes

The AZGFD, funded by and in cooperation with the USGS-GCMRC, has been conducting boat-mounted electrofishing surveys in the Grand Canyon since 2002 (Bunch et al. 2012). This annual monitoring program is thought to be adequate for assessing trends in populations of large-bodied, common fishes susceptible to electrofishing.

5.20.4. Condition and Trend

Table 45. Summary of native fish species resource condition and trend by indicator.

Indicator	Reference condition	Relative condition	Summary comments
Relative abundance/dominance of native and nonnative fish species	Stable populations and dominance by native species		Trends vary by species. Native suckers have declined across their range, but nonnative fisheries are persistent and endangered species within the park are stable or increasing.
Endangered species abundance and distribution	Desired conditions for endangered species populations		Trends vary by species and stream. Three endangered species were extirpated from the park after completion of Glen Canyon Dam. The humpback chub and razorback sucker remain, and both are stable or increasing.
Rare/high-risk nonnative fish species sources	Impacts on native species by nonnative species are minimized		Management is mitigating impacts of nonnatives.
Catch-per-unit-effort of large-bodied fishes	Desired conditions for large-bodied fishes		Catch is increasing across species.

Abundance Highlights by Stream

Van Haverbeke et al. (2013) found the fish community in the Little Colorado River to be dominated numerically by native species in hoop net captures, although they recognized that some species may not be effectively sampled with hoop nets. Relative abundance of native and nonnative fish in Bright Angel Creek varies by reach, with natives dominating in the lower reach of the stream and nonnatives in other reaches. Aquatic habitat and fisheries populations changed dramatically in Shinumo Creek in 2014 after the Galahad Point fire, which burned approximately 10% of the watershed, and was followed by monsoonal rains and high-intensity flooding containing high levels of ash. A monitoring trip conducted by the NPS in September, 2014, found a 99% decline in fish numbers and the extirpation of bluehead sucker, humpback chub, and rainbow trout from the lower 5 kilometers of Shinumo Creek. The humpback chub population in Havasu Creek has been maintained through annual translocations that began in 2011.

Over the past 150 years, the abundance and diversity of native fish in Grand Canyon NP have declined, while abundance and diversity of nonnative fish have increased (Table 46; Gloss et al. 2005; Makinster et al. 2010). Nevertheless, combined capture data of all species show longitudinal change in native and nonnative fish community composition. Near Glen Canyon Dam in Glen

Canyon, the fish community is largely dominated by nonnative species, mainly rainbow trout. Native fish community composition gradually increases to approximately half the fish community near the Little Colorado River confluence. Nonnative brown and rainbow trout dominate the fish community near the Bright Angel Creek confluence, and then native species gradually increase relative to nonnative species until Diamond Creek. Nonnatives begin to dominate the fish assemblage once more near Lake Mead (Figure 54).

Table 46. Relative abundance and diversity of fish species in the Colorado River from Glen Canyon to Separation Canyon. P = present, abundance unknown; A = abundant; C = common; LC = locally common; R = rare. Table adapted from Gloss et al. 2005.

Species	Pre-1850	1958-59	1970-73	1984-86	1990-93
Threadfin shad[$]	–	–	R	–	C
Humpback chub[A]	P	–	R	R	LC
Bonytail chub[A]	P	–	–	–	–
Roundtail chub	P	R	–	–	–
Colorado pikeminnow*	P	R	–	–	–
Speckled dace	P	A	A	A	C
Virgin spinedace[B]	P	–	R	–	–
Woundfin[B]	P	–	–	–	–
Red shiner[C]	–	–	R	–	A
Common carp[C]	–	C	A	A	A
Utah chub[C]	–	R	–	R	–
Golden shiner[C]	–	–	R	R	R
Fathead minnow[C]	–	A	C	A	LC
Bluehead sucker	P	C	C	C	C
Flannelmouth sucker	P	C	C	C	C
Razorback sucker[A]	P	R	–	R	–
Black bullhead[C]	–	C	–	R	R
Yellow bullhead[C]	–	–	–	R	–
Channel catfish[C]	–	A	C	R	LC
Cutthroat trout[C]	–	–	–	R	–
Coho salmon[C]	–	–	R	–	–
Rainbow trout[C]	–	–	C	A	A
Brown trout[C]	–	–	–	C	C
Brook trout[C]	–	–	–	C	R

[A] Endangered

[B] Occurs almost exclusively in smaller streams or tributaries

[C] Nonnative.

Table 46 (continued). Relative abundance and diversity of fish species in the Colorado River from Glen Canyon to Separation Canyon. P = present, abundance unknown; A = abundant; C = common; LC = locally common; R = rare. Table adapted from Gloss et al. 2005.

Species	Pre-1850	1958-59	1970-73	1984-86	1990-93
Plains killifish[C]	–	R	C	R	LC
Mosquitofish[C]	–	R	R	–	LC
Striped bass[C]	–	–	–	R	R
Green sunfish[C]	–	C	R	R	R
Bluegill[C]	–	R	R	–	R
Largemouth bass[C]	–	R	R	R	R
Black crappie[C]	–	–	–	–	R
Yellow perch[C]	–	R	–	–	–
Walleye[C]	–	–	–	–	R
Total number of species	**10**	**17**	**18**	**20**	**22**

[A] Endangered

[B] Occurs almost exclusively in smaller streams or tributaries

[C] Nonnative.

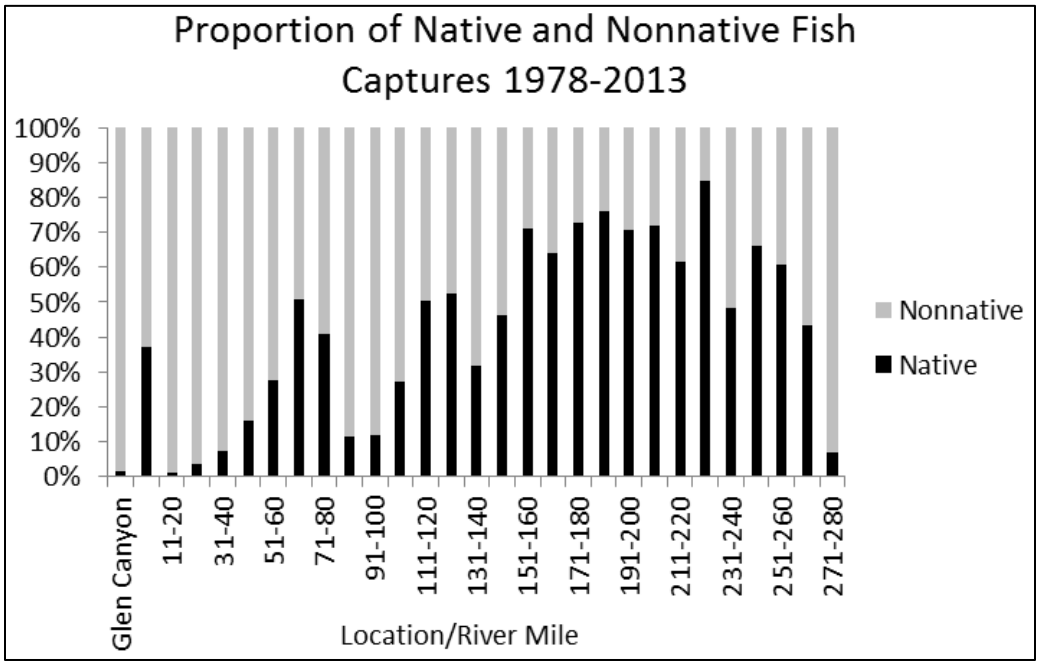


Figure 54. Proportion of fish captures, by all gear types, for native and nonnative fish species by river mile from Glen Canyon Dam to Lake Mead. Captures included data from 1978 through 2013, with some 2014 data included (S. Vanderkooi, USGS, personal communication, 2015). USGS–Grand Canyon Monitoring and Research Center, unpublished data.

Endangered Fish Abundance and Distribution

Endangered humpback chub abundance has fluctuated by tributary and as a result of management actions (e.g., translocations) and disturbance (fire and flooding). Currently the Lower Colorado River basin population of humpback chub in Grand Canyon meets the majority of the recovery criteria (USFWS 2002). Outside of the Little Colorado River and other tributaries, it appears that some humpback chub aggregations may be experiencing long-term increases (30-Mile, Shinumo, Havasu, and Pumpkin Spring) with stable trends in others (Bright Angel, Middle Granite Gorge, Stephen Aisle; Persons et al., presentation to Glen Canyon Dam Technical Workgroup, January 2014; Table 47). However, significant levels of reproduction and recruitment outside the Little Colorado River have not been proven, and thus, population redundancy outside the Little Colorado River has not been established.

Table 47. Humpback chub "aggregations" within Grand Canyon NP (NPS 2013).

Aggregation	River Mile	Population Estimate	95% Confidence Intervals
30-Mile	29.8 – 31.3	52	24–136
Little Colorado River Inflow*	57 – 65.4	n/a	9,000–12,000
Lava Chuar to Hance	65.7 – 76.3	n/a	–
Bright Angel Creek Inflow	83.8 – 92.2	n/a	–
Shinumo Creek Inflow	108.1 – 108.6	57	31–149
Stephen Aisle	114.9 – 120.1	n/a	–
Middle Granite Gorge	126.1 – 129.0	98	74–153
Havasu Creek Inflow	155.8 – 156.7	13	5–70
Pumpkin Spring	212.5 – 213.2	5	4–16

Due to a lack of captures during fish monitoring, razorback sucker were considered "extirpated" from Grand Canyon NP for almost 20 years. However, larval razorback sucker were found via razorback sucker sonic-telemetry and larval fish studies in 2014, led by Bio-West, Inc. and ASIR, Inc. (S. Platania, personal communication).

Rare/High-Risk Nonnative Fish Species Captures

Spatial examination of the occurrences of rare or high-risk predatory nonnative fish helps to identify potential sources of these fish. Almost 50% of all brown trout in the USGS-GCMRC database were captured between River Miles 81 and 90, which is centered on the Bright Angel Creek inflow. Warm-water nonnative fish, including bass and sunfish (Centrachidae), striped bass, walleye, and catfish and bullheads (Ictaluridae) were most commonly captured near the Little Colorado River inflow, near Glen Canyon Dam, downstream of Lava Falls, and to a lesser degree, near the mouth of Kanab Creek.

Catch-Per-Unit-Effort of Large-Bodied Fishes

Nonnative rainbow and brown trout both declined in Grand Canyon NP from highs in 2000 through 2007, and then increased until 2011 (Bunch et al. 2012; Figure 55). Common carp CPUE followed a similar pattern, and increased less dramatically than trout by 2011. Catch-per-unit-effort of both flannelmouth and bluehead suckers have increased significantly since 2004 or 2006 (Bunch et al. 2012).

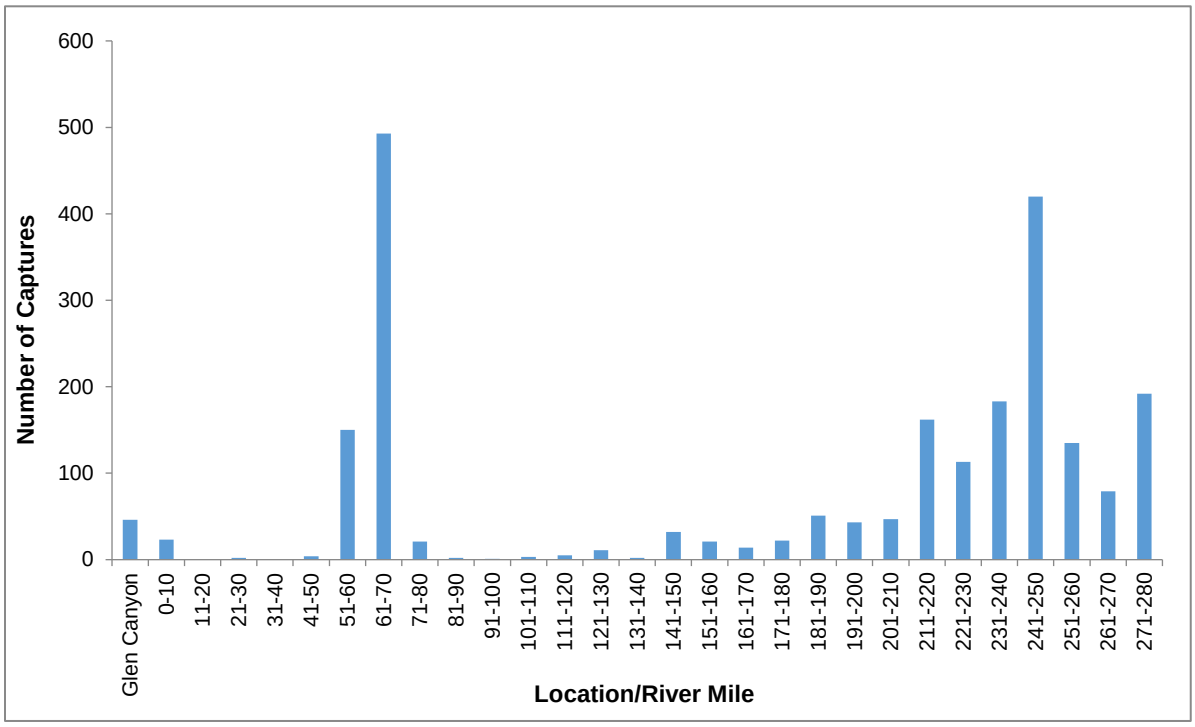


Figure 55. Number of high-risk, warm water nonnative fish captures (bass and sunfish, striped bass, walleye, catfish, and bullheads) by all gear types, by Colorado River mile, between Glen Canyon Dam and Lake Mead, 1978–2013 (USGS-GCMRC unpublished data).

5.20.5. Summary

Multiple stressors, including construction and operation of Glen Canyon Dam, nonnative predators and competitors, and fire and flooding, impact the aquatic invertebrate and fish communities both directly and indirectly. These stressors also interact to impact the fish community at multiple scales, potentially reducing the overall system's resistance to disturbance, and limiting the resiliency of the ecosystem. Cold water released by the dam has not only limited reproduction of warm-water native fish species in the Colorado River, but also may decrease swimming ability of native species, and thus the ability to escape predation by nonnative cold-water predators (Ward and Bonar 2003). Native species were preferentially preyed upon by nonnative trout near the Little Colorado River confluence (Yard et al. 2011), as well as in Grand Canyon tributaries (Whiting et al. 2014; Spurgeon et al. 2014). Competition with nonnonative fish is another likely stressor. In the past, tributaries such as Shinumo and Havasu Creeks were seasonally reconnected with the Colorado River, to allow for recolonization and flow of genetic material between populations; and native species were distributed

much more widely, with robust populations. Currently, the Lower Colorado River Basin's only humpback chub population is maintained by reproduction in a single tributary. At a regional or basin-wide scale, Grand Canyon NP hosts the largest remaining, as well as the only stable humpback chub population. Thus, various stressors and remaining native fish populations need to be managed closely in order to maintain abundance and distribution within the park.

Although the diversity of aquatic macroinvertebrates may be maintained in tributaries (Oberlin et al. 1999; Shinumo Creek, Spurgeon et al. 2014; Bright Angel Creek, Whiting et al. 2014; Shinumo and Havasu Creeks, NPS unpublished data), habitat in the Colorado River currently supports very few invertebrate taxa relative to other tailwaters or Grand Canyon tributaries (Cross et al. 2013; T. Kennedy, personal communication, 2015), possibly because of the altered temperature regime and hydropeaking flows limiting invertebrate recruitment. This is of concern due to the role of invertebrates in the aquatic food web.

5.20.6. Data Needs

There is no comprehensive "stock assessment" for most fish species, park-wide, to address the current condition, even though data may be sufficient to assess trends in some species. To estimate abundance at such a large scale would increase costs significantly, and could increase handling stress and potential mortality of some species (e.g., humpback chub). Nevertheless, general data needs include the following:

- Trend in abundance or CPUE for Colorado River humpback chub aggregations outside of the Little Colorado River.
- Continued research and monitoring of razorback sucker population dynamics. Evidence of spawning has been documented, but recruitment in Grand Canyon NP has not been observed.
- Natal origin of high-risk predatory nonnative species.
- Continued native sucker (bluehead and flannelmouth) population assessment in tributaries, and the Colorado River if feasible (see Walters et al. 2012).
- Modeling of stream channel sensitivity to watershed disturbance. Fire planning needs to consider critical fish populations or infrastructure that may be impacted by fire and changes in hydrology, at a watershed scale.

Specific data use issues include the following:

- Sampling has been conducted inconsistently across space and time, within the entire park. The exception is hoop netting in the Little Colorado River (which doesn't effectively sample some species, such as catfish, carp, trout, small-bodied nonnatives), where hoop netting has been applied consistently since 2000.
- The inconsistent distribution of samples in the Colorado River may skew the results of the rare/high-risk nonnative species indicator assessment.
- Data were not collected to assess overall trend in species composition, but rather to assess effects of specific management actions or trends in specific species in specific locations for

ESA needs (dam operations, or translocations/nonnative trout control in tributaries). Data to determine overall condition and trend of the fish community are not available.

- Tributary trend data were limited to Shinumo, Havasu, and Bright Angel (NPS data), and the Little Colorado River (FWS/GCMRC data summarized). No appropriate trend data are available for other tributaries and for some species, e.g. rainbow trout in Havasu Creek, limiting an assessment of overall condition and trend at the landscape or watershed scale.

5.20.7. Level of Confidence

The data reported here were collected using standard fisheries sampling methodology and can be treated with high confidence.

5.20.8. Sources of Expertise

This section was prepared by Brian Healy, Grand Canyon National Park Fisheries program manager. William Persons and Scott Vanderkooi, USGS–Grand Canyon Monitoring and Research Center, fisheries biologist and Biology program manager, provided data and suggestions on use and limitations of the data.

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5.21. Physical Resources: Caves

5.21.1. Description



The Grand Canyon area contains 474 known caves, many with extraordinary resources. Many organisms depend on caves for a temporary or permanent habitat. There are very few data on area caves in general, and long-term data are particularly lacking. Human visitation is the primary stress on cave resources; however, most caves are rarely, if ever, visited, suggesting that most resources likely remain intact (NPS Photo).

Almost 5.5 million people visit Grand Canyon National Park each year, and very few of them have any idea that an entirely different type of geologic wonder is hidden beneath their feet. Even fewer of them realize that 97% of the park is considered to be part of a larger shared karst landscape. The Grand Canyon protects the largest area of karst limestone bedrock of any national park unit. With so much of the park considered to be karst, all park facilities on both rims of the canyon and all activities have the potential to impact the resources of this significant landscape. The limestone of the Grand Canyon National Park contains 300 known caves and likely harbors hundreds more. These caves are mostly associated with the Redwall-Muav limestone formations and vary in length from a few feet to tens of miles. In total, there are records for 474 caves in the GGCLA assessment area of which only a little more than half have been explored. Seventy-six (76) caves have physical surveys that when added together total more than 63 miles (101 kilometers) of passages. With exploration and documentation just beginning, the caves and karst resources of the Grand Canyon are truly exceptional and rank among the park units created for these types of resources such as Mammoth Cave, Carlsbad Caverns, Jewel Cave, and Wind Cave (Figure 56).

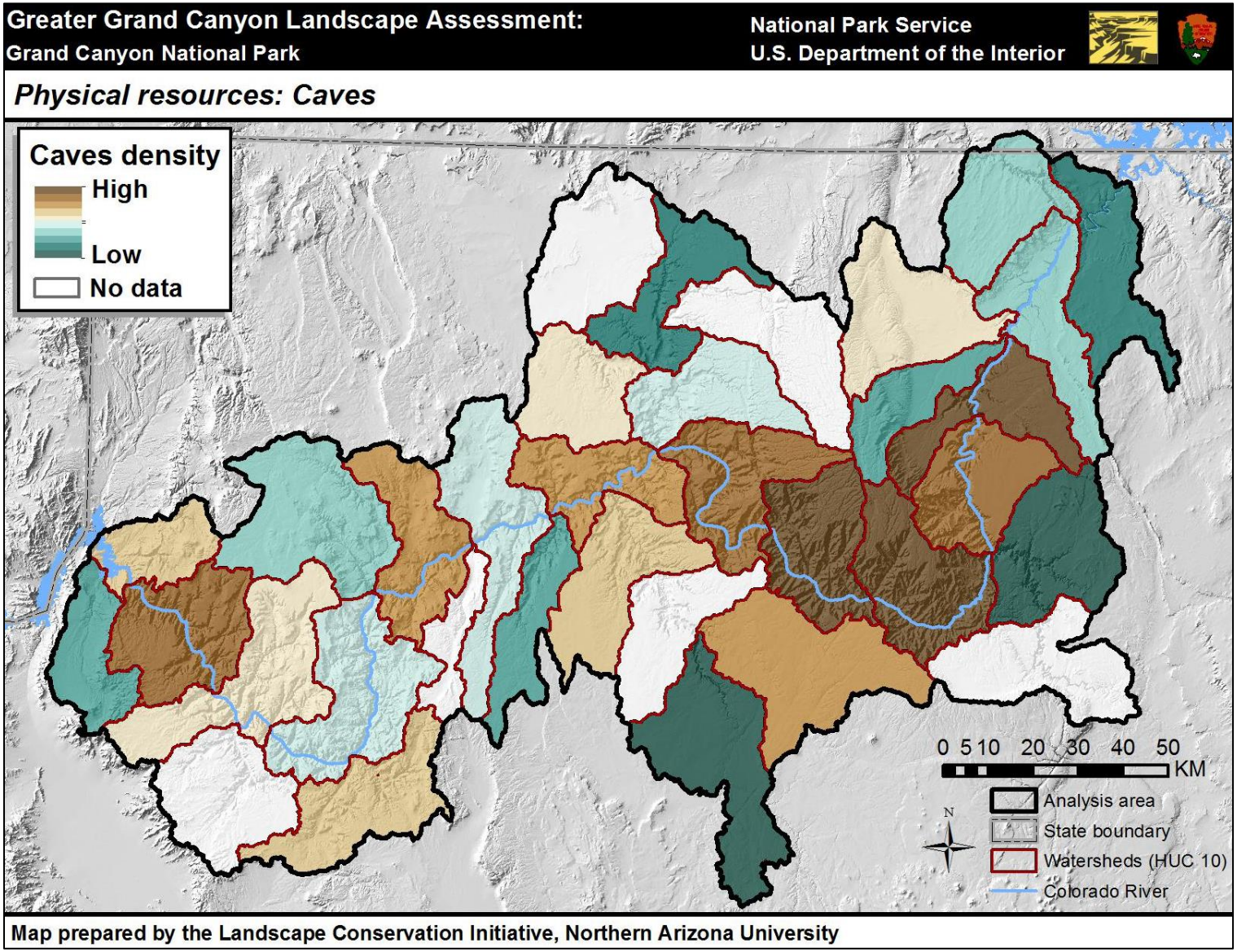


Figure 56. Density of caves in Grand Canyon NP.

Even more remarkable are the contents of Grand Canyon area caves, which feature a vast array of unique and significant speleothems, paleontological remains, archeological artifacts, springs, and cave-dependent wildlife species. The area's dry climate and the inherent sheltered nature of caves make them the ideal environment for preservation of ancient natural and manmade artifacts, often resulting in very rich and rare deposits. The general inaccessibility of the caves further protects artifacts from human disturbance. The combination of concentrated resources and exceptional preservation truly makes the caves of the Grand Canyon area some of the world's most critical and untouched environments. In spite of this, less than 12% (55) have been even basically inventoried to assess the quantity or quality of resources present. This figure was derived from 55 out of 474 caves that have been inventoried.

5.21.2. Indicators/Measures

- Geological resources
- Hydrological resources
- Biological resources
- Paleontological resources

5.21.3. Methods

Whenever possible, data were gathered from in-depth, peer-reviewed studies of the indicators, as these were deemed to be the most reliable. Some simple inventories and trip reports were also available but they are sporadic in nature, conducted by non-experts, and not focused on a single indicator. Broader condition assessments based on these casual, primarily presence/absence reports augment information from the more intensive studies.

Geological Resources

The condition assessment of speleothems is based on mineral condition reports of 13 caves conducted by Hans Bodenhamer in 2011 and 2012 (Bodenhamer et al. 2011; Bodenhamer et al. 2012). Mineral deposits were located in the caves, marked on the cave map, and given numerical ratings for impact, significance, and fragility. Based on these factors a level of concern was calculated for each feature. Sediments covering cave floors also contain information that help researchers reconstruct paleoclimates, provide habitat for cave-adapted species, and may provide information about the history of local cave development and regional geologic history. These deposits are often neglected in inventory work and as such are often poorly represented in datasets. Grand Canyon area caves are no exception and the lack of data precludes their use as an indicator.

Only two caves have available long-term microclimate data collected by HOBO data loggers: Bat Cave has one temperature logger with nearly 7 years of temperature data, from November 2002 to August 2009. The exact position of this logger is unknown, but based on the temperature range it is believed to be within the transition zone of the cave. Double Bopper Cave has 2 years of data, from October 2010 to October 2012, from two loggers—one just outside the cave and one approximately 3,000 feet inside the cave. A third logger, about 3 miles in, collected data from October 2011 to

October 2012. These temperature records are compared to those on the surface as well as those in different parts of the cave (when available) to assess the condition and trend of the microclimate.

Hydrological Resources

Within the cave environment, water is present as streamflow, pools, or drip water. No data are available on water quality or quantity for drips or pools. Five park caves with active streams do have some data; these streams emerge as springs and are addressed in the springs and seeps section of this document.

Biological Resources

Bat population surveys conducted sporadically over many years in two caves—Bat Cave and Stanton's Cave—are primarily official surveys performed by bat researchers and are therefore focused on counting bats as accurately as possible. Fifteen surveys of the Mexican free-tailed bat (*Tadarida brasiliensis*) were conducted in Bat Cave from 1994 to 2007, and seven surveys of Townsend's big-eared bat (*Corynorhinus townsendii*) were conducted in Stanton's Cave from 1989 to 2003.

Some of the most important, abundant, and endangered species in cave ecosystems are the often overlooked macroinvertebrates. Multiple scientific papers have been published on the macroinvertebrate inventories of six caves in the area—Babylon Cave, Bat Cave, Cave of the Domes, Crystal Forest, Roaring Springs Cave, and Tse'an Cho (Wynne et al. 2007). Eight others have been the subject of a single study, somewhat useful for assessing conditions but not trends (Muchmore 1981; Drost and Blinn 1997; Wynne et al. 2007). The numbers of unique species found in each cave each year were counted as an indication of species diversity. Due to the absence of adequate temporal data, however, the trend is designated unknown.

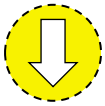
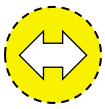
Paleontological Resources

Seventy publications on paleontological resources in 18 area caves were compiled into a list of unique species found in each cave to evaluate the diversity of finds (Santucci et al. 2001). Due to a lack of continuous data on paleontological conditions, the trend of this indicator is unknown.

As with paleontological resources, cave environments preserve archaeological resources very well. Many Native American artifacts have been found in park caves, including split-twig figurines, beads, pots, arrows, torches, and prayer sticks, representing many local cultures throughout time (Reilly 1973; Euler 1978). More recent historical sites are abundant in the canyon and are often associated with caves.

5.21.4. Condition and Trend

Table 48. Summary of cave resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Geological resources	Historical speleothem and microclimate data		Speleothems are in good condition. Microclimates show slight warming, which could impact geological resources in the future. Data are limited.
Hydrological resources	Historical streamflow, pools, or drip water availability		Little is known about pools and drip water, but climate change is likely to reduce groundwater availability across the region.
Biological resources	Historical surveys of bats and macroinvertebrates		Bats show resilience to human disturbance, although white-nosed syndrome is a concern nationwide and if it appears in Grand Canyon could significantly impact bats that hibernate in the region. The only known endemic macroinvertebrate, a pseudoscorpion, may be extinct.
Paleontological resources	Historical availability of paleontological deposits		Caves contain a wealth of deposits. They can be damaged by human disturbances such as fire, but are generally well protected.

Geological Resources

Although the presence of speleothems in caves and their aesthetic value is well known, their delicacy, diversity, and scientific importance are often overlooked. Many decorations in Grand Canyon caves, such as gypsum hair and cave pearls, are quite rare and may offer new insights into cave formations as well as the hydrologic history of the area (Hill and Polyak 2010). Speleothems may also play an essential role in assessing local paleoclimates because their growth rate is dependent on water availability and soil CO_2 levels. By studying the annual growth layers of these deposits, scientists can tease out hundreds of thousands of years of information (Gascoyne 1992; Lauritzen and Lundberg 1999; Linge et al. 2001), including temperature (Lauritzen 1995), biomass (Ersek et al. 2009), and water balance (Bar-Matthews et al. 1997). Of the 13 caves evaluated, the largest amount of speleothems of high concern was 4%, and all but one cave had a majority of features in the categories of little or no concern.

The microclimate in a cave is often vastly different from the conditions on the surface. The cave microclimate is divided into three areas, defined by their influence from the surface climate. The climate of the entrance zone is highly variable and most affected by changes in the outside climate; the deep zone has a relatively stable temperature and high humidity; and the transition zone lies in between and can seasonally behave in either fashion (Tobin et al. 2013). The sizes of these zones

vary depending on cave morphology and surface climate. In the deep zone the temperature is generally constant and reflects the mean annual surface temperature, allowing for the assessment of long-term climate change (Buecher 1999). Humidity in a cave is often higher than the outside, and it cycles throughout the year as airflow patterns change with the seasons (de Freitas 2010). Many cave-adapted species are dependent on this high humidity and constant temperature environment, and changes in microclimates can be devastating for such populations. This assessment compiled 7 years of daily median temperature data in Bat Cave from park data files that show temperatures that fluctuate with the seasons and represent an attenuated version of the surface values. The trendline of the data shows a slight warming over time, indicative of the recent warming trends both regionally and globally.

Hydrological Resources

In dry environments like the Grand Canyon, water is an extremely important and vulnerable resource, and understanding the hydrology is vital for estimating supplies and keeping water clean. In areas with significant karstic bedrock the complexity of the hydrologic system makes the situation much more delicate, as is the case with the groundwater supply in the area, most of which is stored within the karstic Redwall and Muav limestones. All of the perennial surface tributaries to the Colorado River in the region are maintained by water stored in these karst aquifers, emerging in tributaries as springs (Hill et al. 2008), while on the Kaibab Plateau karst systems are so well-established that there is essentially no surface drainage at all (Huntoon 1970).

Biological Resources

Bats are the archetypal cave-dwellers and are an important part of their ecosystems. Insectivorous bats are the primary predator of nocturnal insects, including mosquitos and agricultural pests (Chung-MacCoubrey 2013). Caves often act as ideal maternity or hibernation roosts, providing essential temperature stability and refuge from predators for many local bat species. Since bats are small creatures that expend high energy, they have a tight energy budget, and because insects are scarce in the winter, bats must often hibernate or migrate to avoid starvation. The stable microclimates found in caves make them ideal roosts as the relatively warm winter temperatures reduce thermoregulatory energy requirements (Kunz 1982; Hill and Smith 1984).

Bat Cave is home to a drastically fluctuating population of Mexican-free tailed bats, ranging from 200 to 285,000 over 13 years of studies (Pape 2014). A great deal of this fluctuation is likely due to the fact that the data were collected at varying times of the year, and this bat species tends to winter in Mexico and summer in the American Southwest (O'Shea et al. 2003). As a result, the data are too seasonally varied to determine any long-term trends. However, it seems to be a good sign that the most recent summer count (June, 2005: 285,000) is the highest population on record.

By contrast, we have fewer data on Stanton's Cave than Bat Cave, but Stanton's makes an interesting case study due to its documented history of human disturbance. NPS inventories show that the population of Townsend's big-eared bats in Stanton's Cave has fluctuated with the intensity of human disturbance over the years, but consistently shows signs of recovery after disturbance events.

Grand Canyon caves are home to more than 35 documented species of macroinvertebrates, including crickets, spiders, harvestmen, springtails, and water-dwelling amphipods (Drost and Blinn 1997; Wynne et al. 2007). Due to the unusual and harsh environment, many species of macroinvertebrates are highly adapted to life in the cave, exhibiting features such as loss of pigmentation, regressed eyes, or strongly developed extra-ocular senses (Biswas 2009). Additionally, the isolation of caves often results in endemism of the species within (Culver et al. 2000), leaving these highly specialized and concentrated creatures very sensitive to habitat loss.

Macroinvertebrate presence and diversity is not especially high in local caves due to the general lack of moisture (Pape 2014). Three caves (Roaring Springs, Tapeats, and Thunder River) contain springs and therefore have the capability of housing more macroinvertebrates. Roaring Springs Cave has been the sole subject of two studies, one of which found 22 species, the highest of all official surveys. Cave of the Domes is a uniquely interesting case as it is home to one of the only known macroinvertebrates endemic to the area—the Grand Canyon cave pseudoscorpion (*Archeolarca cavicola*). The creature is very well adapted to caves in comparison to other pseudoscorpions, with larger, longer appendages and more reduced posterior eyes (Muchmore 1981). This high degree of adaptation makes it unlikely that the pseudoscorpion moves between caves. Unfortunately, data on this creature are limited to a single specimen found in 1978.

Paleontological Resources

The shelter, aridity, and stable climate of caves in the Grand Canyon have provided an ideal location for the preservation of paleontological resources, including rare soft-tissue subfossils, dung, packrat middens, and older fossil materials found in the surrounding bedrock (Santucci et al. 2001). The only specimen of soft-tissue remnants of the extinct Harrington's mountain goat and keratinous hornsheaths have been found in Grand Canyon caves (Mead et al. 1986). Dung deposits in Grand Canyon caves have provided important information on the behavior of ancient animals, their diet of local flora, and evidence of paleoclimates (Cole 1992; Santucci et al. 2001).

Packrat middens are collections of material such as plants, bones, and other detritus that have been built up from generation to generation, sometimes for thousands of years, resulting in the preservation of a nearly continuous record of paleoclimate and species presence for much of the Quaternary period (Wells 1976). The most diverse deposits have been found in Stanton's Cave, which has yielded the remains of 217 species. Perhaps the most distinguished site is Rampart Cave, location of the thickest and most intact deposit of Shasta ground sloth (*Nothrotheriops shastensis*) dung in the world (Santucci et al. 2001). Layers of this dung, dated as old as 40,000 years, contain a wealth of plant and pollen data.

As an example of the potential fragility of these resources, the most significant known damage to them occurred at Rampart Cave in 1976 when the dung deposit caught on fire and burned for more than 6 months (Santucci et al. 2001). This destroyed not only most of the dung, but also much of the other resources in the cave as well (packrat middens, sloth bones). Today, Rampart Cave is gated and rarely entered, but this case illustrates how one incident can have a devastating effect.

5.21.5. Summary

Human activities comprise the biggest stressor on cave resources in general and on the indicators used for this assessment specifically. Due to the sensitivity and seclusion of the cave environment, many resources can be negatively impacted by even the most careful and best-intentioned visitors. Some resources are so sensitive that even well-educated visitors can cause negative impacts. Speleothem and paleontological resources are almost exclusively affected by human use, with few other factors causing negative impact.

As cave visitation increases—particularly by casual, non-permitted users with minimal, if any, education on cave resources —so does the risk of speleothem impact. Broken features are the extreme end of impact, but things as simple as tracking mud onto flowstone or depositing skin oils on minerals can also cause damage (Horrocks 2013). In caves with drips, pools, or streams, changes in local hydrology can lead to acidification of water and possible dissolution of features (Baker and Genty 1998). Also, human-caused changes such as entrance alterations or increased visitation can alter cave humidity levels and lead to changes in the ability of water to precipitate minerals onto existing formations (Baker and Genty 1998).

For macroinvertebrates and bats, human use is the primary stressor, but other environmental stressors can significantly impact the biology of caves. Bats in eastern North America are currently facing the threat of white-nose syndrome, a fungal disease that is highly contagious among colonies and boasts mortality rates over 90% (Cryan et al. 2010; Chung-MacCoubrey 2013). Although the epidemic has not yet reached the western United States, it is believed that it could be spread from cave to cave via natural bat migration patterns or via the contaminated clothing, shoes, and gear of cavers (Shelley et al. 2013).

Pollution of the cave environment is another major potential stressor for cave life, especially for cave-dwelling macroinvertebrates. Cave environments are particularly vulnerable to water-borne pollutants, which can enter the system at a great distance from the known cave, reach the cave environment rapidly, and persist in the system for an extended period of time. Additionally, changes in the hydrologic input can be disastrous, whether via water pollutants, loss of washed-in nutrients, or loss of water supply (Panek and Despain 2013). Often the water acts as a conduit to bring faster and more drastic changes to the ecosystem. Cave-dwelling macroinvertebrates also have been shown to respond to even slight variability in microclimate within caves (Tobin et al. 2013). With changes in surface climate forcing changes in cave microclimate, it is likely that species adapted to the cave environment could be subject to larger stresses. The direness of the problem and the sensitivity of macroinvertebrates to common environmental issues are illustrated by the fact that they comprise more than 50% of the animals listed as imperiled by The Nature Conservancy (Culver et al. 2000).

Cave microclimates can be affected by two primary stressors: human modification of cave passages and climate change. Modifications to cave passages can impact air flow in the system, changing humidity and temperature regimes in sections of caves. Caves, in general, reflect the average annual surface temperatures and as a region warms, cave environments will also warm.

5.21.6. Data Needs

- More caves as the subject of studies
- More peer-reviewed scientific studies on indicator conditions
- Reliable, standardized, long-term data to evaluate trends
- More data on caves outside of the Grand Canyon itself
- Better visitation data for more caves
- More focus on indicators other than speleothems in impact studies
- Increased long-term photo monitoring of resources
- GIS mapping of established cave routes and resources
- Sufficient data to assess cave sediments, microbiota, drip water, and pools
- Increased research on speleothem fragility and significance as well as impact
- Evaluation of individual cave stressors
- Multiple HOBOs in caves to show microclimates in different areas
- Long-term humidity data
- Annual, standardized bat population counts
- Improved techniques for bat counts
- Repeated macroinvertebrate inventories in individual caves
- Abundance estimates for macroinvertebrates
- Studies of individual cave energy chains and stressors to the cave ecosystem
- Mapping of suitable macroinvertebrate habitat and possible threats
- Data on paleontological specimen conditions and numbers of artifacts
- The exploration, survey, and inventory of additional caves to specified standards

5.21.7. Level of Confidence

Overall, the level of confidence in the assessment of cave conditions and trends is very low. Of many caves in the analysis area, only 474 have been visited or are suspected to have been visited (i.e., visible holes in the cliff face that have yet to be explored), fewer have definitely been explored, and only a very small fraction have been the subject of formal studies. Some indicators are better researched than others, but two indicators in this report have low confidence levels and three are rated as very low simply due to the lack of quality data. Even where a few robust studies exist to assess the conditions of caves, there is rarely enough continuous data collection to assess a trend.

Furthermore, the nature of caves as separate and unique entities does not allow for much extrapolation across the landscape, so the small sample sizes assessed here are more problematic than

for other more connected environments. This characteristic also makes the establishment of reference conditions more difficult, since individual caves would have a different natural baseline for each indicator.

Many of the indicators included here are challenging to inventory, especially in the formidable cave environment, so unless a study is extremely thorough, many things may be overlooked. The idea that absence of evidence is not evidence of absence is particularly relevant in the case of cave research. Moreover, simply getting to certain parts of the cave may be arduous or even impossible. In the Grand Canyon area, getting to a cave entrance itself can be difficult enough to deter researchers. As a result, even known caves are often better studied based on how easy it is to reach them, rather than for the scientific value of their resources.

5.21.8. Sources of Expertise

This section was prepared by Marissa Kelly, karst resources intern at Grand Canyon NP, with assistance from D. L. Pate, cave resource specialist with the National Park Service, V. Santucci, paleontology resource specialist with the National Park Service, and B. W. Tobin, National Park Service hydrologist.

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5.22. Physical Resources: Seeps and Springs

5.22.1. Description



Springs and seeps in the greater Grand Canyon landscape provide base flow to the Colorado River and drinking water to wildlife and visitors in an otherwise arid environment, making them arguably the most valuable natural resource in the focal area. However, they have been subject to significant pressures from water supply development and potential contamination. There are approximately 900 known springs in the GGCLA. Roaring Springs is the sole water supply for Grand Canyon's employees and millions of annual visitors. Springs support valuable riparian habitats, with very high species diversity. They are centers of activity on the landscape, used by park wildlife. Grand Canyon springs are often locations of exceptional natural beauty and hold cultural significance for traditionally associated tribes. Due to a lack of consistent data collection techniques, condition and trend for springs across the full analysis area cannot yet be evaluated quantitatively. However, for Cottonwood, Pumphouse, and Indian Garden Springs, where repeated data collection has occurred, significant declines in discharge have been detected, and anecdotal trends suggest widespread declines (NPS Photo).

Springs are defined as ecosystems where groundwater reaches the surface of the earth either at or near the land-atmosphere or land-water interface. Seeps are low-flow springs that may be insufficient as a dependable backcountry water source (Springer et al. 2008). Ten of the twelve classes of spring types (Springer et al. 2008) are found in the Grand Canyon, ranging from nearly imperceptible seeps that are only visible due to riparian plant growth, to large sources that create waterfalls on cliff faces. Flow from an individual spring's ecosystem often varies within and between years, with the highest

flows of springs associated with spring snowmelt and with lowest flows occurring during late fall and early winter (Rice 2008). Many Grand Canyon springs function as outlets of large regional karst aquifer systems, which are characterized by water replenishing aquifers via sinkholes and flowing through pore space, fractures, conduits, and caves (Huntoon 2000).

The largest springs in the Grand Canyon region are karst springs that exhibit signs of both rapid conduit flow and slower matrix flow (Ross 2005; Schindel 2015). Most of the larger springs, such as Roaring Springs, Blue and Havasu Springs, Vasey's Paradise, and Thunder River Spring lie north of the Colorado River and are fed from precipitation on the Kaibab Plateau. Several large and many smaller but equally important springs emerge south of the Colorado River, and these have been the subject of monitoring and modeling efforts (Grand Canyon Wildlands Council 2002, 2004; Bills et al. 2005). Springs and seeps contribute to the base flow of nearly all perennial Colorado River tributaries (Grand Canyon National Park 2015).

Springs are enormously important resources in arid regions; not only do they supply essential surface water for dependent terrestrial species, but they support diverse and spatially restricted aquatic communities. As a result, their contribution to regional biorichness is immense, making them keystone ecosystems (Stevens and Meretsky 2008). Springs influence the spatial distribution of wildlife, support riparian communities where species diversity can be up to 500 times greater than in the surrounding landscape (Grand Canyon Wildlands Council 2004), and are of great ethnographic importance to native peoples (Stevens and Meretsky 2008). Water quality and quantity at springs can thus determine the condition and trend of a diverse array of regional resources.

5.22.2. Indicators/Measures

- Spring presence
- Discharge
- Water quality

In the greater Grand Canyon landscape, drivers of environmental change such as climate change and increased human development may affect spring water quality and quantity via reduced precipitation, increased groundwater pumping, and contamination from mining and other human activities. However, a lack of long-term, consistent datasets makes it difficult to assess spring baseline conditions or water quality and quantity trends across the landscape. To adequately understand the likely impacts of these stressors on spring availability and quality in the future, it is necessary to gather all information currently available and carefully craft future data collection to enable robust trend analysis.

5.22.3. Methods

Reports on the condition of springs are often divided into two separate assessments: that of the ecosystem dependent on the water emerging from the aquifer and that of the aquifer itself. This resource condition assessment focuses on the physical and chemical conditions of the springs, seeps, and associated aquifers in the study area.

A spring ecosystem represents the cumulative signal of the process occurring across the entire watershed that feeds it. These signals originate primarily as precipitation on the surface, which is modified by the pathways water takes into and through the subsurface, ultimately emerging at the spring. Many factors influence how a spring's flow and water quality vary over time, from plant water use (Brooks et al. 2009) to subsurface flow pathways (Tague and Grant 2004), to precipitation type, amount, and frequency (Godsey et al. 2013; Lopez-Moreno et al. 2014). Therefore, spring flow can vary considerably over the course of years and seasons, making it difficult to detect significant trends and highlighting the importance of repeated measures of assessment. Repeated and consistent measurements of spring characteristics have been rare in the GGCLA, so condition and trend can be assessed for a few individual springs but at the landscape scale, qualitative evaluation is challenging. Therefore, below we summarize existing data availability and discuss the level of data collection that will be required for a future quantitative condition and trend assessment.

In order to accurately assess the condition of spring ecosystems, it is first important to understand the primary variables that determine a spring's natural hydrologic behavior. This requires data on the surface area associated with a spring, the underlying geology, localized evapotranspiration, and the spring ecosystem's vegetation. Substantial information is available on Grand Canyon vegetation and geology, but there is little information on evapotranspiration or the surface area extent of the aquifers feeding park springs (Rice 2008). The characteristics of karstic aquifers (aquifers with significant limestone components) can be determined through hydrograph separation techniques (Kovacs et al. 2005; Vitvar et al. 2003) and multivariate statistical techniques (Doctor et al. 2006; Tobin 2013). Due to the nature of these karst aquifers, it is often not possible to extrapolate aquifer responses from one region or one set of springs to another (Goldscheider and Drew 2007), so condition assessment in a large study area is possible only if a large number of springs have substantial hydrologic data.

The indicators needed to calculate springs condition include water chemistry, flow, and floral and faunal assemblage inventories that have been collected during both high and low flow conditions. In terms of existing data, this would mean that each spring and seep has been surveyed two or more times using comparable and comprehensive methods. The Springs Stewardship Institute (SSI), which is based at the Museum of Northern Arizona and works to collect and collate data on regional seeps and springs in partnership with researchers and land management agencies, has developed inventory protocols at several levels. Level 1 inventories consist of a rapid reconnaissance survey to georeference the water source and determine sampling needs (Stevens et al. 2011). Level 2 inventories include detailed documentation of baseline physical, biological, human impact, and administrative characteristics (Stevens et al. 2011). Those variables are also employed for Level 3 inventories, which involve monitoring of springs selected for long-term studies and repeated measurement of variables (Figure 57; Stevens et al. 2011).

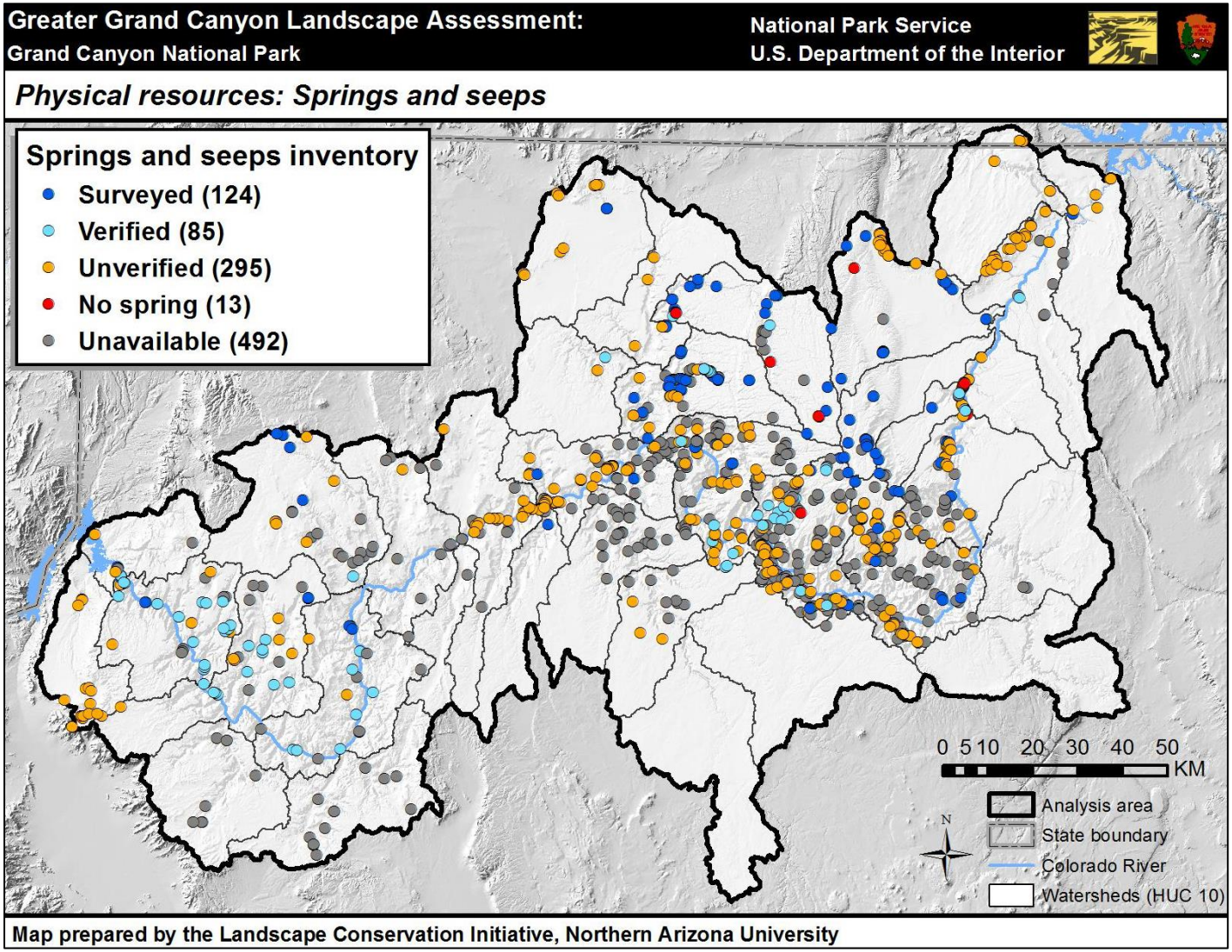


Figure 57. Map displaying verified or reported spring location by inventory result. Unavailable = reported springs without completed inventory. No spring = inventory conducted but no spring found. Unverified = inventory conducted but not verified. Verified = inventory conducted and spring found. Surveyed = spring located and surveyed for physical, biological, human impact, and administrative characteristics.

Calculating spring condition requires data including high and low flow water chemistry, flow rates, field water quality data, and biological inventories during high and low flow conditions so that characteristics such as recharge area (Florea and Vacher 2006); relative contributions of fissure, conduit, and diffuse flow (Karimi et al. 2005); and relative importance of allogenic vs. autogenic recharge (Tobin and Schwartz 2012) can be inferred. These variables can be used to group springs by similarity (Doctor et al. 2006; Tobin 2013). This then provides baseline conditions for springs of different types in the study area. Grand Canyon NP and outside researchers, including the Springs Stewardship Institute, are collating existing data and collecting additional data in order to establish these baseline conditions and develop consistent monitoring schedules.

5.22.4. Condition and Trend

Table 49. Summary of seeps and springs resource condition and trend by indicator.

Indicator	Reference condition	Relative condition	Summary comments
Presence of springs	Historical accounts of spring presence		Not all reported springs have been verified and some have been found to be dry or absent. However, spring discharge remains critical to most perennial tributaries of the Colorado River in the GGCLA.
Discharge	Baseline discharge		Repeated and standardized measurements of discharge have been conducted for only a few springs, but most of those show declining discharge. Regional trends include declining precipitation (due to current and projected drought) and increasing groundwater withdrawal for human development, suggesting a reduction in discharge at other springs is also likely.
Water quality	Baseline water quality		Insufficient water quality baseline data collection and monitoring have been conducted. However, both natural and anthropogenic contaminants have been identified in the few samples that have been analyzed however the lack of data makes it impossible to project this to the entire study area.

There are approximately 900 known springs in the GGCLA area, and given the rugged topography, there are likely many additional springs that have not yet been discovered or verified. A basic map of the springs indicates that records are concentrated along the Colorado River and within the central corridor of Bright Angel Trail/Kaibab Trail (Figure 58). This could be a result of higher use of these areas by recreationists and researchers, rather than indicative of true relative spring densities. Of the known springs, approximately 750 (83%) are located in Grand Canyon NP, with the remaining springs in surrounding lands. Most large springs are located off of the north rim of the Grand Canyon, fed by precipitation from the Kaibab Plateau. Two important exceptions to this are Havasu and Blue Springs, which are located below the south rim on adjacent tribal lands.

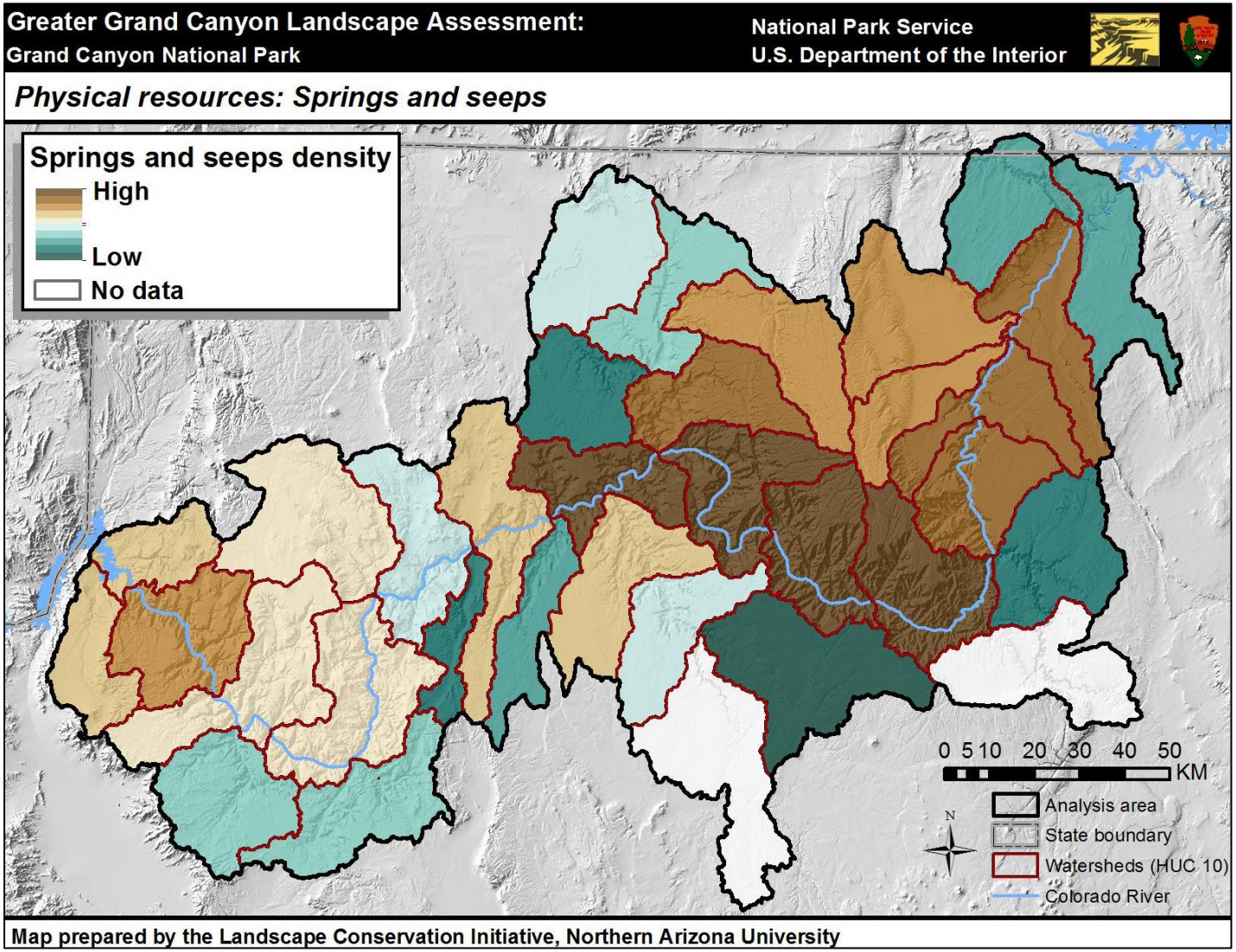


Figure 58. Map displaying density of spring occurrence by HUC 10 watershed.

Geospatial analysis shows that 200 of 750 springs in Grand Canyon NP (26%) are directly associated with riparian vegetation (spring locations are within 50 meters of mapped riparian vegetation with a minimum mapping unit of 0.5 ha) suggesting that they are perennial springs large enough to establish a perennial surface stream. Fine-scale vegetation data are not yet available for surrounding lands outside of Grand Canyon NP. Of the 750 known Grand Canyon NP springs, 321 emerge from karst aquifers (spring location within 50 meters of limestone bedrock), and most of the springs associated with riparian vegetation are in this group (130 of 200, or 65%). This indicates that most of the perennial springs in the park emerge from karst aquifers. These springs contain groundwater derived from multiple sources (Crossey et al. 2006) flowing through a highly variable aquifer system (Huntoon 2000; Fitzgerald 1996).

Grand Canyon NP currently has access to spatial data for 753 springs; of these, 104 (14%) have some level of associated survey data. Current information for these springs stands as a first step toward establishing needed datasets. For three of these springs (Cottonwood Spring, Pumphouse Spring, and Indian Garden Spring), data collection has been enough for researchers to identify statistically significant declines in discharge over time (Kobor 2004; Rihs et al. 2004). Discharge gauges at Cottonwood Spring collected continuous data between October 1994 and January 2003 and recorded declines in median quarterly discharge over that time (Figure 59). Similarly, discharge gauges at Pumphouse Spring collected continuous data between July 1995 and January 2003, and they recorded significant declines (Figure 60). However, gauges at Hermit Spring showed no change in discharge trend between October 1994 and January 2003 (Rihs et al. 2004). At Indian Garden Spring, discharge gauges collected continuous data between 1994 and 2001, and recorded a decline of 25% in winter base flow from the spring (Rihs et al. 2004). Furthermore, existing groundwater models suggest some level of spring flow decline resulting from groundwater withdrawal south of the canyon (Rice 2012).

Thirteen springs (≤ 2%) in the study area have some continuous monitoring data (Vasey's Paradise, Blue Spring, Angel Spring, Emmitt Spring, Roaring Spring, Modred Spring, Tapeats Spring, Wall Spring, Havasu Spring, Hermit Spring, Garden Spring, Pipe Spring, and Cottonwood Spring). Temperature has been measured continuously for all of these sites, while temperature, specific conductivity, and stage have been measured for six (0.8% of all springs in the analysis area). Researchers have attempted to document the seasonal behavior of these springs and to model their flow behavior (Adams 2005; Ross 2005; Brown 2011; Schindel 2015). For example, between April 2003 and October 2004, Adams (2005) measured flow rates ranging from 0.29 to 0.59 liters/minute at Cottonwood Spring and 1.59 to 4.59 L/min at Pumphouse Spring; some springs in the region flow at mere trickles whereas others supply water to millions of park visitors each year.

Park staff estimate that current data collection and analysis efforts will eventually allow them to begin assessing regional long-term patterns and trends but this is still a few years away (B. Tobin, personal communication, 2015). Active efforts to gather water quality and quantity information are underway, and the importance of springs to regional resources is well established.

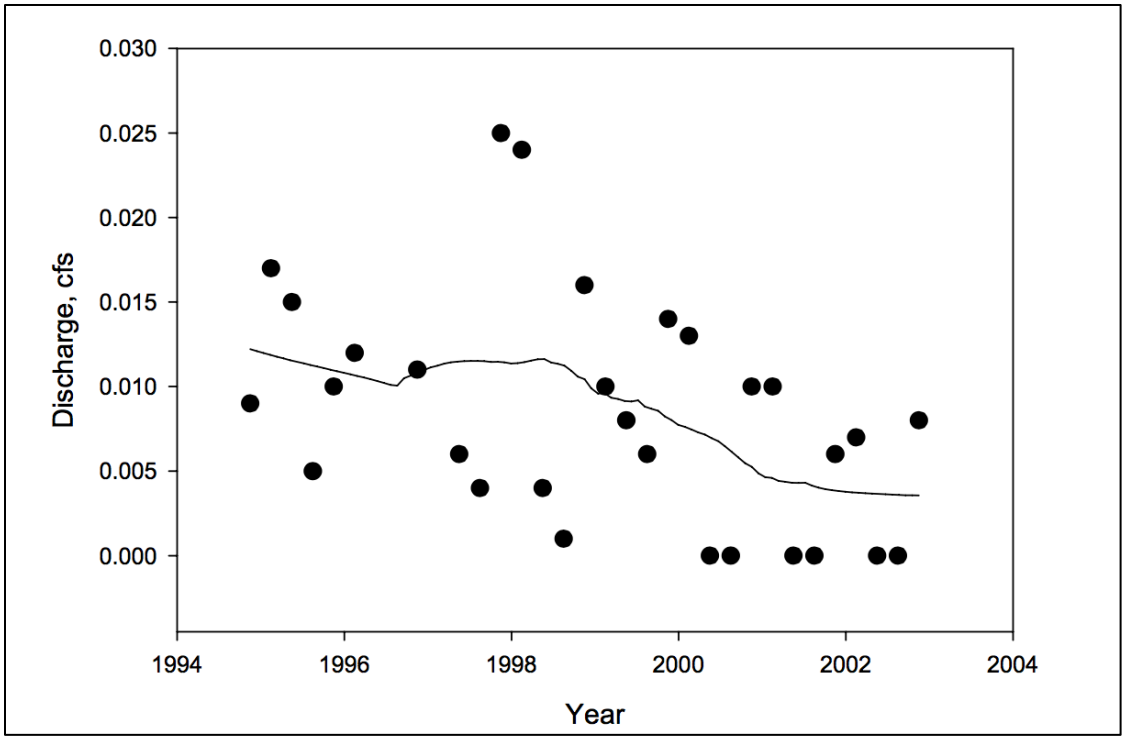


Figure 59. Median quarterly discharge at Cottonwood Creek with a locally weighted scatterplot smooth line (from Rihs et al. 2004).

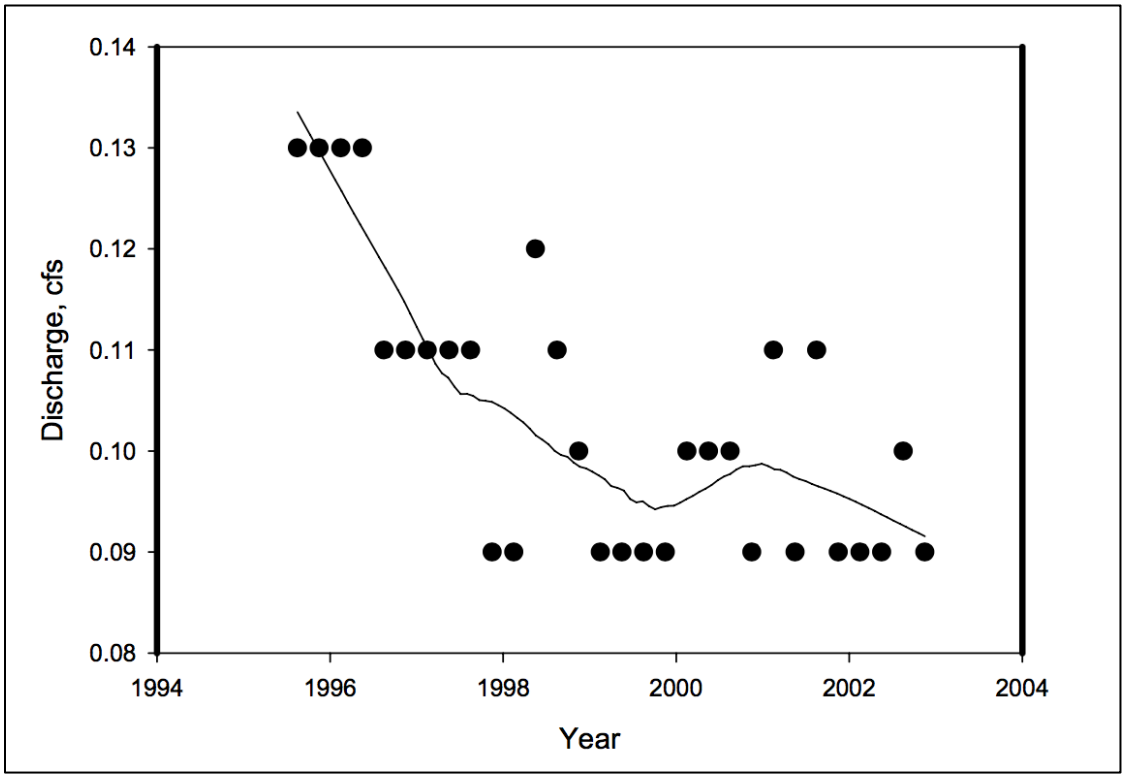


Figure 60. Median quarterly discharge at Pumphouse Creek with a locally weighted scatterplot smooth line (From Rihs et al. 2004).

The data in hand indicate declines in flows of Cottonwood, Pumphouse, and Indian Garden Springs, and known environmental changes in the region suggest that spring water quantity across the full analysis area is likely to be in decline; however, the implications for water quality are not clear. Regional population growth trends and climate projections indicate that a hotter, drier climate will result in increased groundwater withdrawal, likely reducing the quantity of water in springs (Rice 2012; USBOR 2012). Land use activities such as new Tusayan development and other residential and commercial developments, uranium mining, and increased recreation may impact spring water quality (Kacaroglu 1998), particularly since contaminant inputs are likely to be less diluted when flow rates are reduced.

We can expect several of the key stressors in the analysis area to affect seeps and springs (Table 49). Groundwater withdrawal will increase with increased regional development and has the potential to impact discharge rates. The human population in the region is expected to double between the years 2000 and 2050 (Rice 2012), leading to escalating water demand. Increased recreation and visitor use can elevate water pumping across the full analysis area and also locally influence water quality via increased contamination and sedimentation of springs located in heavy use areas (Grand Canyon National Park 2015). Indeed, *E. coli* contamination was observed in spring-fed creeks sampled in 1995–1996, evidently stemming from Phantom Ranch, Cottonwood, and Roaring Springs septic systems (Grand Canyon National Park 2015). Uranium extraction may lead to chemical or mineral contamination of springs located near active mines: elevated radionuclides have been found in Horn Creek Spring and other sites, likely resulting from past uranium mining (Rice 2012; Grand Canyon National Park 2015). Climate change is predicted to reduce snowpack and exacerbate drought conditions in the future (Rice 2012), again resulting in decreased groundwater recharge of springs and potentially reduced discharge.

5.22.5. Summary

Although various studies have collected data on springs in the study area, and many agencies have active springs inventory and monitoring programs, there is insufficient information to determine an overall condition for springs and seeps in the analysis area. Due to the karstic nature of many of the spring systems in the park and surrounding area, it is essential to not only understand what is occurring at the mouths of springs, but also to understand conditions, processes, and risks affecting source water areas and the aquifer itself, such as flow paths, potential contamination sources within the recharge area, and other factors (Ford and Williams 2007).

Due to the known biorichness and ethnographic importance of springs in the GGCLA region, data on water quality and quantity of springs in the analysis area is a current priority for the Springs Stewardship Institute (http://springstewardshipinstitute.org/) and for Grand Canyon NP, which has been working actively for several years to fill in current data gaps. As described above, a condition and trend assessment will be possible when this data collection has been extended across multiple time periods and spring types so that both baseline conditions and trend over time can be evaluated.

5.22.6. Data Needs

- Spring inventories should be conducted at each spring during both high and low flow conditions, with both conditions inventoried at least twice, preferably during a dry and a wet year. Data inventories must include water chemistry, field water quality parameters, flow, biological contaminants, flora, and fauna as described by Stevens et al. (2011).
- Water quality assessment requires continuous monitoring of temperature, specific conductance, and stage (with enough point discharge measurements to calculate flow). For karst aquifers, dye traces can be used to determine the extent of groundwater recharge areas associated with springs in the study area as well as to document quick flow processes.
- In addition to ongoing spring water quality and quantity data collection, it is often desirable to assess the overall availability of groundwater in these systems as a means of assessing impacts from climate change or human disturbance in the basin. For both karst and non-karst systems, a network of monitoring wells would allow assessment of changes in water level within the groundwater system at a regional scale (Fetter 2001). Monitoring wells would facilitate assessment of current aquifer levels, general aquifer properties (such as hydraulic conductivity), and changes over time, as well as providing a means to improve calibration of existing regional groundwater models. These models can then be used to assess potential changes related to future impacts.
- Biannual water sampling for biological contaminants will be needed to assess impacts related to aquifer contamination.

5.22.7. Level of Confidence

Because no springs have been thoroughly evaluated across multiple time periods and flow conditions, a quantitative condition assessment is not yet possible. Continued data collection on spring water quality and quantity, across a diversity of spring types and over multiple years, will allow an assessment of condition and trend. However, this vital spring/seep resource may be in decline due to multiple stressors.

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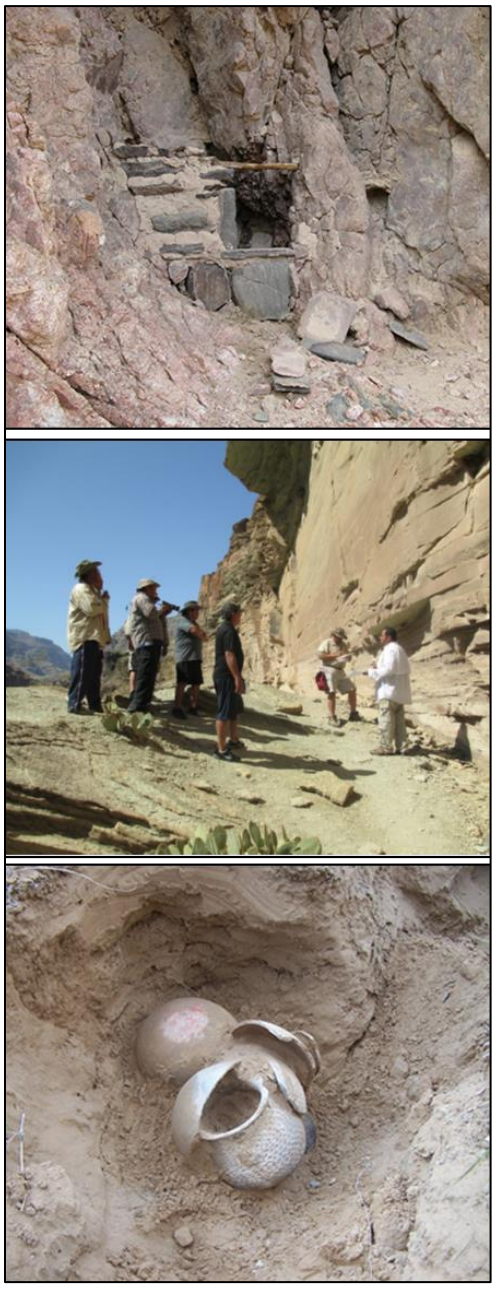
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5.23. Cultural Resources: Introduction

5.23.1. Description



Historic structures, archaeological sites, and artifacts like pottery are amongst the many cultural resources found in the greater Grand Canyon region. Images from Grand Canyon NP cultural resources program (NPS photos).

The Greater Grand Canyon Landscape Assessment (GGCLA) differs from other NRCAs in that it covers cultural as well as natural resources. For the purposes of this report, and at the suggestion of stakeholders in GGCLA Workshop 1 and in the Cultural Resources Technical Work Group, we divide the cultural resource category into archaeological and ethnographic resources.

Grand Canyon National Park, situated on the Colorado Plateau, has offered refuge and resources to people throughout 12,000 years of human use and occupation. Archaeologists generally divide the human history of Grand Canyon into six broad periods; Paleoindian, Archaic, Formative, Late Prehistoric, Protohistoric, and Historic. The physical manifestations of Grand Canyon's prolonged human history are represented in archaeological sites throughout the park and surrounding area. Archaeological sites are fragile, nonrenewable, and often irreplaceable objects, features, or structures that reflect past lifeways or the history of an individual or a group of individuals. Understanding human and non-human effects on archaeological sites is crucial to the resources' long-term preservation (Grand Canyon National Park Backcountry Management Plan Environmental Impact Statement draft 2014).

Today, the Grand Canyon remains significant for its ongoing role in the lives and traditions of American Indians. Those landscapes, objects, plants and animals, or sites and structures that are important to a people's sense of purpose or way of life are known as ethnographic resources. Access to the cultural resources of Grand Canyon is important to Traditionally Associated Tribes because of the special meanings these resources have for the histories of these groups. Traditional cultural places and ethnographic resources are closely linked with tribes' sense of purpose, existence as a community, and development as ethnically distinctive peoples (NPS 2006). In general, American Indian peoples want the greatest protection possible provided for the cultural resources they value that are outside their reservation boundaries.

Tribes associated with Grand Canyon view it as a Traditional Cultural Property (TCP) and believe that it deserves the highest level of protection allowable. A TCP is a property eligible for inclusion in the National Register of Historic Places "because of its association with the cultural practices or beliefs of a living community (Parker and King 1998)". TCPs connect modern communities with ancestral ones. Properties (archaeological sites, landscape areas and other ethnographic resource types) that are considered traditional cultural properties by the park's Traditionally Associated Tribes are treated as eligible for listing in the National Register of Historic Places by the park (Brennan, personal communication, September 2014).

It is the NPS's responsibility to identify and protect the cultural resources under its jurisdiction. NPS authority for cultural resource management derives from a number of laws and Executive Orders, including the NPS Organic Act of 1916, National Historic Preservation Act of 1966 (as amended) and the Archaeological Resources Protection Act of 1979 (see Appendix B of NPS-28 1998 for a complete list). Cultural resource protection laws are meant to ensure that federal land managers work to protect cultural resources on public land. The Secretary of the Interior's Standards and Guidelines for Archaeology and Historic Preservation provide guiding principles for archaeological and historic preservation activities and methods (see Appendix C of NPS-28). Management of cultural resources

by the NPS is guided by NPS-28: Cultural Resource Management Guidelines (NPS-28 1998) and National Park Service Management policies (NPS 2006) as well as the laws mentioned previously.

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5.24. Cultural Resources: Archaeological

5.24.1. Description



The high density of archeological sites across the greater Grand Canyon landscape represents 12,000 years of diverse cultures, including traditionally associated tribes of the Grand Canyon region. The current condition of these sites is assessed based on their individual characteristics, accessibility, and disturbance mechanisms. Sites within Grand Canyon NP are monitored by the park's cultural staff; information from adjoining agencies or tribal lands was not available for this assessment. Photo: Large room excavated at Furnas Flats (NPS photo).

According to the Grand Canyon Archaeological Sites Database, 5,187 archaeological sites have been documented in Grand Canyon NP, encompassing six commonly accepted periods of archaeological history: Paleoindian (~12,000–8,000 years ago), Archaic (~8,000–2,500 years ago), Formative (~2,500–700 years ago), Late Prehistoric (~700–470 years ago), Protohistoric (~470–115 years ago), and Historic (~165–55 years ago; Grand Canyon NP 2015). Monitoring data, including condition assessment and disturbance records, are available for 3,060 of the documented sites. The remaining 817 sites have not been fully recorded and no associated condition or disturbance data are available.

During the Paleoindian period, small groups of people are thought to have moved across very large areas, while primarily hunting megafauna. The Archaic period brought more consistent use of a wider range of game and plant foods, as people continued to adjust to a changing climate. The Formative period is marked by cultivation of crops and more permanent homes, such as pit houses, and it was during this time that multi-room structures known as pueblos appeared in the canyon. Ancestral Puebloan people cultivated foods to supplement their diet of wild foods and game, while a cultural group called by archaeologists the Cohonina concurrently inhabited settlements near the river, perhaps cultivating maize, and making pottery distinct from that of the Ancestral Puebloan people. During the Late Prehistoric period mobile hunters and gatherers came to the canyon, as

people from the west included the canyon in their seasonal movements and began to settle (Grand Canyon NP 2015).

The Protohistoric period, following the arrival of white settlers, was characterized by increasing conflict and resettlement of indigenous groups (Grand Canyon NP 2015). Some tribes experienced forced relocation onto reservations and out of the Grand Canyon, whereas others continued to use sections of the canyon and its surroundings for refuge and subsistence. Finally, the Historic period includes sites from American Indian and Euro American cultural groups, such as structures, mining and ranching remnants, and tourist facilities (Grand Canyon NP 2015).

Some sites within the analysis area contain evidence of use across more than one archaeological period, whereas others date to a single period. A number of the sites cannot be assigned to a specific period due to a lack of chronologically sensitive artifacts that correspond to particular dates. Each archaeological period produced site types with varying degrees of sensitivity to a multitude of stressors and threats, such as home sites with stone structures, storage sites containing stone granaries and their contents, wooden structures of all types (homes, ceremonial structures, fence lines, and fire lookouts), and artifact scatters of prehistoric or historic origins.

Stressors and Threats

Threats to archaeological sites are documented through repeat visits (recorded in the Archaeological Sites Database), physical inspection of the site area and site features, completion of tabular data sheets, and use of repeat photography. Sites are at risk from a number of disturbance mechanisms, including human and environmental processes. Common disturbances and threats include water runoff, wind erosion, artifact theft, vandalism, inappropriate waste disposal, rodent activities, bison impacts, fire, and the operation of Glen Canyon Dam. Some human disturbances are unintentional, stemming from day-to-day user disturbances such as foot traffic through sensitive areas and lack of awareness of what sites look like in order to avoid disturbing them. Vandalism, or intentional damage to archaeological features and objects, rarely occurs but has particularly serious consequences to preservation of site integrity (Grand Canyon NP 2015). Sites that are near or adjacent to heavily visited locations are at particular risk from human disturbances.

5.24.2. Indicators/Measures

- Site condition

5.24.3. Methods

Only about 6% of park lands have been inventoried for cultural resources (Grand Canyon NP 2015), although surveys for previously unknown archaeological sites are ongoing. We therefore do not know the total number of sites in the analysis area, but based on the known distribution of sites in the park, the number may be as high as 60,000 (National Park Service 2016). Sites managed by the park are listed, or are eligible for listing, on the National Register of Historic Places. Such sites are significant under one or more of the National Register significance criteria according to their retention of one or more of the seven elements of integrity: location, setting, association, materials, workmanship, design, and feeling. Sites are monitored to determine whether these elements of

integrity are being diminished and what treatments are necessary to slow or halt the disturbances to preserve site eligibility.

Archaeological sites along the river have been monitored for many decades. Elsewhere, limited archaeological site inventories began before the 1960s and have continued into the present, providing the documentation currently used for assessment of archaeological resource condition, which is a metric of site stability (National Park Service 2016). Condition monitoring follows standard protocols to enable tracking of change over time (Dierker 2011). Condition is categorized according to guidelines established for the Archaeological Sites Management Information System, or ASMIS, developed by the National Park Service as a monitoring standard for all park service areas. These standards have been slightly revised by the Grand Canyon cultural resource staff to further reflect the seven elements of integrity. The condition values are described as follows:

- Good: No noticeable deterioration by natural forces or human activities. Present archaeological values and integrity are not threatened. The aspects of integrity that make the site significant have not been diminished.
- Fair: Evidence of deterioration by natural forces or human activities. The aspects of integrity that make the site significant are being diminished. Without the appropriate corrective treatment, the site will degrade to a poor condition and the site's National Register eligibility may be threatened.
- Poor: Evidence of severe deterioration by natural forces or human activities. Site integrity is diminished.

At present, 55% of documented sites are considered in good condition, 13% are considered in fair condition, 3% are considered in poor condition, and the rest (1,310 sites) are unevaluated (National Park Service 2016). Site condition can change between monitoring events because of disturbances from human or environmental factors or because management actions such as erosion control have halted or reversed site degradation. Site condition was averaged by HUC 10 within Grand Canyon NP, using the most recent site condition score (Figure 61). While site condition varies by watershed, this may be due to unequal numbers of known sites across the analysis area. For example, western Grand Canyon indicates a higher percentage of sites in good condition, however, a smaller number of sites are known in that area compared to eastern Grand Canyon.

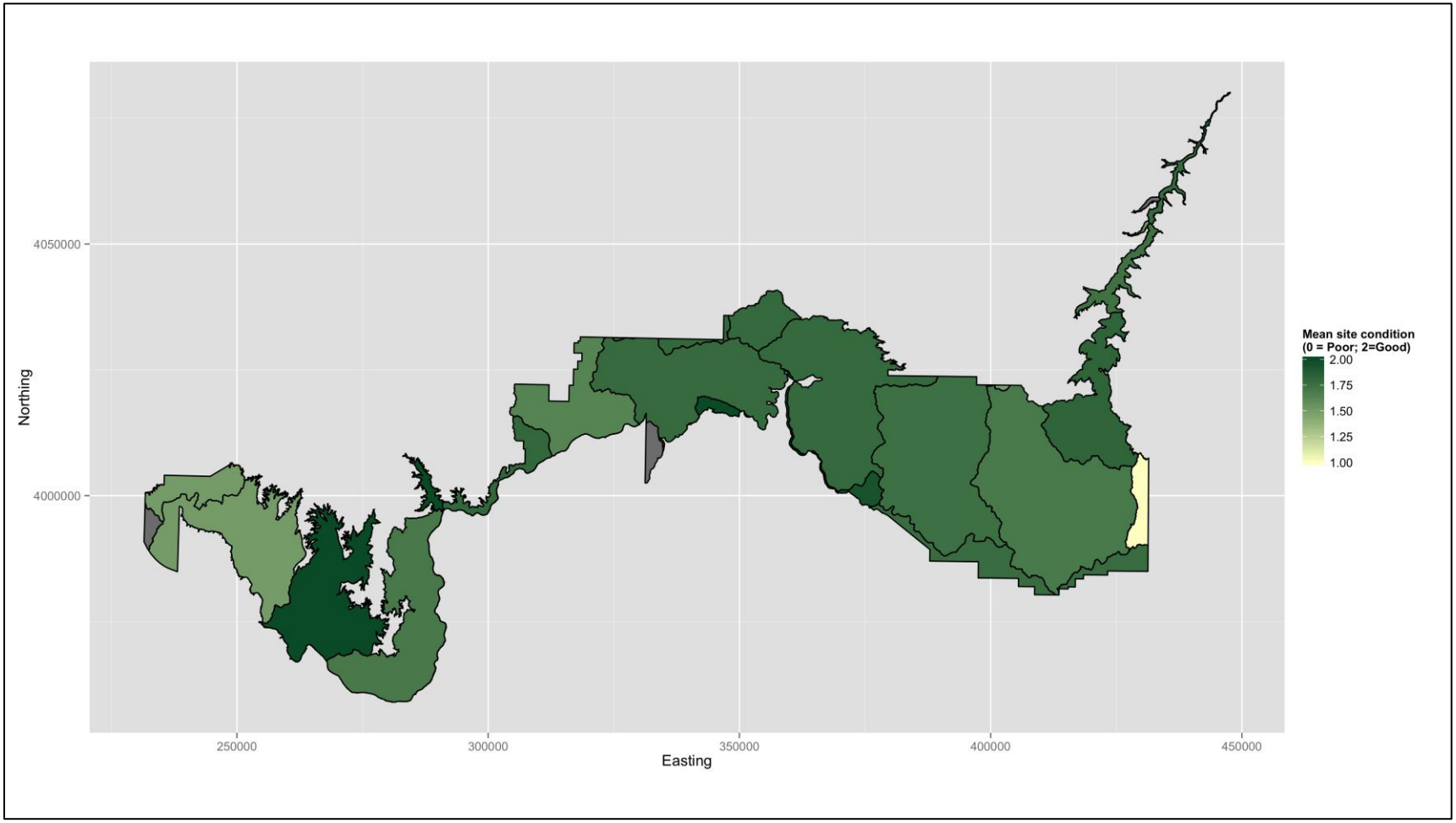


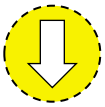
Figure 61. The average condition of archaeological sites in each HUC 10 within the park. The most recent site condition score was used for sites that were visited more than once. Site condition ranged from good to poor, with light colors indicating poor site condition and dark indicating good site condition. Gray areas indicate no sites or sites with no data.

In addition to site inventories and condition monitoring, a monitoring effort to specifically document impacts of bison on archaeological sites was undertaken in 2014. Of the 24 sites visited, thirteen showed evidence of bison presence including trampling, trails, waste, and wallow formation (National Park Service 2015). Two other sites showed adverse effects due to bison activity. At these sites, artifacts were displaced and concealed as a result of wallows within the site boundaries (National Park Service 2015).

An assessment of the overall trend in site condition is challenging for several reasons. Due to limited resources, only a small percentage of sites can be visited frequently enough to enable observation of change over time. Also, data collection by multiple individuals has sometimes led to different interpretations of condition categories, although current protocols and training procedures should help reduce such observer errors. This evaluation of trend is therefore based on our understanding of current conditions combined with consideration of stressors across the greater Grand Canyon landscape and their likely impact on archaeological resources.

5.24.4. Condition and Trend

Table 50. Summary of archaeological resources condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Site condition	National Park Service Archaeological Sites Management Information System (ASMIS)		Most surveyed sites are in good condition, but many sites are unsurveyed, records beyond the boundaries of the park (and probably site protections) are lacking, and some sites are considered to be in fair or poor condition. Some sites contain irreplaceable cultural and historical value; good condition (stable and intact in situ) is the desired state for all sites.

5.24.5. Summary

Threats to archaeological sites in the analysis area include human user impacts (leading to both intentional and non-intentional damage) and environmental processes such as erosion, animal burrowing, bison trampling, and vegetation encroachment (National Park Service 2015, National Park Service 2016). Threatened sites are important to historical and scientific research, but also have intangible and unquantifiable cultural importance for the Grand Canyon's traditionally associated tribes, which acknowledge the canyon's rim lands, inner canyon, and river corridor as an ancestral Traditional Cultural Property (TCP; National Park Service 2016). Among the archaeological resources currently documented within the park, 161 sites are expressly identified as important to one or more of these tribes; many more are likely important but such information has not been released by the tribes. Sites may be considered sacred, traditional, and crucial to cultural identity for one or

more living cultures. Tribal members visit these sites and monitor their condition (Grand Canyon NP 2016). Management practices for identified sites are intended to acknowledge and safeguard tribal as well as scientific values.

Monitoring and treatment currently takes place for only a fraction of the archaeological sites present across the greater Grand Canyon landscape. As human activity and user disturbances increase in the canyon over future decades, continued monitoring and protection of archaeological sites will be a critical need.

5.24.6. Data Needs

- Repeated condition assessments of documented sites are necessary for trend analysis.
- Cross referencing of existing data sources to align assessments and interpretations should continue for evaluation of trend data.
- Baseline condition assessments are needed for more than a quarter of documented sites.

5.24.7. Level of Confidence

Most documented archaeological sites within Grand Canyon NP have been visited and their condition has been assessed following standardized protocols; current condition information for these sites therefore has high confidence. Site conditions beyond the park's boundaries are currently unknown, leading to low confidence in current information. Spatial distribution of site condition has a lower confidence because variation in total known and surveyed sites per watershed means the condition of an individual site influences the averaged HUC site condition by different weights depending on watershed.

5.24.8. Sources of Expertise

This section was prepared by Ellen Brennan and Jennifer Dierker of Grand Canyon NP, with assistance from Clare Aslan and Jean Palumbo. Luke Zachmann of Conservation Science Partners conducted analysis and mapping.

5.24.9. Literature Cited

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5.25. Cultural Resources: Ethnographic

5.25.1. Description



The Grand Canyon region has witnessed more than 12,000 years of human use and occupation. The great significance of the region's cultural heritage lies in the richness and diversity of the people that adapted to the harshness of the climate and landscape, and for whom the land and its natural resources are sacred and imbued with spiritual meaning. Eleven American Indian tribes retain important connections to the Grand Canyon area, with some considering the canyon their original homeland and place of origin. Although the entire Grand Canyon region and all of the resources it contains are considered ethnographic resources and are important to the tribes, only a small portion of the park has been inventoried for ethnographic resources, mainly along the river corridor (NPS Photo).

Ethnographic resources are a category of cultural resources recognized by the National Park Service because they are important to peoples traditionally associated with lands that have been incorporated into federal land areas. They include objects, places, sites, structures, landscapes, and natural resources that have traditional cultural meaning and value for the groups that are associated with them (NPS 2002). To American Indian tribes traditionally associated with national park areas and other federal lands, ethnographic resources are one way to pass on cultural beliefs, traditions, and history to future generations. Ethnographic resources have important historical attributes for traditionally associated peoples, but may not be directly associated with the reason that a park was established, and may not be appropriate for interpretation for the general public due to cultural sensitivities.

The NPS recognizes that American Indians view the environment without borders, holistically. It is the entire Grand Canyon region that is important to traditionally associated tribes. Therefore, it is important to look at the full range of resources and concerns, irrespective of boundaries. The park's Ethnographic Resource Inventory database documents 532 resources, which include archaeological

sites, natural resources, specific places, and larger landscapes encompassing physical features. It is important to note that documented resources represent only a small portion of the ethnographic resources important to the canyon's traditionally associated tribes. The total number of such resources is likely to never be known due to the sensitivity of such information.

5.25.2. Indicators/Measures

- Traditional Cultural Properties
- Ethnographic resources
- Cultural landscapes

5.25.3. Methods

The GGCLA Technical Work Group identified cultural landscapes as an indicator for the health of ethnographic resources in the Grand Canyon region. The group also selected historic trails and social gathering places; hunting and subsistence gathering places; and unobstructed views of geological features with cultural significance as indicators for ethnographic resources. Additional cultural resources later added to the list include the Colorado River and mineral resource extraction places, shrines, sacred places, and offering sites. Since these categories encompassed Traditional Cultural Properties included in Grand Canyon NP's Ethnographic Resources Inventory (ERI) database, and since the park has identified desired conditions and management targets for those TCPs (Grand Canyon NP 2014a), it was decided that TCPs would serve as the single indicator to cover those others listed here.

Traditional Cultural Properties/Ethnographic Resources

A Traditional Cultural Property (TCP) is eligible for inclusion in the National Register of Historic Places because of its association with the traditional cultural practices of a living community that are rooted in that community's history and are important in maintaining the continuing cultural identity of the community. Traditions are the beliefs, customs, and practices of a living community of people that have been passed down through the generations, usually orally or through practice (Parker and King 1998).

Examples of TCPs in the Grand Canyon region include locations associated with (1) the beliefs of traditionally associated Indian groups about their origins; (2) a location where American Indian religious practitioners have historically gone and are known or thought to go today, to perform ceremonial activities in accordance with traditional cultural rules of practice; (3) a location where a community has traditionally carried out economic, artistic, or other cultural practices important in maintaining its historic identity; or (4) trails that were used to travel, for example, to resource collection locations, to social interactions with other tribes, for trade, and for religious pilgrimages and ceremonies.

Data Sets Used To Evaluate Indicators of Ethnographic Resources

We evaluated the indicators that were selected by the park for the 2014 Backcountry Management Plan (Grand Canyon NP 2014b). Information on ethnographic resources in Grand Canyon NP was obtained from the park's Ethnographic Resource Inventory (ERI) and Archaeology databases, as well

as the ethnographic resources report compiled by Hedquist and Ferguson (2012) for the park's Backcountry Management Planning process that is currently underway.

Reference Conditions and Values for Indicators

The condition of indicators of ethnographic resources was obtained from the Desired Conditions report developed for the 2014 Backcountry Management Plan and by park staff, after park and tribal representatives conducted field examinations of specific locations, noting threat and disturbance mechanisms, severity of disturbance, disturbance to National Register elements of integrity, and treatment recommendations to reduce disturbance effects. Monitoring of ethnographic resources follows established protocols for park and tribal monitors. Tribal groups also work in the canyon to monitor important cultural and natural resources in conjunction with the Glen Canyon Dam Adaptive Management Program.

5.25.4. Condition and trend

The condition of indicators of ethnographic resources summarized in Table 51 is based on evaluations conducted by Grand Canyon NP staff (Grand Canyon NP 2014a).

Table 51. Summary of ethnographic resource condition and trend by indicator.

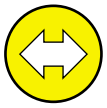
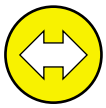
Indicator	Reference framework	Relative condition	Summary comments
Cultural landscapes	Documented landscape areas are maintained at current levels or are improved. Cultural and natural values are preserved. Character-defining features are preserved. Aspects of integrity (for NR) are preserved. The percentage of landscapes in good condition (as reported in PMDS) is stable or reflects an increase in the number of locations in good condition.		Four of 16 cultural landscapes identified are in good condition, 3 are in fair condition, and 9 have not been evaluated. Most if not all of these landscapes are related to Euro-American development.

Table 51 (continued). Summary of ethnographic resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Traditional Cultural Properties (TCPs); Ethnographic resources	TCPs are preserved for their cultural importance and protected from impacts. The current conditions of TCPs and ethnographic resources are maintained at current levels or are improved. TCPs and ethnographic resources are preserved in situ whenever possible. Constructed trails are not present at TCP's or sacred sites except at well-known and open locations. Social trails are not present except where traditional uses continue (Hopi Salt Mine). Other visitor-related impacts are not present (graffiti, fire rings, evidence of camping, trash, and waste). Archaeological and architectural elements show limited evidence of visitor disturbances. Important natural resources (plant, mineral) are conserved and restored as appropriate to the mission of the National Park Service and to sustain traditional cultural practices. Access to sacred sites and opportunities for quiet, solitude, and privacy exists.		All of these are documented in the Grand Canyon ethnographic database.

Cultural Landscapes

Sixteen cultural landscape areas have been identified as of September 2011. Most, if not all, are associated with EuroAmerican development and do not appear to be associated with American Indian cultural resources. Of these, four are considered in good condition, three are considered in fair condition, and nine have not been evaluated. Good condition is defined as showing "no clear evidence of major negative disturbance or deterioration by natural and/or human forces. The inventory unit's cultural and natural values are as well preserved as can be expected under the given environmental conditions." Fair condition is defined as showing "clear evidence of minor disturbances and deterioration by natural and/or human forces, and some degree of corrective action is needed within 3–5 years to prevent further harm to its cultural or natural values. If left to continue without the appropriate corrective action, the cumulative effect of the deterioration of many of the landscape features will cause the inventory unit to degrade to a poor condition" (Page et al. 2009).

Traditional Cultural Properties/Ethnographic Resources.
Identification and documentation of TCPs is ongoing in Grand Canyon NP. Each project is addressed in consultation with the traditionally associated tribes. As of June 2013, the following ethnographic resources had been documented in the park's ERI database: 25 landscapes, 367 natural resources, 68 places, including archaeological sites and specific places on the landscape, and 7 miscellaneous items.

Monitoring Of Ethnographic Resources in the Canyon by Traditionally Associated Tribes.
Five tribal entities conduct monitoring programs in the Colorado River corridor in conjunction with the Glen Canyon Dam Adaptive Management Project—the Hopi Tribe, the Hualapai Tribe, the Navajo Nation, the Southern Paiute Consortium, and the Zuni Pueblo. Each entity monitors the plants, animals, and ethnographic or archaeological sites that are important to the tribe. There is substantial overlap in the resources that are important to each tribe. Monitoring methods are varied. Some use qualitative judgments of tribal members gathered through questionnaires. Some include vegetation sampling along transects resulting in measurable data. Some are a combination of both. These monitoring results were not incorporated into this resource condition assessment.

Gaps in Ethnographic Resource Knowledge
Inventory of ethnographic resources has been conducted in only a small portion of the park, mainly the river corridor. This results in a substantial data gap in our knowledge about ethnographic resources. The park's efforts to document ethnographic resources in other areas of the park is ongoing.

Stressors to Ethnographic Resources in Grand Canyon NP
The park has identified two major categories of disturbances and stressors to archaeological and ethnographic resources: human and non-human. These categories are further broken down into specific disturbances such as trailing (human), and flooding (non-human). Park archaeologists have identified water erosion as the most frequent disturbance to sites and sites areas, followed by visitor disturbances of various sorts. The traditionally associated tribes see human impacts, including the displacement, removal, or destruction of artifacts and the inappropriate visitation to sensitive areas, as having the greatest effects on ethnographic resources. Wind and water erosion are deemed secondary. Other stressors on ethnographic resources include park projects, ecosystem-wide changes in vegetation resulting from climate change, and the operation of Glen Canyon Dam.

5.25.5. Summary
Representative ethnographic sites and resources along the Colorado River corridor are well covered by park and tribal monitoring programs. However, moving away from the river corridor, there is a paucity of data about the exact nature of ethnographic resources present. The park will continue to work with the tribes to identify and document traditional cultural properties located off the river corridor through the Backcountry Management Plan.

5.25.6. Data Needs
More data are needed to define site conditions according to tribal perspectives and recommendations. Results of natural resource condition assessments of plants and animals that are important to tribes

should be included in ethnographic resource condition assessments. Other types of stressors identified by tribal entities should also be included. For example, the tribes that participate in the Glen Canyon Dam Adaptive Management Program include activities that conflict with tribal values as a category of human impacts that adversely affect ethnographic resources, such as when non-tribal members visit or leave offerings at tribal sacred sites. Park staff will continue to work with the tribes to address these needs through the Backcountry Management Plan. However, it is important to acknowledge that we will never know all there is to know about ethnographic resources due to their sensitivity (E. Brennan, personal communication, 2015).

5.25.7. Level of Confidence

The level of confidence for the condition findings for cultural landscapes and ethnographic resources that the park monitors and for the sites that the tribes monitor is high. However, these findings are more qualitative rather than quantitative.

5.25.8. Sources of Expertise

This section was prepared by Jean Palumbo with assistance from the following Grand Canyon NP staff: Ellen Brennan, Cultural Resource Program Manager; Janet Cohen, Tribal Program Manager; and Jennifer Dierker, Archaeologist. The draft of this section was reviewed by Timothy Begay, Navajo Nation Historic Preservation Department; Charley Bulletts, Director of Cultural Resources for the Kaibab Band of Paiute Indians; Peter Bungart, Senior Archaeologist for the Hualapai Tribe; Leigh Kuwanwisiwma, Director, and Terry Morgart, Cultural Preservation Office, the Hopi Tribe.

5.25.9. Literature Cited

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5.26. Visitor Experience: Daytime Viewshed

5.26.1. Description



When Grand Canyon National Park was developed, the canyon became largely protected from new below-the-rim development. As a result, visitors can access unspoiled canyon vistas from observation points along both rims. Observation points allow particularly extensive vistas of the eastern portion of the canyon. Historical structures predating the park's development are in most cases designed to blend in to the canyon landscape (e.g., the Desert View Tower). Stressors to the viewshed include increasing air pollution and developments within the analysis area and outside the park boundary. Photo: View of Kwagunt Butte, Malgosa Crest, and Nankoweap Mesa in Grand Canyon NP (NPS photo).

The Grand Canyon is visually stunning, combining starkly contrasting rock bands with multicolored vegetation transitions. The viewshed, or the opportunity to see uninterrupted, natural vistas of the canyon's interior, is a primary attraction for visitors and a primary value for regional stakeholders. A current stressor to the daytime viewshed within Grand Canyon NP is poor air quality, which impedes visibility. Outside the park, economic development, windfarms, and the possible opening of uranium mines could fragment stretches of forest that are currently intact and could impact the natural viewshed at locations within the analysis area.

5.26.2. Indicators/Measures

- Unimpeded, undisturbed viewsheds and lines of site from key lookouts

5.26.3. Methods

The analysis used here is based on topography—physical characteristics not subject to rapid change. There is therefore a high level of confidence regarding the physical viewshed.

This ArcGIS viewshed analysis used topographic layers to determine how much of the surrounding landscape can be seen from a particular observation point. Darker shading in Figure 62 indicates watersheds where particularly high proportions of the canyon can be seen from multiple observation points. A lack of below-the-rim development helps to maintain natural and unbroken views within the canyon. Air quality concerns may impact this resource in the future. Outside the canyon itself, proposed development and mining could mar views in a number of locations, particularly near the proposed Escalade development at the confluence of the Little Colorado and Colorado Rivers.

The current viewshed allows remarkable vistas of the interior of the canyon, particularly in the eastern portion of the analysis area. Watersheds with particularly high viewshed significance (that is, between 8.87% and 16.4% of the total watershed is visible from rim observation points) include Bright Angel Creek–Colorado River and Sheep Wash–Little Colorado River. However, poor air quality reduces visibility, and factors such as wildfires and vehicular traffic, both of which are increasing in frequency over time, can contribute to poor air quality. Current and proposed developments just outside the park boundary can also affect the viewshed by obscuring natural landscapes with artificial structures.

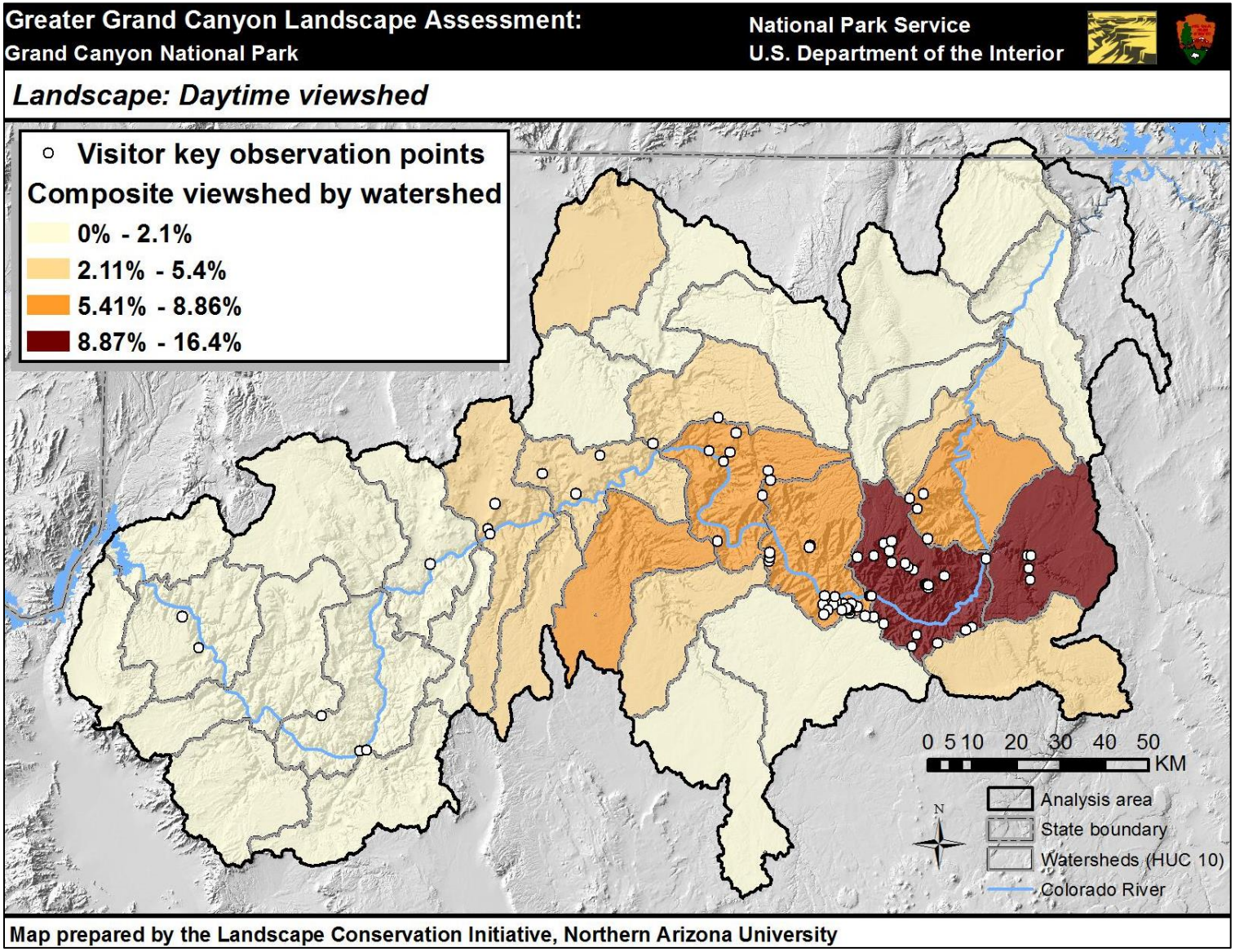


Figure 62. Topographic layers were used to determine how much of the surrounding landscape can be seen from a particular observation point.

5.26.4. Condition and Trend

Table 52. Summary of viewshed condition and trend by indicator.

Indicator	Reference condition	Relative condition	Summary comments
Unimpeded, undisturbed viewsheds and lines of site from key lookout points	Historic viewshed with pristine air quality		Diminishing air quality and proposed development may reduce the viewshed over time

5.26.5. Summary

Although the viewshed overall has changed little over the years, there are factors that could alter this in the future. The straight-line rim-to-rim distance is far enough that poor air quality can hinder views of the far rim. Poor visibility can result from wildfire smoke and air pollution haze resulting from mining and distant sources, such as industry and vehicular traffic. Monitoring of pollutants has detected increases in ozone within the park since 1990 and slight decreases in the deposition of sulfur pollutants. Nitrogen pollutants have remained stable (National Parks Conservation Association 2010).

Major sources of air pollutants can be distant and may include metropolitan areas in surrounding states, and even Mexico. Indeed, southwesterly winds bringing haze from southern California are responsible for the worst air quality days in the Grand Canyon (Davis and Gay 1993). Nearby coal-fired power plants, such as the Navajo Generating Station and Four Corners Power Plant, may also play a role. Additional power plants that have been proposed in the region could affect air quality in the future (National Parks Conservation Association 2010). The closure of the Mojave Generating Station in 2005 resulted in a decrease in fine sulfates but no increase in visibility, contrary to expectations (Terhorst and Berkman 2010).

Fires, including controlled burns, can also affect air quality and should therefore be managed with care and with consideration for visibility (National Parks Conservation Association 2010).

In addition to these air quality concerns, current and proposed developments outside the park boundary could affect the natural viewshed by obscuring natural landscapes beneath and behind artificial structures. The most notable of these is the proposed Escalade development, which would create tourist infrastructure at the confluence of the Colorado and Little Colorado Rivers.

5.26.6. Data Needs

Future viewshed could be impacted by air pollutants stemming from drought and wildfire. A better understanding is needed of likely future drought and fire patterns and frequency and how they affect the greater Grand Canyon landscape.

5.26.7. Level of Confidence

The spatial layers and ArcGIS analysis techniques have a high level of confidence. Confidence in future trends are low given uncertainty about future development.

5.26.8. Sources of Expertise

This section was prepared by Clare Aslan. Analysis was performed by Jill Rundall.

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5.27. Visitor Experience: Natural Acoustic Environment

5.27.1. Description



A natural acoustic environment is fundamental to the overall visitor experience in Grand Canyon NP and the surrounding region, as well as important to overall ecosystem health. The difference in recorded noise levels between existing and natural sound sources is an indicator of the influence of humans on the natural acoustic environment. Particularly high departures from natural conditions in the analysis area occur on private and state trust lands (NPS Photo).

Natural sounds are an important part of the natural landscape protected by national parks, and have been identified by the public as a key component of the national park visitor experience (McDonald et al. 1995; Haas and Wakefield 1998). However, anthropogenic noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

Sound plays a critical role in intraspecies communication, courtship and mating, predation and predator avoidance, and effective use of habitat. Wildlife can suffer adverse behavioral and physiological changes from intrusive anthropogenic sounds. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, and separation of mothers and young (Selye 1956; Clough 1982; USDA 1992; Anderssen et al. 1993; NPS 1994).

NPS Management Policies (§ 4.9) require the NPS to preserve the park's natural acoustic environment and restore the degraded acoustic environment to the natural condition wherever possible. Additionally, NPS is required to prevent or minimize degradation of the natural acoustic environment from noise. The physical sound sources (wildlife, waterfalls, wind, rain, and cultural or

historical sounds), regardless of their audibility, are referred to as the natural acoustic environment of a particular location. Managers can create objectives for safeguarding both the acoustic environment and the visitor experience. Across the greater Grand Canyon landscape, noise sources that impact the acoustic environment include airplane overflights of the canyon (see Stressors: Overflights), vehicles and NPS buses along the rim, and voices and motors from large numbers of river rafters throughout the river corridor.

5.27.2. Indicators/Measures

- Difference between existing and natural ambient sound levels

5.27.3. Methods

The intensity, duration, and distribution of sound sources can be assessed by collecting sound pressure level (SPL) measurements, digital audio recordings, and meteorological data in assessment areas. The natural ambient sound level–the acoustical condition that exists in the absence of human-caused noise—represents the reference level against which the NPS measures any impacts to the acoustic environment. The existing ambient sound level refers to the current sound intensity of an area, including both natural and human-caused sounds.

Assessment of the natural acoustic environment must include the effects of noise on human health and physiology, the effects of noise on wildlife, and the effects of noise on the quality of the visitor experience. Known human responses to measured sound levels can assist interpretation of quantitative noise metrics—for context, studies suggest that sound events as low as 35 dBA (where dBA = A-weighted decibels) can affect human blood pressure in sleeping individuals (Haralabidis et al. 2008). The World Health Organization recommends that noise levels inside bedrooms remain below 45 dBA (Berglund et al. 1999). Noise levels exceeding 35–45 dBA could therefore impact visitors camping in or near the assessment area.

The EPA identifies 52 dBA as the threshold beyond which noises interfere with audiences listening to a speech in a raised voice at 10 meters (EPA 1974); this is relevant to the effects of ambient noise on interpretive programs in parks. Finally, noises exceeding 60 dBA can impact normal voice communications at a distance of 1 meter (EPA 1974), and would therefore impact communications between hikers and visitors viewing scenic vistas in the park.

Sound pressure level predictions for Grand Canyon NP were drawn from a national dataset of sound measurements in national parks, supplied by the National Park Service (http://www.nature.nps.gov/sound/mapfaq.cfm). Quantities in the dataset indicate the L_{50} sound pressure level, expressed as dBA re. 20µPa (where re. 20µPa = decibel levels at normal atmospheric pressure), at various measurement points. The L_{50} level for each point is the decibel level exceeded half of the time at that location. This metric represents the median predicted sound level at a given point in the study area. Acoustic measurements were collected empirically by the National Park Service and combined with explanatory geospatial data. Predictions represent a typical daytime hour during the summer with calm weather conditions.

Additional Grand Canyon NP sound data were collected from 2005 to 2009 for the purpose of a baseline natural ambient calculation. Sites were chosen based on air tour routes, management zones, and other points of interest. These data provide an ambient starting point against which deviation from natural acoustic conditions can be evaluated. The majority of the sites recorded data for 30 days, with a few sites collecting data for the entire summer and winter season. Sound monitoring units were moved from site to site during this data collection period. Based on these methods, baseline ambient sound (L_{50}) results for a variety of sites are presented in Table 53. Particularly high ambient sound levels are found in sites such as parking lots and near river rapids.

Table 53. Baseline ambient sound (L_{50}) results for sites in Grand Canyon NP.

Description	Day Ambient (dBA) L50
Hermit Rd off of road, 1 mile from gate	17.9
Tuweep warm desert scrub	19.2
Fossil Canyon GA corridor	19.9
Tuweep cold desert scrub	21.3
Papago Canyon	21.8
Bright Angel Trail, 3.7 Mile	23.7
Ponderosa pine replicate (Swamp Ridge)	25.5
Cape Royal	27.3
Zuni air tour corridor	27.8
Tuweep Campground	28.3
Old Cape Solitude Trail	28.3
Point Imperial	31.4
South Rim	31.5
Yaki Point	31.8
South Kaibab Trailhead	35.4
NR Campground	35.9
Tusayan Ruins and Museum	35.9
SR, residential area (NPS)	36.7
NPS Admin, maintenance, residence area	36.9
Hermit's Rest Trailhead parking	36.9
NR entrance road	37.3
Schist Camp, river left, RM 96, no rapids	40
Mather Campground	41.3
East Rim Road, Mile 251	41.3
North Kaibab Trailhead	42.7

Table 53 (continued). Baseline ambient sound (L_{50}) results for sites in Grand Canyon NP.

Description	Day Ambient (dBA) L50
NPS Maintenance, helo, bus	43.8
NR VC parking lot	47
Desert View parking lot	47.3
South entrance road	51.7
Mather Point parking lot	52.3
Village Loop Rd, west end	56.6
Matkatamiba rapids, river right, class 2, RM 148	63.3
Kanab rapids, river right, class 3, RM 144	63.75
Forster rapids, river left, class 6 RM 123	65.175
122-Mile rapids, river left at high water, class 5, RM 122	67.95
Waltenburg rapids, river right at river's edge, class 7, RM 112	68.275
205-Mile rapids, river left, class 7	68.6375
Crystal rapids near river's edge, river right, class 10, RM 98	70.1
Upset rapids, river right, class 8, RM 150	70.95
Lava Falls, class 10, RM 179	71.075
Hermit rapids, river left, class 9, RM 95	73.55
Granite rapids at river’s edge, river left, class 9, RM 93	77

5.27.4. Condition and Trend

Table 54. Summary of the condition and trend by indicator of the natural acoustic environment.

Indicator	Reference framework	Relative condition	Summary comments
Difference between natural ambient and existing ambient sound levels	Natural ambient sound levels provide a baseline for this resource.		The difference between natural and existing sound levels is particularly prominent in private and state lands south of the park, as well as in isolated pockets on tribal lands. As visitation to the region continues to increase, the number of people and amount of traffic may continue to increase the difference between natural and existing sound level across the analysis area. Overflights also impact natural sound levels, discussed in this report as a separate stressor.

Particularly pronounced differences between natural and existing sound levels have been measured on state, private, and tribal lands (particularly in HUC 10 watersheds Upper Havasu Creek, Heather Wash, Diamond Creek, and Burnt Spring Canyon–Colorado River; see Figures 63, 64, and 65). By jurisdiction, differences between natural and existing sound levels are greatest on private lands (mean difference = 3.07 dBA) and state lands (mean difference = 2.98 dBA), followed by tribal (mean difference = 2.8 dBA), NPS (mean difference = 2.18 dBA), BLM (mean difference = 1.83 dBA), and USFS (mean difference = 0.97 dBA) lands. The low difference observed on USFS lands may be at least partially attributable to the high natural sound levels on USFS lands in the northern portion of the analysis area, where the sound of wind in ponderosa pine forests yields a high average natural sound level.

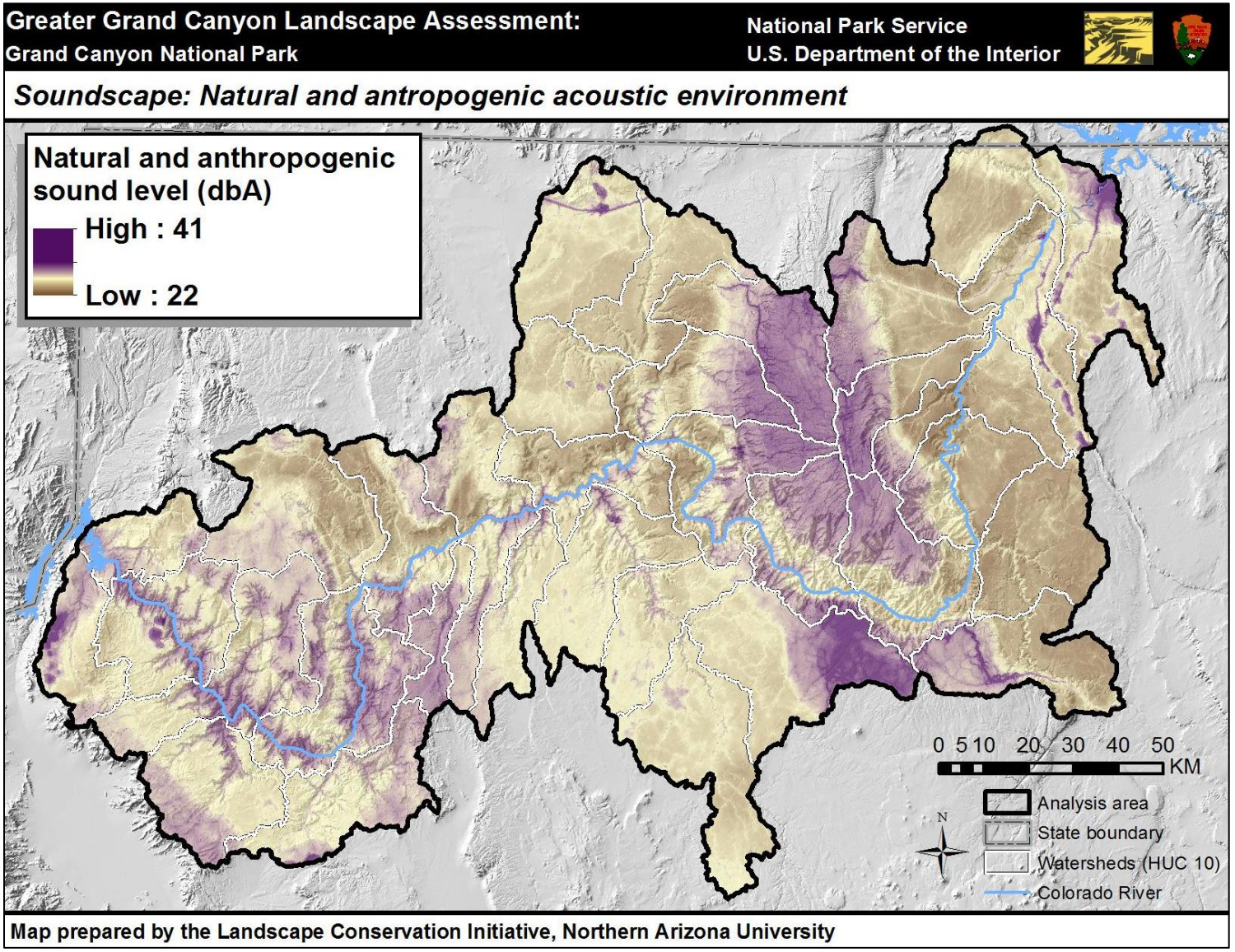


Figure 63. Natural and anthropogenic sound levels across the greater Grand Canyon landscape (does not include overflights).

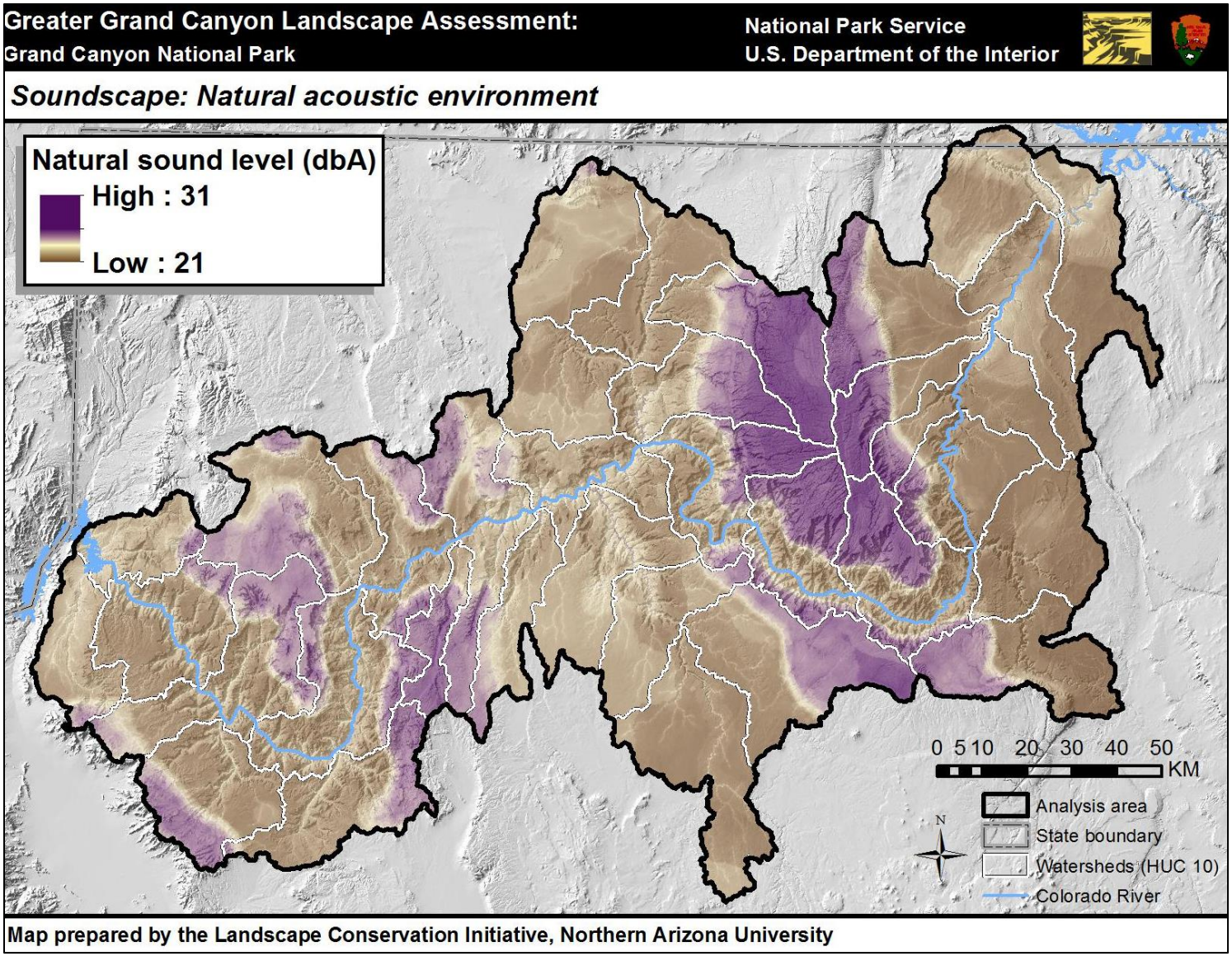


Figure 64. Natural sound levels across the greater Grand Canyon landscape.

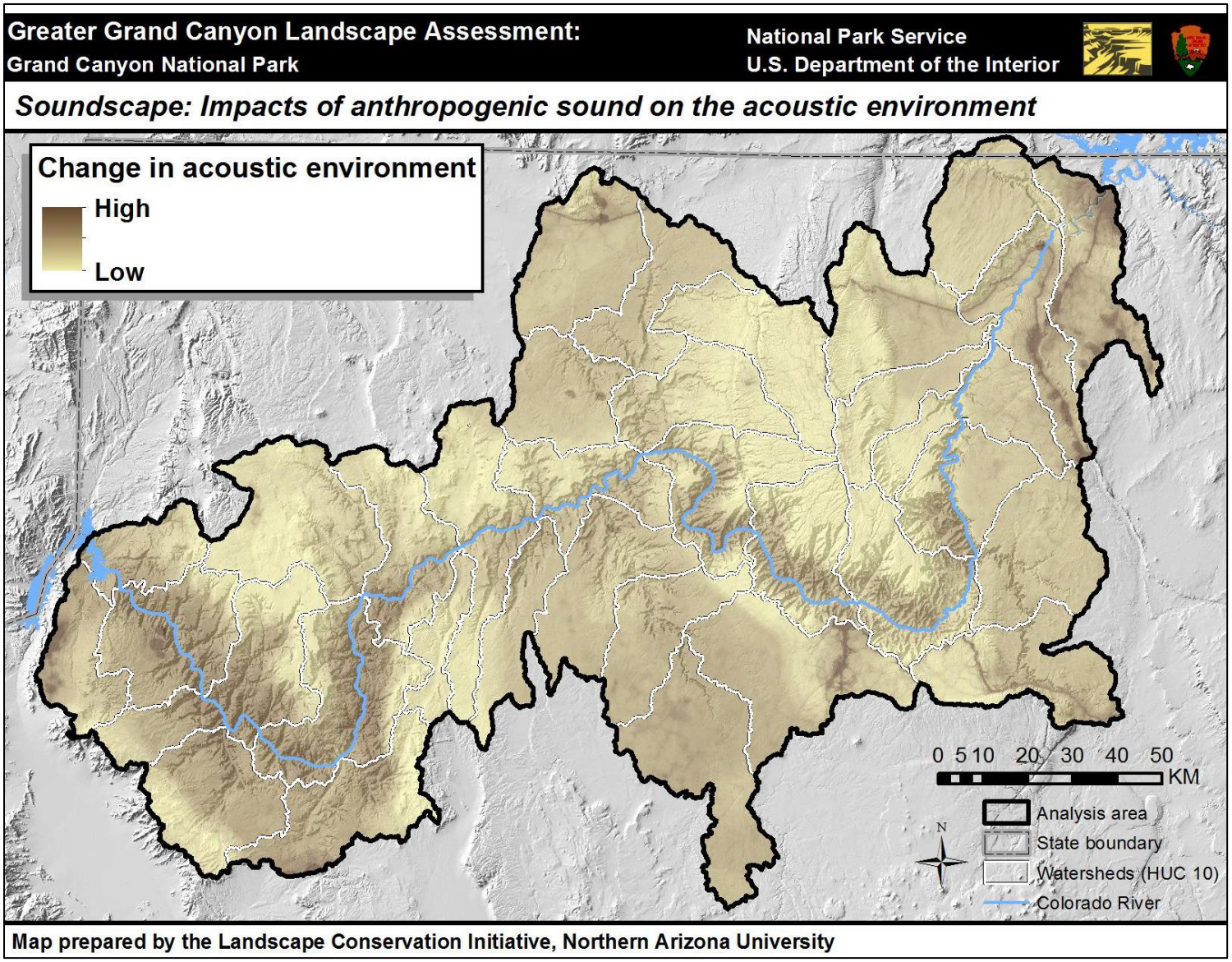


Figure 65. Changes in the acoustic environment across the greater Grand Canyon landscape.

5.27.5. Summary

Natural sounds include those upon which ecological processes and interactions depend. Examples of natural sounds in parks include sounds produced by birds, frogs, or insects to define territories or attract mates; sounds produced by bats to navigate or locate prey; and sounds produced by physical processes such as wind in trees, flowing water, or thunder. Human-caused noise has the potential to mask these sounds. Examples of human-caused sounds heard in parks include vehicles, generators, watercraft, and human voices, as well as overflights (see Stressors: Overflights). In the greater Grand Canyon area, the river and ponderosa pine forests are areas where high natural sound levels occur. Regions with frequent vehicular traffic and human activity exhibit high anthropogenic sound levels and are therefore most impacted. Spatially, these impacts are concentrated in the southern portion of the analysis area, on state, private, and tribal lands.

5.27.6. Data Needs

- As regional populations and visitation continue to grow, monitoring of the acoustic environment and how it is impacted by proposed residential and tourism developments will be essential to guide potential future mitigation.

5.27.7. Level of Confidence

Ambient sound levels were collected at specific points and combined with geospatial data to create a single model underlying associated maps. The National Park Service then assessed map accuracy by using a cross-validation method to predict individual values from the remaining values in the dataset and found that predictions fell within 3.1 dB of measured values across natural sites (http://www.nature.nps.gov/sound/mapfaq.cfm). More frequent and targeted sound data collection within the analysis area, focusing on locations of concern such as the rim drive or roaded lands in jurisdictions surrounding the park, would elevate confidence for the Grand Canyon landscape.

5.27.8. Sources of Expertise

This section was prepared by Clare Aslan, with assistance from Jill Rundall and The NPS Natural Sounds and Night Skies Division. The division scientists help parks manage sounds in a way that balances the various expectations of park visitors with the protection of park resources. They provide technical assistance to parks in the form of acoustical monitoring, data collection and analysis, and development of acoustic baselines for planning and reporting purposes. For more information, see http://www.nature.nps.gov/sound/.

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5.28. Visitor Experience: Night Skies

5.28.1. Description



Night skies are an important resource—ecologically, culturally, and economically—in the greater Grand Canyon region. Night sky quality is currently very good, and visitors flock to this region to experience views of constellations they often cannot see from their own homes. Future sky quality may be impacted by growth and development in the West, extending anthropogenic light pollution into currently pristine areas. Photo: The Milky Way seen from Grand Canyon NP (NPS Photo).

About half of earth's species are nocturnal, and artificial light at night that alters naturally dark skies is thought to cause disorientation and behavioral changes, possibly leading to death in amphibians, light-sensitive insects, and migrating birds. Phenological changes, altered distributions of species, and changes in predator-prey relationships can occur (Rich and Longcore 2006; Holker et al. 2010), and it is possible that artificial light at night may affect biodiversity and food webs (Kyba and Holker 2013).

Night skies are a significant element of cultural heritage, driving cosmology, stories, and the tracking of time and season throughout history (Rogers and Sovick 2001). Night skies are also an important scientific resource, serving as a natural laboratory for astronomers. For visitors to Grand Canyon NP, night skies add to the wilderness value and experiences of solitude. Naturally dark night skies draw people to the region, contributing "astrotourism" dollars to the economy. Indeed, Grand Canyon NP offers regular Star Programs and an annual, week-long Star Party. It is estimated that two-thirds of Americans cannot see the Milky Way from home (Cinzano et al. 2001)—viewing constellations and dark skies is becoming a rare and valued experience. In the GGCLA study area, the Grand Canyon–Parashant National Monument has been designated as an International Dark-Skies Park, and Grand Canyon NP has taken steps to apply for the designation.

5.28.2. Indicators/Measures

- Bortle Scale
- Zenithal Limiting Magnitude
- Sky Quality Index
- All-sky light pollution ratio
- Local light, use of light shielding and diffusion on fixtures

A number of indicators are relevant to assessing the quality of night skies. Managers must distinguish between the lightscape and the photic environment when monitoring night skies. The lightscape is an experiential or aesthetic quality—the human experience of the night, both sky and terrain. The photic environment is the pattern of light at all wavelengths, not just those that humans experience, and it affects species and natural processes (Moore et al. 2013).

- The *Bortle Scale* is a semi-quantitative measure of light pollution on a scale of 1 to 9, with 1 being the most pristine (Bortle 2001; Duriscoe 2015).
- The *Zenithal Limiting Magnitude* (ZLM), sometimes also reported as the naked eye limiting magnituted, is the brightness of the faintest star observable to the unaided human eye. This qualitative measure can vary by observer. A value of 6.6 is pristine under average conditions, 7.4 is excellent, and lower than 6.3 indicates degraded sky quality (Duriscoe 2015).
- The *Sky Quality Index* (SQI) is a measure of artificial sky glow, with a range of 0 to 100. Values of 0–20 indicate a "perpetual twilight" with only the brightest stars visible, and values from 80 to 100 indicate that skies exhibit natural characteristics throughout (Dursiscoe 2015). We report all sky SQI.
- The sky glow caused by anthropogenic light pollution combines with the natural brightness of the night sky to form our total viewing experience of night sky brightness. The amount of glow contributed by human sources can be summarized using the *All-sky light pollution ratio* (ALR), the ratio of the average sky luminance from artificial sources to the natural reference condition. ALR is a unitless, linear measure. For example, an ALR of 0.5 indicates 50% more light than from natural reference conditions (Duriscoe 2015).
- The *number of fixtures using light shielding and light diffusion* contributes to impacts on the night sky experience. This indicator measures a jurisdiction's contribution to local light pollution.

5.28.3. Methods

The National Park Service Night Skies Team collected baseline sky quality documentation in Grand Canyon NP in 2007 and 2008. Data were collected at Lipan Point and Powell Memorial on the canyon's south rim and Bright Angel Point on the north rim. A variety of metrics assessing photic and lightscape quality were measured to provide a "snapshot" of sky conditions and an estimate of the impact from light pollution (Duriscoe 2015). In October of 2015, the Night Skies Team collected additional sky quality documentation in Grand Canyon NP. These included repeat measures of the

Powell Memorial Site and additional site measures at Mather Visitor Center, Navajo Point, Point Imperial, and Cape Royal (Duriscoe et al. 2016).

ALR was determined using two approaches: ground-based data collection and spatial modeling using satellite imagery. The NPS Night Skies Team collected ground-based data on ALR in 2007, 2008, and 2015 as part of the effort described above. They used a research-grade camera to obtain photometric measures of the entire night sky (Figure 66, top). Natural sky brightness, as modeled in Duriscoe 2013, was subtracted from these images, leaving the estimated artificial sky glow (Figure 66, bottom). ALR was calculated by taking the ratio of artificial sky glow to natural reference condition values. The information was collected at specific sites, but is considered the most accurate and precise approach for determining light pollution within a 200 kilometer area, capturing light from across the region depending on atmospheric conditions and topography. We report the mean ALR values.

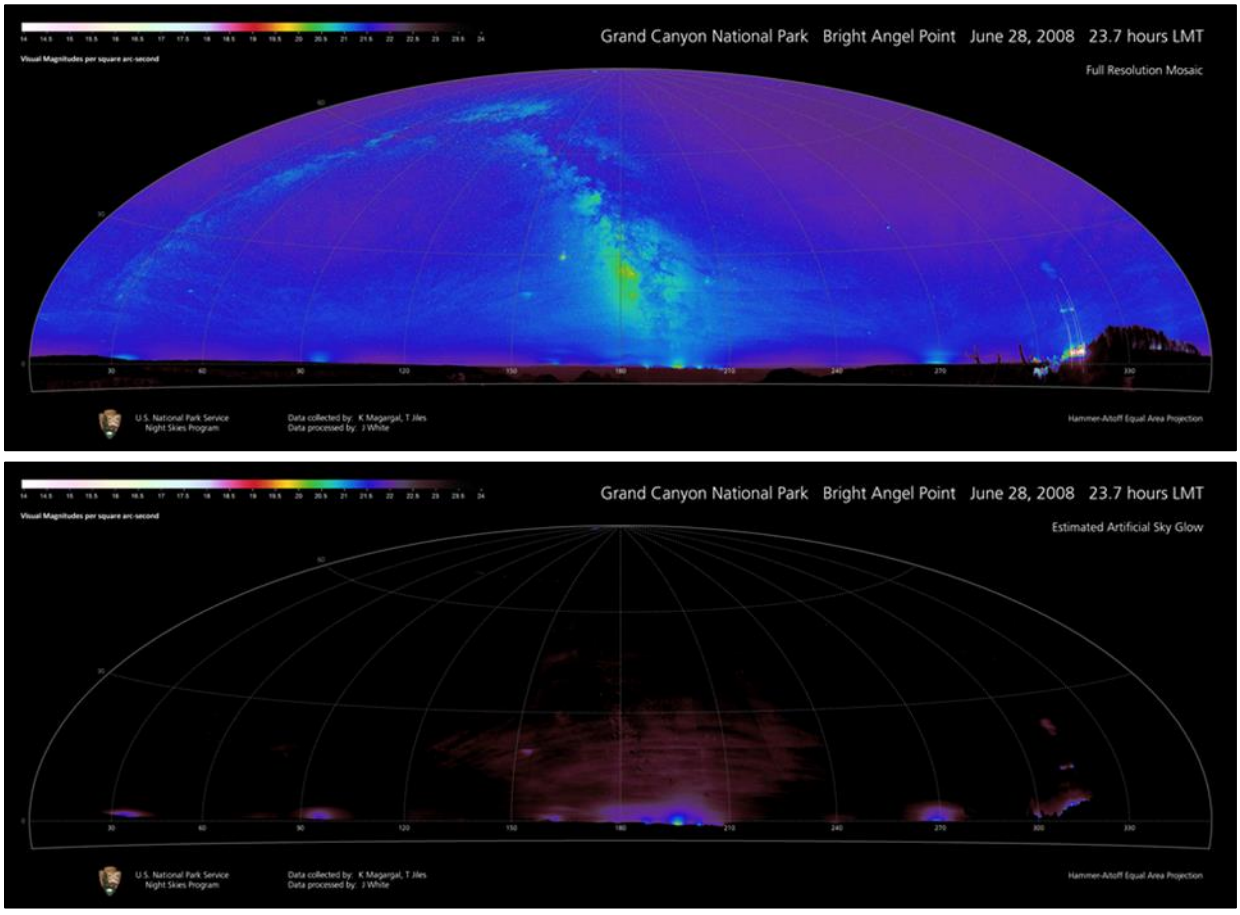


Figure 66. The reference values of natural sky brightness are subtracted from the original image of total night sky brightness captured by camera (top), resulting in an estimate of the sky glow contributed by anthropogenic sources (bottom).

The spatial model of ALR was developed for the contiguous United States and Europe using satellite imagery from 1997 taken from the 2001 World Atlas of Night Sky Brightness, which reports night

sky brightness at the zenith (sky directly above the observer). A neighborhood analysis was then used to estimate brightness over the entire sky. These values were compared to natural sky brightness, resulting in a map of the ALR (Duriscoe et al. 2013; Moore et al. 2013). Spatial ALR values are reported as medians. This spatial model provides information for a large coverage area but has medium confidence due to the coarse resolution; each pixel in the model represents 900 m. Thus, it provides a more general, area-wide description of sky quality.

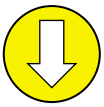
From 2013 to 2014, about 5,050 lights were surveyed at 270 localities (such as buildings, roads, trails, campgrounds, and parking lots) throughout Grand Canyon NP, including at Roaring Springs, Manzanita Bunkhouse, Tuweep Ranger Station, Phantom Ranch, and Desert View. The lights were geo-located and a variety of details about each fixture were recorded. We summarized these data in percentages to establish the number of shaded and diffused fixtures in the park.

5.28.4. Condition and Trend

Table 55. Summary of night skies resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
Bortle Scale	Light pollution indicator described on a scale of 1 to 9, with 1 being the most pristine and classes 1–3 indicating good condition (Moore et al. 2013).		In 2007 and 2008 a Bortle class of 2 and 3 was recorded in the park, indicating good condition. Sampling in 2015 again recorded class 2 and 3. Increased development may cause increased light pollution in the future.
ZLM	6.6 is pristine under average conditions, 7.4 is excellent, and lower than 6.3 indicates degraded sky quality (Duriscoe 2015).		In 2007 and 2008, ZLM values of 6.9 and 7.2 in the park indicated pristine to excellent conditions. In 2015, ZLM values remained in this range. Increased development may decrease ZLM values.
SQI	An index of artificial sky glow ranging from 0 to 100. Values greater than 75 are considered good condition (Moore et al. 2013) and values above 80 indicate natural skies (Duriscoe 2015).		In 2007 and 2008, SQI values ranged from 97.9 to 98.1 in the park, on a scale of 100, indicating very good condition. In 2015, the range of values expanded to 95.4 to 98.9, and the value for Powell Memorial point decreased slightly. However, all values remain about 80, indicating natural skies. Increased development may decrease SQI values in the future.
ALR ground-based	For parks like Grand Canyon, values of 0.33 or less are considered good (Moore et al. 2013).		In 2007 and 2008, ALR values ranging from <0.04 to 0.1 were collected in the park, indicating that the sky is between <4 and 10% brighter than natural conditions, and in good condition. In 2015 the values again ranged from <0.04 to 0.1, and were unchanged at Powel Memorial point.

Table 55 (continued). Summary of night skies resource condition and trend by indicator.

Indicator	Reference framework	Relative condition	Summary comments
ALR spatial model	For parks like Grand Canyon NP, values of 0.33 or less are considered good (Moore et al. 2013).		ALR over the GGCLA analysis area ranged from 0.04 to 0.78 with a median value of 0.12. Median value indicates good condition, but localized areas within the GGCLA study area have higher levels of light pollution.
Park light inventory	Percentage of lights shaded or diffused.		Currently, 25% of park fixtures are fully shielded and 28% are diffused. A park light management plan currently under review by the International Dark Sky Association will likely include actions to increase the percentage of shaded and diffused fixtures.

The baseline data for this region provide a snapshot of conditions for a number of indicators of sky quality collected in 2007 and 2008 (Table 56). In 2015, sky quality data was again collected in the park (Table 57). The 2015 collection revisited Power Memorial, and the 2008 Bright Angel Point location may be compared to Cape Royal. Data were also collected in several new locations. All of the indicators have similar values between measurements taken in 2007 or 2007, and in 2015, showing no upward or downward trend. Over longer periods of time, development and growth in populated areas has the potential to increase, and these indicators may show a downward trend in the future as anthropogenic light increases over time. The exception to this is the local light inventory conducted in 2013–2014. Because efforts to designate the park as an International Dark Sky Park require a plan for increased light shading and diffusion, this indicator will likely trend towards an increased percentage of light fixtures in the park containing shades and diffusion mechanisms.

Table 56. Baseline data on a variety of sky quality indices were collected in 2007 and 2008.

Date	Location	Bortle Scale	ZLM	SQI	ALR ground-based
6/21/2007	Bright Angel Point (North Rim)	n/a	n/a	98.1	0.05
6/14/2007	Lipan Point (South Rim)	2	7.2	97.2	0.05
9/12/2007	Powell Memorial (South Rim)	2	7.3	96.1	0.10
3/29/2008	Lipan Point (South Rim)	3	7.4	97.1	0.07
3/29/2008	Desert View parking Lot	3	7.3	98.9	< 0.04
6/27/2008	Bright Angel Point (North Rim)	3	6.9	98.0	0.04
6/28/2008	Bright Angel Point (North Rim)	3	6.9	97.9	0.05

Table 57. Data on a variety of sky quality indicies were collected in 2015. This included repeat measures of Powell Memorial and additional data collection locations.

Date	Location	Bortle Scale	ZLM	SQI	ALR ground-based
10/11/2015	Powell Memorial (South Rim)	2	7	95.4	0.10
10/11/2015	Mather Visitor Center (South Rim)	3	7	95.7	0.08
10/11/2015	Navajo Point (South Rim)	3	7	98.9	< 0.04
10/13/2015	Point Imperial (North Rim)	3	7	97.8	0.04
10/13/2015	Cape Royal (North Rim)	2	7.1	95.8	0.09

As modeled over the landscape, ALR ranged from 0.04 to 0.78 with a median value of 0.12 over the study area. ALR varied by jurisdiction (Table 58). The HUC 10 units with the highest ALR were concentrated in the farthest west part of the study area, including Lower Havasu Creek, Spencer Canyon, Surprise Canyon, Burnt Spring, Grapevine Wash, Mohawk Canyon, Whitmore Wash, and Diamond Creek (Figure 67). The ALR spatial model relies on data collected in 1997, and likely is an underestimate of current ALR conditions.

Table 58. The all-sky light pollution ratio was calculated for the study area using satellite imagery. Median values of ALR varied by land jurisdiction, with USFS lands receiving the least anthropogenic light and lands bordering developed areas receiving the most.

Jurisdiction	Median ALR spatial model
NPS	0.13
USFS	0.07
Tribal lands	0.12
BLM	0.11
Private	0.14
State Trust	0.13

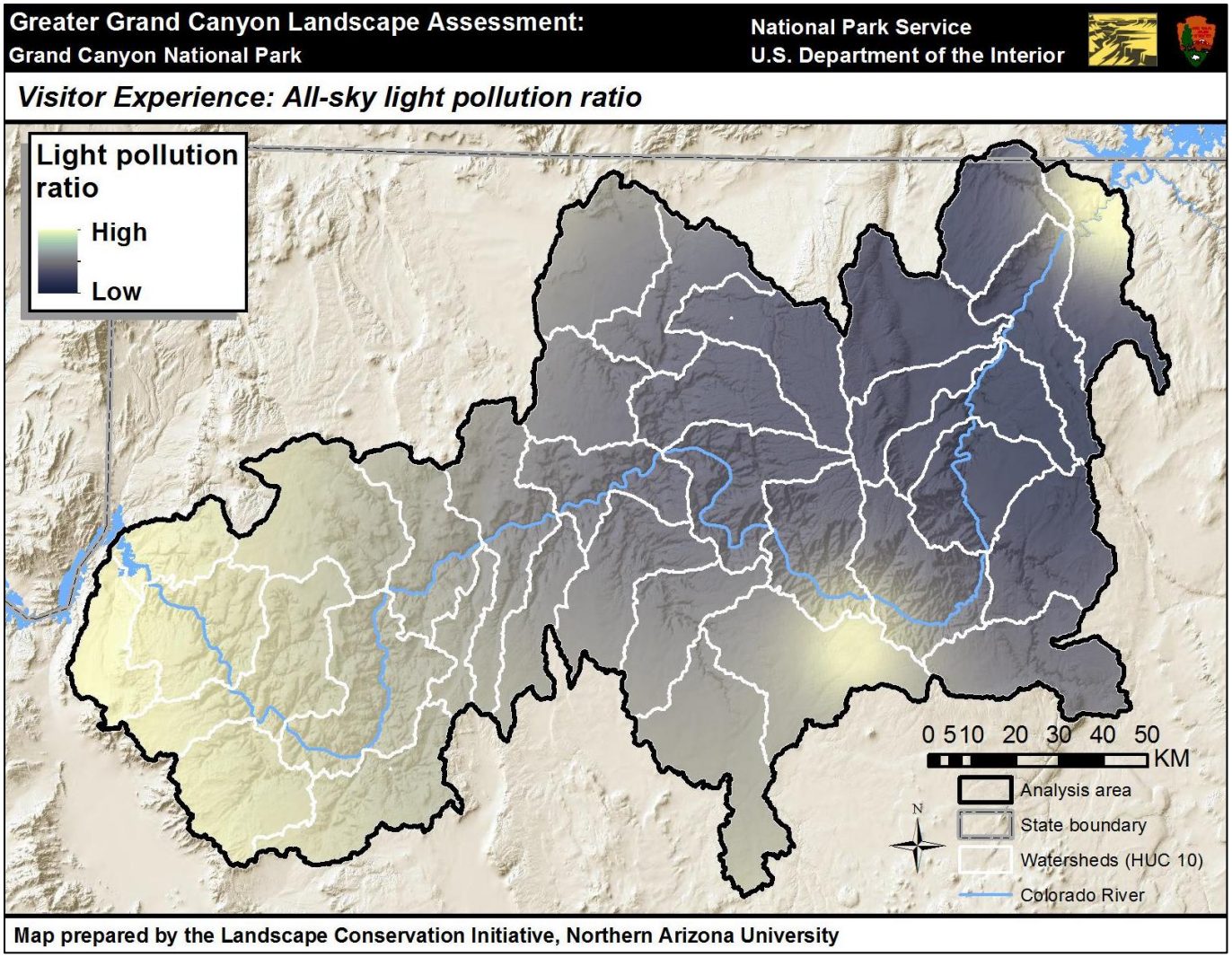


Figure 67. All-sky light pollution ratio over the analysis area ranged from 0.04 to 0.78 with a median value of 0.12 over the study area. The ALR is a ratio of the average anthropogenic sky luminance to natural conditions. It provides a coarse description of the resource condition at the landscape scale. An ALR of 0.12 means there is 12% more light in the environment than from reference conditions.

5.28.5. Summary

Existing information suggests that the current condition of dark night skies across the GGCLA area is of high quality. Human development that creates light at night, including energy production and cities, are the primary stressors on night sky quality. There are 26 populated places within 300 kilometers of Grand Canyon NP, all with the potential to produce artificial sky glow, including Grand Canyon Village, Phoenix, Flagstaff, Las Vegas, St. George, Tuba City, Tusayan, Prescott, and Page. Nearby wind and uranium developments also affect the quality of night skies. While the location with repeat measure sky quality data did not show a trend from 2007-2015, in general, the inland West is the most rapidly growing region in the United States and the most recent U.S. Census lists Colorado, Arizona, and Utah in the top 10 states with the most rapidly increasing populations (Muskal 2014). This growth and concomitant increasing development could make the naturally dark skies found in the center of the GGCLA analysis area more rare and decrease quality in the future.

Within the project area, local action to reduce light pollution focuses on infrastructure and shielded lights. Grand Canyon–Parashant National Monument has been designated as an International Dark Sky Park, and Grand Canyon NP has taken steps to apply for that designation. Guidelines for exterior lighting in the park are being drafted that outline best practices to limit light pollution within park boundaries and protect the night sky for park visitors and for nocturnal wildlife. Examples of ideal light fixtures and bulbs outlined in these guidelines will guide park staff in planning light retrofits. Spatial viewshed analysis will assist in evaluating the potential trespass of light into wilderness areas. Lighting inventory data collection and analysis protocols created at Grand Canyon NP are the foundation of a recently developed Task Agreement between the National Park Service and the International Dark Sky Association coordinated by the NPS Intermountain Region and Natural Sounds and Night Skies Division to develop lighting assessment protocols for use at all national parks and potentially other public lands.

5.28.6. Data Needs

- Repeat measures of sky quality indices to monitor and track trends in data across the landscape.

5.28.7. Level of Confidence

The spatial model of ALR uses data that were collected in the late 1990s. A newer model is under development using 2014 imagery but is not yet available. The amount of anthropogenic light in the analysis area around Las Vegas, Flagstaff, Page, Tusayan, and other developed areas has likely increased since the 1990s, suggesting that the model may underestimate ALR per pixel, particularly in and near developed areas. However, the median value across the analysis area is unlikely to be an underestimate given the large proportion of the area with a very low ALR.

5.28.8. Sources of Expertise

This section was prepared by Sasha Stortz. Laura Williams, Grand Canyon Association, Santiago Garcia, Grand Canyon NP, and Jeremy White, National Park Service Natural Sounds and Night Skies Division contributed background, data, and expertise.

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5.29. Visitor Experience: Recreational Resources

5.29.1. Description



The sparsely inhabited Grand Canyon region, with its immense topographic diversity and stunning vistas, has long been considered a recreational mecca. Visitors can easily access and explore Grand Canyon National Park's 1.1 million acres of remote backcountry (95% of the park's area) as well as the expansive national forests and BLM lands adjacent to the park. Photo: Hiker nearing Cathedral Stairs while descending the Hermit Trail (NPS photo by Michael Quinn)

Recreational resources include man-made features such as trails and historic structures open to the public. Grand Canyon National Park is home to multiple National Historic Landscape Districts, which provide services to park visitors but which also attract visitation and require protection themselves. The Arizona Trail, designated a National Scenic Trail, passes through Grand Canyon National Park as well as across the extended study area. Recreational resources also include campgrounds, unmaintained trails, routes used by canyoneers and backpackers, and observational viewpoints.

The majority of visitors experience the Grand Canyon from developed South and North Rim areas, while other visitors venture to the Inner Canyon backcountry and river, or more remote areas within the study area. Backcountry visitors have opportunities for a range of recreation experiences. Over one million acres of undeveloped backcountry, hundreds of trail miles, and 277 river miles provide opportunity for exploration, personal challenge, discovery, learning, social interaction, and/or solitude.

In addition to man-made features, visitors to all parts of the study area may also value less tangible and non-manmade recreational resources such as weather, seasons, vegetation variations, wildlife,

and sensory experiences of nature. Beaches along the river, water sources relied on during hiking trips, as well as vistas, night skies and natural sounds are also resources that contribute to visitor experience, and many of these elements are addressed elsewhere in this document.

Recreational resources addressed in this section, including some facilities provided by management agencies and well-established trails, remain relatively constant over time. However, resources may experience significant stressors such as overflights (affecting natural sounds), air quality (affecting vista clarity), uranium extraction (affecting water quality), or Colorado River dam operations (affecting beach sizes).

5.29.2. Indicators/Measures

- Trail segments
- Recreational facilities
- Recreational opportunities
- Vista points
- Campsite density

5.29.3. Methods

This assessment of man-made recreational resources employed GIS layers highlighting the occurrence of various recreational resources, enabling identification of HUC 10 watersheds with the highest and lowest density of such resources, including official trail segments for Grand Canyon National Park, Bureau of Land Management, and Kaibab National Forest lands. BLM records include historic trails, which were verified for current use by comparing trail data with aerial photographs. Other available data included the presence of recreational facilities in wilderness zones, the spectrum of recreational opportunities, key observation and vista points, campsite density, and recreational routes in NPS backcountry management zones.

Trail Segments

Trails within the canyon region may be maintained or unmaintained. Maintained trails in Grand Canyon NP are historic and cultural resources. Unmaintained trails, other trails along or near the canyon rim, and those in the wider study area, are also valued by many hikers who prefer areas with less visitation or less strenuous grades. Historic trails can include culturally sensitive routes, such as traditional paths, which may not be marked or generally known. Trails are subject to damage such as erosion from weather events and use by hikers, stock, or bicyclists, where allowed. Visitor impacts on culturally sensitive sites are of concern to managers and traditionally associated Indian tribes in and outside of the park (National Parks Conservation Association 2010).

Recreational Facilities

Some recreational facilities, such as buildings that house many of the interpretive displays along the rim, are in historical-designated buildings that may have very low maintenance budgets

Three National Historic Landmark Districts, as well as many other historically significant structures within Grand Canyon NP are open to visitors who can view interpretive displays, view cultural objects, obtain food, lodging or gifts, or simply rest. Maintenance of these historic structures requires special tools and techniques, as well as adherence to a variety of laws and regulations. Other built structures facilitate entry to scenic areas and access to the Inner Canyon for recreationists. Maintenance needs of buildings and other facilities are affected by the increasing volume of visitation and use, changing weather patterns, and emerging types of use, such as increased bicycle use on trails where it is allowed or increased needs for accessibility in historic structures. Risks to recreational facilities include the pressures of meeting increasing demand with a non-increasing resource, maintenance in remote areas, and the difficulty of prioritizing such maintenance with limited resources including funds and personnel.

Recreational Opportunities

A diversity of recreational activities, many regulated through permits and other requirements, are available within the park boundaries. Examples include hiking, bicycling, walking, running, backpacking, canyoneering, whitewater rafting, picnicking, camping, stock use, etc. Outside the park but within the analysis area are opportunities for ATV use, rock climbing, helicopter and fixed-wing aircraft flights, and expanded opportunities for stock use and cycling.

Observation Points

Vista points along the north and south rims of the Grand Canyon attract large numbers of visitors.

Campsite Density

The highest density of formally designated car campsites occurs on the rims (particularly the South Rim). Additionally, car campers may camp at large along dirt roads in the surrounding areas outside of the park but still within the study area. For hikers, the highest density of campsites occurs along the Kaibab and Bright Angel Trails within the Grand Canyon.

5.29.4. Condition and Trend

Table 59. Summary of recreational resources condition and trend by indicator.

Indicator	Reference condition	Relative condition	Summary comments
Trail segments	Condition and density of trail segments		Density of trail segments remains constant over time, although the number of social trails may increase with increased visitation. Trail conditions deteriorate over time due to erosion caused by weather, geology, and use. Deteriorating condition of some segments is difficult due to remoteness, access, and maintenance budgets

Table 59 (continued). Summary of recreational resources condition and trend by indicator.

Indicator	Reference condition	Relative condition	Summary comments
Recreational facilities	Condition of recreational facilities		High volume of use, changing weather patterns, and low budgets can cause condition decline. Historic building mitigation is made challenging by requirements for historic building maintenance as well as budget issues.
Recreational opportunity spectrum	Diversity of recreational activities		Demand for types and levels of different recreational activities fluctuates with visitation levels, demographics, and emerging recreational uses. Generally, this diversity remains constant over time.
Observation points	Density of vista points		Declining air quality could impact vista quality
Campsite density	Density of campsites		Density of campsites has remained constant over time. Pressure on informal “at large” campsites from spillover of campers not accommodated at campsites may increase as visitation increases

5.29.5. Summary

The highest density of recreational resources occurs in the Bright Angel Creek–Colorado River, Shinumo Creek–Colorado River, and Tapeats Creek–Colorado River (HUC 10) watersheds (Figure 68). Low-occurrence areas are located beyond the borders of the park, but layers representing recreational resources may also be less complete beyond the park borders, making it difficult to compare such sites with locations within Grand Canyon NP.

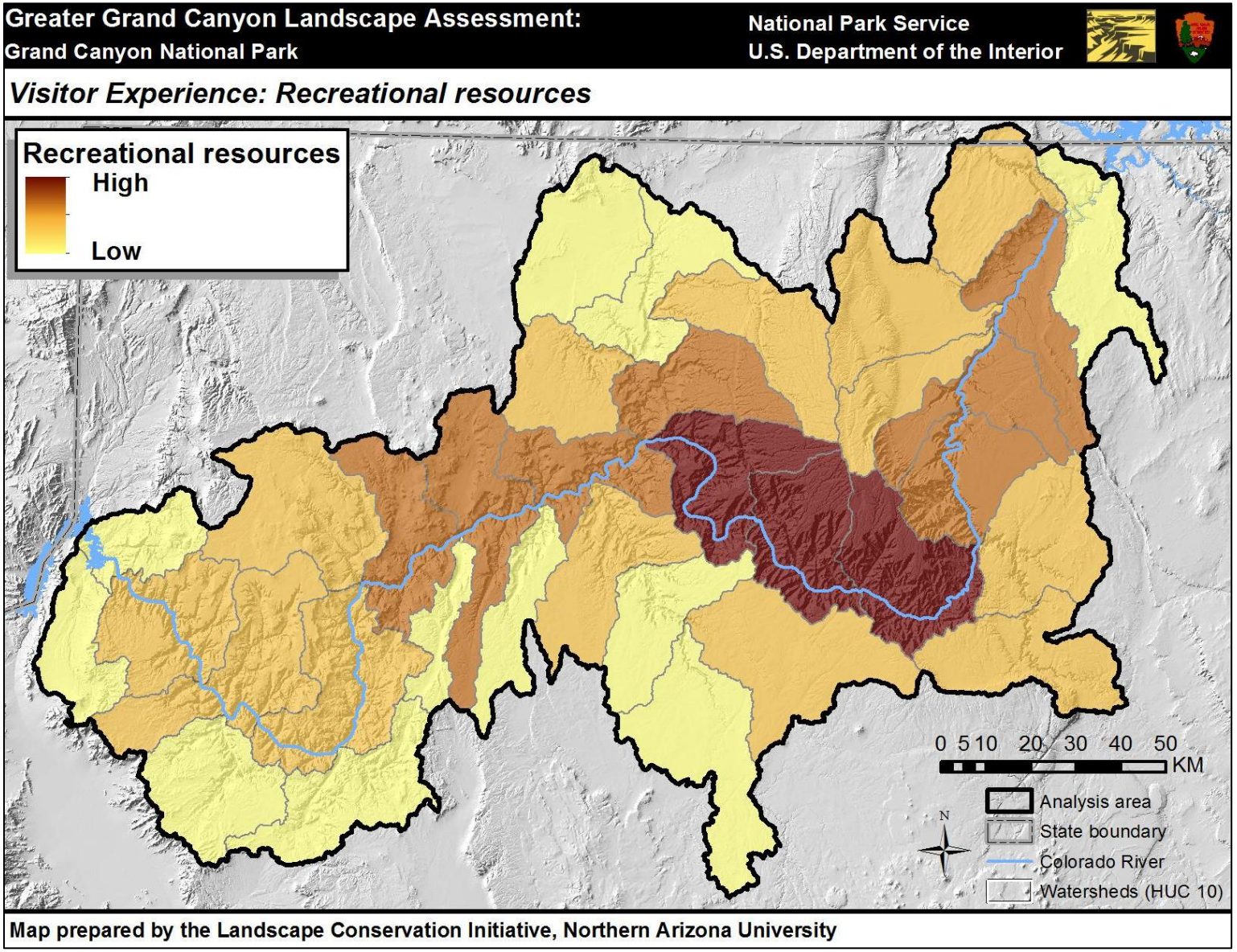


Figure 68. Density of recreational resources by watershed in Grand Canyon NP.

Trails and other recreational resources are distributed throughout the multiple jurisdictions of the greater Grand Canyon landscape. Recreational activities served by these resources include dayhiking and trail running (no permit required), backpacking and overnight camping (heavily regulated), stock use (regulated), river running (regulated), canyoneering, and bicycling (outside wilderness areas; Grand Canyon National Park 2015). Particularly dense recreational facilities can be found along the south rim and below the rim in the main corridor comprising Bright Angel Trail, Phantom Ranch, and the South Kaibab Trail. The main corridor trails are heavily traveled by hikers and by mules.

Recreational infrastructure, including trails, is considered a primary value for the park and surrounding areas, but can also be a cause for concern when it intersects with high-impact stressors, or when high numbers of recreationists impact habitats, cultural sites, and other key locations in the analysis area. The backcountry includes well-developed trails and campgrounds; primitive areas with trails but low use and few amenities; and wild areas where route-finding is often necessary (Grand Canyon National Park 2015) (Figure 69). In all areas, the highest visitation periods are in the late spring and early fall.

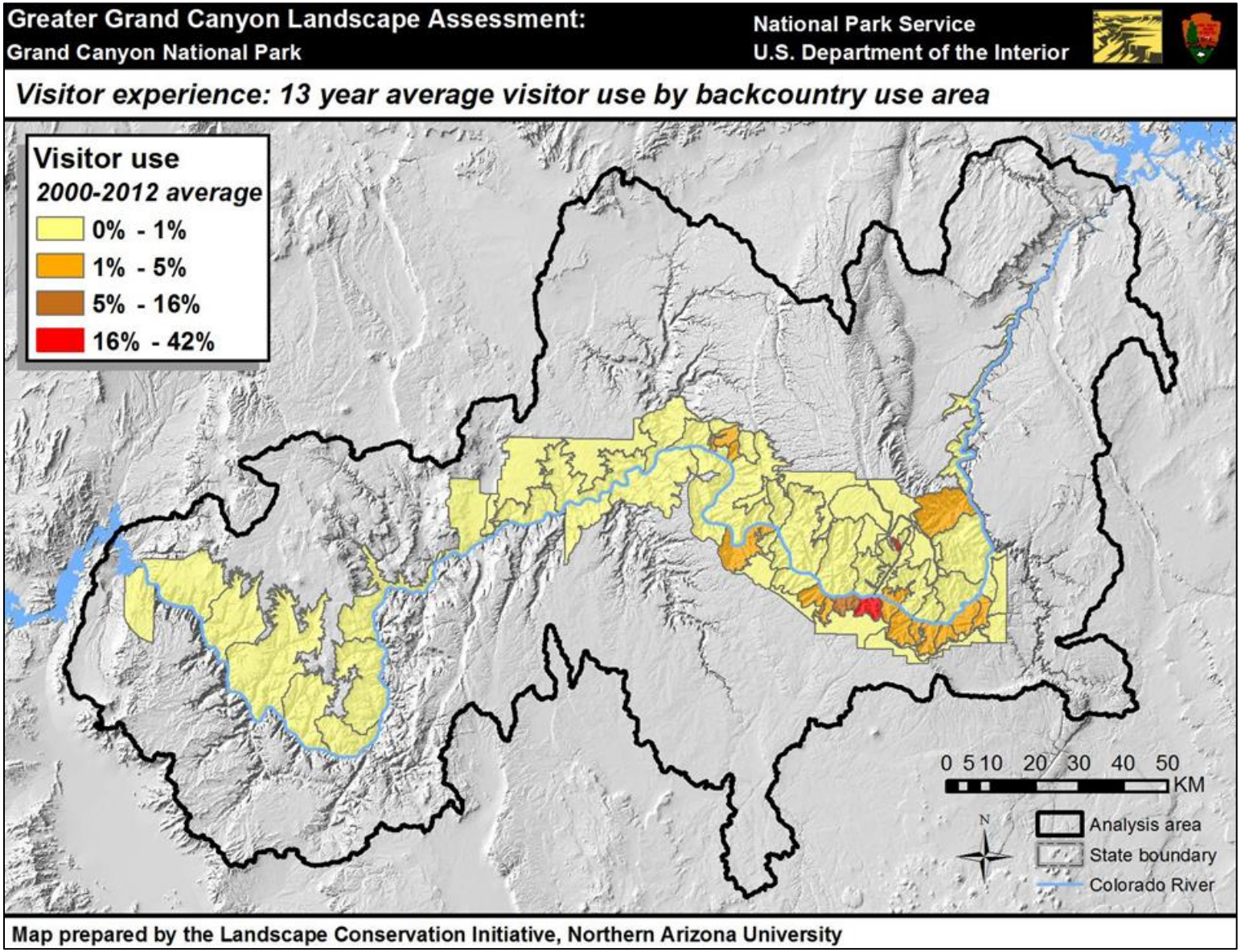


Figure 69. Density of visitor use, 2000–2012, in Grand Canyon NP.

5.29.6. Level of Confidence

Data for infrastructure do not change as rapidly as many ecological variables; however, there are certainly unofficial, unmarked, or historic trails and infrastructures not contained in the layers used.

5.29.7. Sources of Expertise

This section was prepared by Clare Aslan. Analysis was performed by Jill Rundall using datasets provided by managing agencies (NPS, BLM, and U.S. Forest Service) verified through aerial photography. Laura Shearin, Grand Canyon NP, reviewed this section.

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5.30. Visitor Experience: Wilderness

5.30.1. Description



Assessment of wilderness character for a region includes evaluation of the area's natural quality, untrammeled quality, opportunities for solitude or primitive and unconfined recreation, and undeveloped quality. In assessing wilderness character for the GGCLA area, the highest degree of wilderness character was found in areas mostly within the Grand Canyon NP administrative boundary, and also areas outside the park that are currently designated as wilderness. Based on our analysis, 45% of all lands within the analysis area are above the 80th percentile for wilderness character (USFWS Photo).

All designated wilderness is managed under the Wilderness Act of 1964, which mandates that agencies ensure the "preservation of wilderness character" in places so designated. Each wilderness within the National Wilderness Preservation System is managed by one or more federal agencies, including the Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and U.S. Forest Service. Grand Canyon NP proposed wilderness is managed in the same manner as designated wilderness. In 2008, representatives from these agencies and the U.S. Geological Survey published a conceptual framework, "Keeping it Wild," wherein wilderness character is defined in a way that links management actions directly to the language of the Wilderness Act (Landres et al. 2008).

Wilderness character is assessed by evaluating the following:

- Natural quality, where high natural quality refers to ecological systems and living communities that are free from the effects of human actions.
- Untrammeled quality, where high untrammeled quality means that wilderness is free from management actions to manipulate or control ecological systems.
- Outstanding opportunities for solitude, or primitive and unconfined types of recreation, measured for a given location as the ability of visitors to be unaware of sights and sounds of

other people inside wilderness, and of occupied and modified areas outside of the wilderness. Areas high in this metric are free of facilities that impinge upon self-reliant recreation and of management restrictions on visitor behavior.

- Undeveloped quality, where high undeveloped quality indicates lack of permanent infrastructure related to modern use and occupation, lack of motorized equipment and mechanized transport, and lack of inholdings within wilderness.

Wilderness character is assessed and monitored by assigning indicators to each of these key elements of wilderness. Carver et al. (2013) took this framework a step further, developing a spatial modeling approach to map wilderness character variability and distribution across a landscape. Based on this framework and modeling approach, wilderness character quality maps have been produced for Death Valley National Park (Tricker et al. 2012), Sequoia Kings Canyon National Park (Tricker et al. 2014), Olympic National Park (Tricker et al. 2013), and others. This approach has been selected to assess wilderness character for the GGCLA and can be used by land managers to help address these key questions (Landres et al. 2008):

- What is the current state of wilderness character in the analysis area?
- How is wilderness character changing over time?
- How are stewardship actions affecting wilderness character?
- What stewardship priorities and decisions would best preserve wilderness character?

Wilderness character assessments are implemented to establish a baseline for monitoring wilderness conditions in general, and in light of current and looming threats such as development, resource extraction, and climate change. In addition, wilderness character is an important aspect of the visitor experience from a National Park Service perspective. Wilderness character mapping provides a tool for managers to evaluate the effects of management actions and changing conditions on wilderness character over time, and to assess the spatial extent of the impacts of planning alternatives for wilderness and backcountry stewardship.

5.30.2. Indicators/Measures

- Biorichness
- Degree untrammeled
- Quality of the natural acoustic environment
- Quality of night skies
- Ecological integrity

5.30.3. Methods

The wilderness character resource condition assessment for the GGCLA follows a simplified approach, rooted in the framework described above but constrained by the data available for the area of interest. The spatial extent includes multiple land jurisdictions, which makes it difficult to acquire consistent data across the area. However, assessments that have been developed for other sections of

the GGCLA, such as biorichness and ecological integrity, capture many measures of wilderness character elements, permitting an informative assessment of wilderness character indicators (Table 60).

Table 60. The Keeping It Wild wilderness character framework as applied by Landres et al. (2008), with datasets used and weights applied in this GGCLA assessment.

Wilderness Character Quality	Indicators	Datasets used in GGCLA assessment	Weights
Natural quality	Plant and animal species and communities; physical resources; biophysical processes	Biorichness	0.25
Untrammeled quality	Actions authorized or not authorized by the federal land manager that manipulate the biophysical environment	Untrammeled (Landres et al. 2008; Tricker 2012, 2013, 2014)	0.25
Solitude or primitive and unconfined recreation quality	Remoteness from sights and sounds of people inside the wilderness; remoteness from occupied and modified areas outside the wilderness; facilities that decrease self-reliant recreation; management restrictions on visitor behavior	Natural acoustic environment and night skies	0.125 each 5.4
Undeveloped quality	Non-recreational structures, installations, and developments; Inholdings; use of motor vehicles, motorized equipment, or mechanical transport	Ecological integrity	0.25

Biorichness

Data selection was based on relevance to wilderness character, data availability, and data quality. Park staff contributed their expertise by helping to select datasets and design the analysis. We did not mask out definitively non-wilderness areas prior to analysis, as in previous approaches (Tricker et al. 2012, 2013, and 2014), due to the subjective nature of such decisions in a multi-jurisdictional scenario. Our results therefore include a full spectrum of wilderness character, from developed non-wilderness to relatively pristine wilderness. We modeled data such that degree of wilderness character was emphasized instead of wilderness degradation; thus, higher values represent higher wilderness character. All data were assigned a value on a 0–1 scale (where 1 = highest wilderness character), represented at 30 meter spatial resolution, and projected in NAD83 UTM Zone 12 North (ESRI 2014).

We combined into a single indicator each of the following: biorichness, degree untrammeled by management action, quality of natural acoustic environment and night sky, and ecological integrity. The sum of indicator weights is 1, with each indicator contributing an equal proportion of that sum, and elements combining to represent a single indicator (e.g., natural acoustic environment and night sky) assigned proportionately lower weights. The rationale for these indicators and the data sources representing them are described in Table 60.

The biorichness dataset, the product of the resource condition assessment of biorichness for the GGCLA, is derived from several indicators: geophysical diversity, surface water availability, vegetation community diversity, and net primary productivity. Biorichness was selected to represent the potential natural quality of wilderness character because it most efficiently encompasses the recommended elements of natural quality: plant and animal species and communities, physical resources, and biophysical resources (Landres et al. 2008). High values for this indicator represent high natural quality.

Untrammeled

Unlike other datasets used in this assessment, the data used to assess degree of trammeling were synthesized solely for this purpose. Data inputs identified occurrence of management activities including wildfire suppression, prescribed fire use, thinning, harvest, exotic vegetation treatment, and restoration activities (Landres et al. 2008; Tricker 2012, 2013, 2014). Spatial data were obtained from the Public Events Model Ready Disturbance dataset for 1999–2012 from Landfire (1.0.3, 2013), and supplemented with 2013–2014 fire perimeter data (USDA Forest Service 2015), Grand Canyon NP fire history 1930–2012 (National Park Service 2015a), and Grand Canyon NP exotic control sites (National Park Service 2015b). Data for non-management disturbance types (unsuppressed wildfire, weather, insects, and disease) were removed. All data were combined into a single dataset representing presence/absence of disturbance in binary form. Because the presence of disturbance does not necessarily restrict disturbance effects to only that location, we estimated effective disturbance to surrounding lands by calculating a mean disturbance value (a focal mean statistic) for areas surrounding each location with disturbance present, using a 5000-acre neighborhood size based on the minimum area considered for wilderness designation. The result is a representation of disturbance that reflects relative levels of disturbance in areas surrounding known disturbance to capture impacts on wilderness character across the landscape. The resulting model was used to represent untrammeled quality, with values closest to one representing highest untrammeled quality.

Natural Acoustic Environment and Night Skies

The indicators for solitude or primitive and unconfined recreation quality include the non-natural noise component of the continental-scale natural acoustic environment modeled by the National Park Service (270 meter resolution; National Park Service Continental Noise Model 2014) and the non-natural light component of a night skies dataset (432 meter resolution) developed by NOAA/NGDC (2013), both resampled to 30 meters. These two datasets were combined equally to represent anthropogenic noise and light sources within the GGCLA study extent, such that high values represent lowest levels of non-natural noise and light sources impacting wilderness character.

Ecological Integrity

This dataset, which is a product of the resource condition assessment evaluation of ecological integrity for the GGCLA, is derived from several sources, including data on urban and built-up areas, housing, cropland, mines, roads and railroads, power lines, recreational use and accessibility, campsites, and backcountry sites. This index of estimated impact of development is based on areal extent and magnitude of multiple stressors at multiple scales, and efficiently encompasses most indicators recommended for assessment of the degree to which a site is undeveloped (Landres et al.

2008). This dataset is modeled for wilderness character such that high values for ecological integrity represent low levels of development and thereby high levels of wilderness character.

5.30.4. Condition and Trend

To obtain spatial summary statistics of these data, we examined the full range of output values for wilderness character and divided the values into 10 classes using classification by natural breaks (Figure 70), where breaks are determined statistically to separate data into 10 naturally occurring clumps, allowing identification of the highest quality areas (ESRI 2014). The wilderness character and trend values (Table 61) reveal that only about 20% of the land area within the GGCLA study extent falls below the 60th percentile of wilderness character, while 45% of the land area is above the 80th percentile, with 9% above the 90th percentile. That is, although most of the land area is of relatively high wilderness character quality, only 9% is degraded to the least degree possible. Focusing on the indicators, 93% of the GGCLA study extent exhibits ecological integrity values of 8 or higher, 68% is considered untrammeled (data suggest no manipulation by management action), and less than 1% is significantly impacted by artificial light. About 65% has an impacted natural acoustic environment and only 20% has the highest biorichness potential.

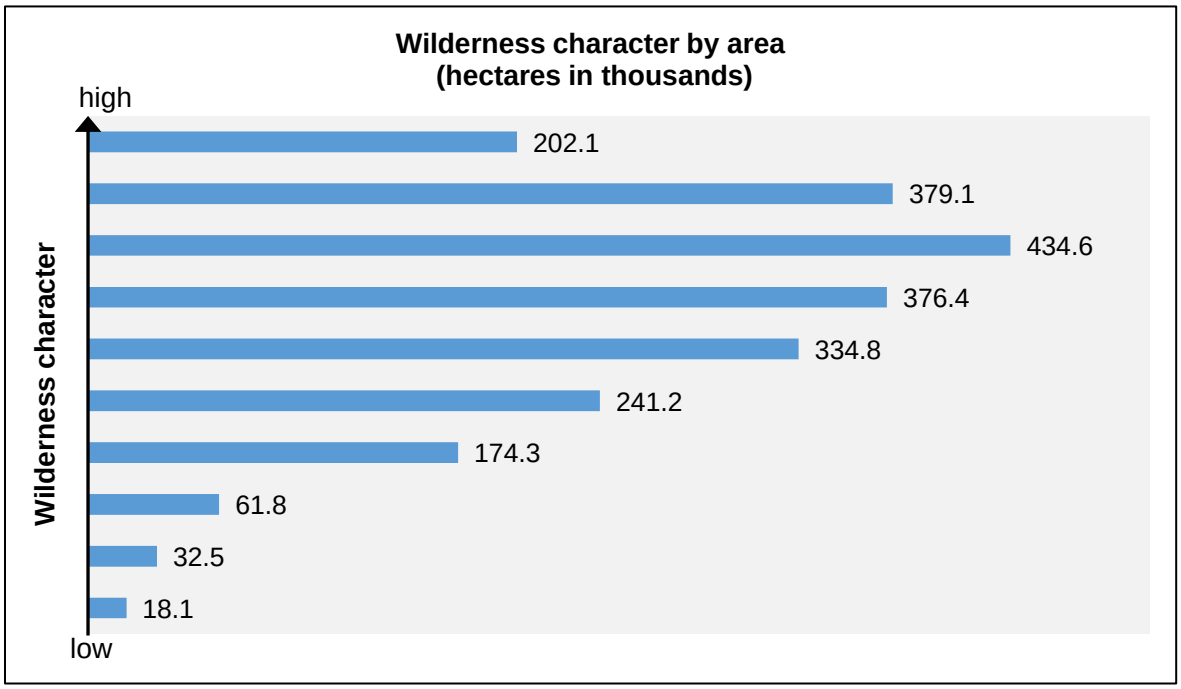


Figure 70. Wilderness character by land area, according to 10 categories determined by natural breaks in the range of output values (lowest is 1 and highest is 10).

Table 61. Summary of wilderness character condition and trend by indicator.

Indicator	Reference condition	Relative condition	Summary comments
Biorichness potential	Existing wilderness or other areas with high levels of potential biorichness		20% of the GGCLA area has optimal biorichness potential (values of 8 or higher on a scale of 1 to 10).
Degree untrammeled	Existing wilderness or other areas that have not been manipulated by management action.		68% of the GGCLA area is considered untrammeled. Continued treatment of fuels and exotic vegetation will cause trammeling. However, the effects of these treatments could be balanced by restoring natural quality (in this case, biorichness potential) over time.
Natural acoustic environment and night skies	Existing wilderness or other areas without non-natural sound or light sources.		At a coarse scale, 0.05% of the GGCLA has detectable light pollution, whereas 65% is highly affected by non-natural sound, which has a much stronger influence on solitude than impacts from non-natural light sources. Continued human development has the potential to decrease the opportunities for solitude in the GGCLA.
Ecological integrity	Existing wilderness or other areas without direct human modification impacts		93% of the GGCLA area exhibits an ecological integrity value of 8 or higher on a scale of 0-10. However, continued human use pressures would decrease ecological integrity.

Wilderness character is visualized on a map where values from all four indicators are combined into a model of overall wilderness character (Figure 71). The values are symbolized using the minimum-maximum stretching method (ESRI 2014).

There are five existing designated and one proposed wilderness areas on the greater Grand Canyon landscape (Table 62). Existing designated and proposed wilderness areas exhibit high wilderness character, as seen in Figure 72. This knowledge helps validate the modeling approach and provides confidence in the results for the broader landscape.

Of the land that falls into the top 10% for wilderness character (Figure 73), 60% occurs within NPS jurisdiction, 16% is tribal, and USFS and BLM each manage about 12% (Figure 74). By land ownership, the highest average wilderness character occurs on NPS lands (8.3 on a scale of 1–10) and the lowest on State Trust lands (7.4). Notably, all jurisdictions have average wilderness character values of 7.4 or higher, suggesting that wilderness character across the GGCLA analysis extent, regardless of jurisdiction, is relatively high.

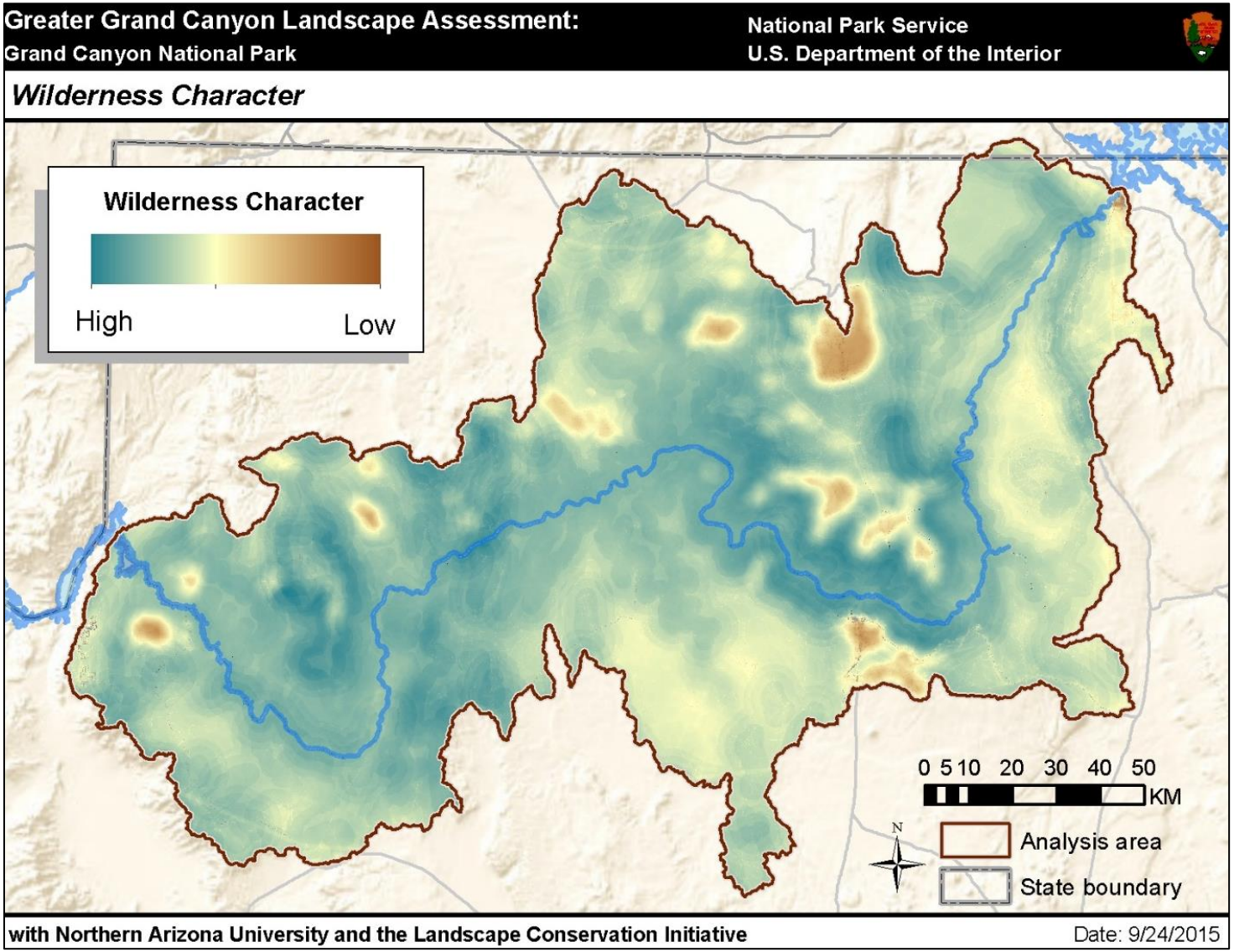


Figure 71. Wilderness character map for GGCLA analysis area.

Table 62. Wilderness areas within GGCLA study extent

Wilderness Area	Acres	Jurisdiction	Status
Mount Trumbull	7,880	BLM	Designated
Mount Logan	14,650	BLM	Designated
Kanab Creek	68,223	BLM, USFS	Designated
Saddle Mountain	41,140	USFS	Designated
Paria Canyon–Vermillion Cliffs	110,816	BLM	Designated
Grand Canyon National Park (NRS 2010)	1,143,918	Grand Canyon NP	Proposed

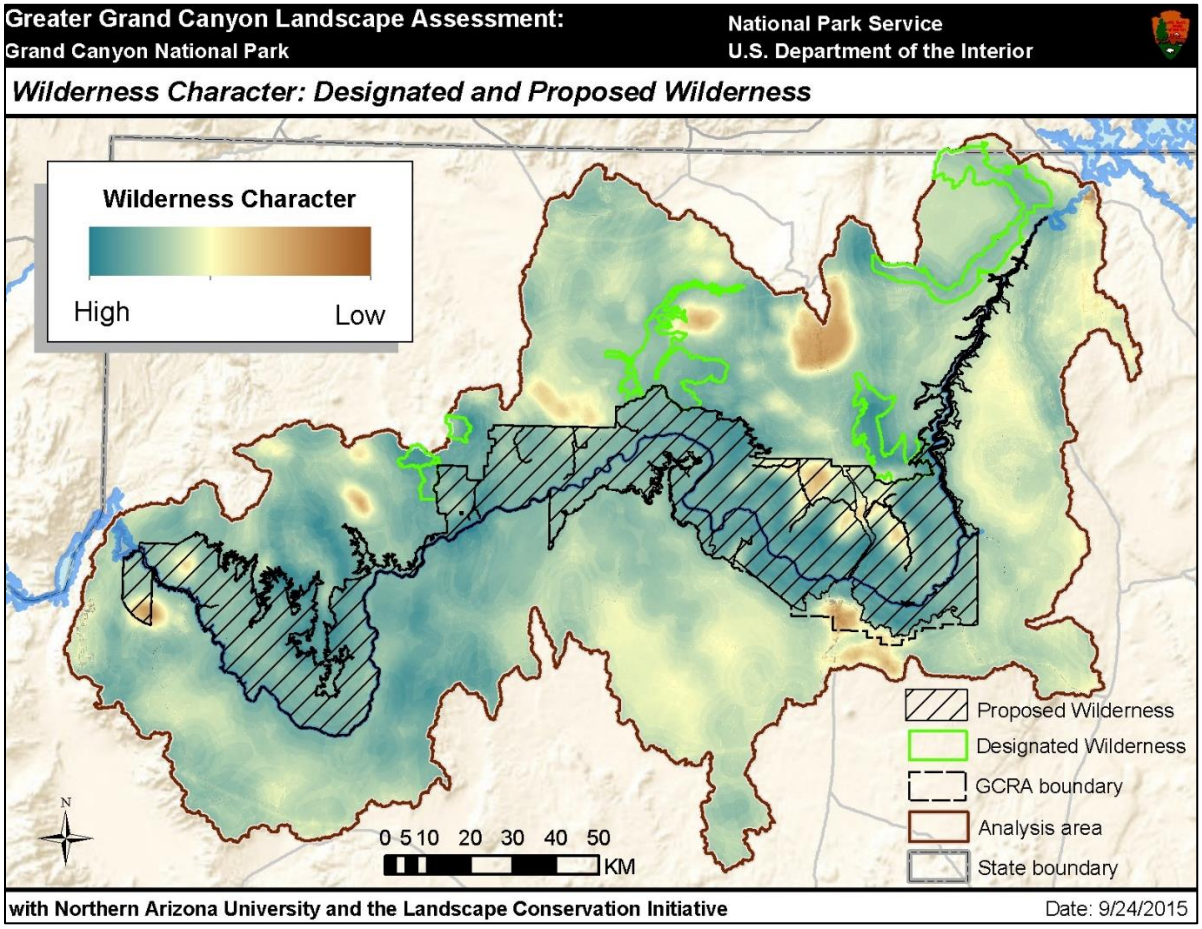


Figure 72. Overlay between wilderness character and designated and proposed wilderness.

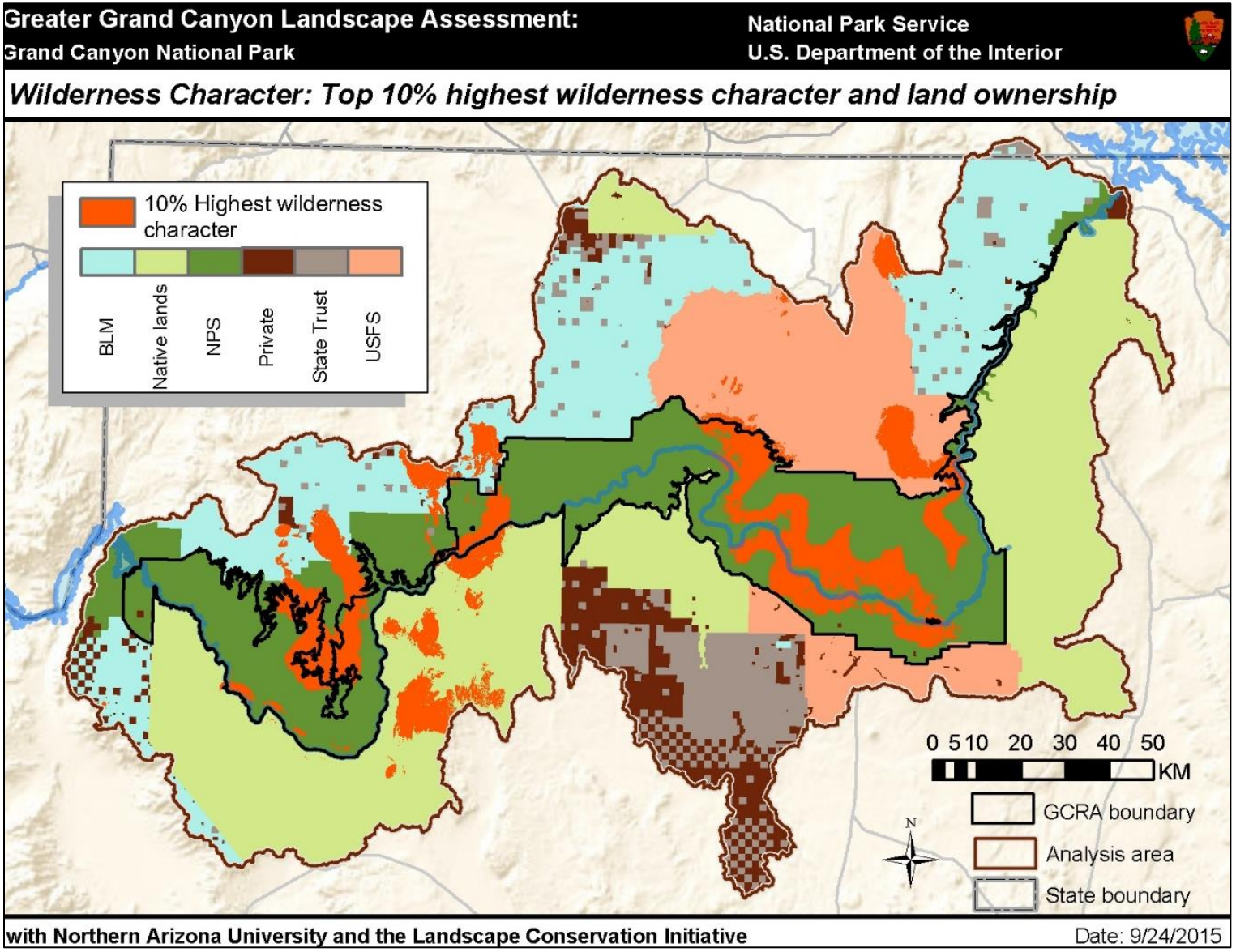


Figure 73. Location of the top 10% highest wilderness character.

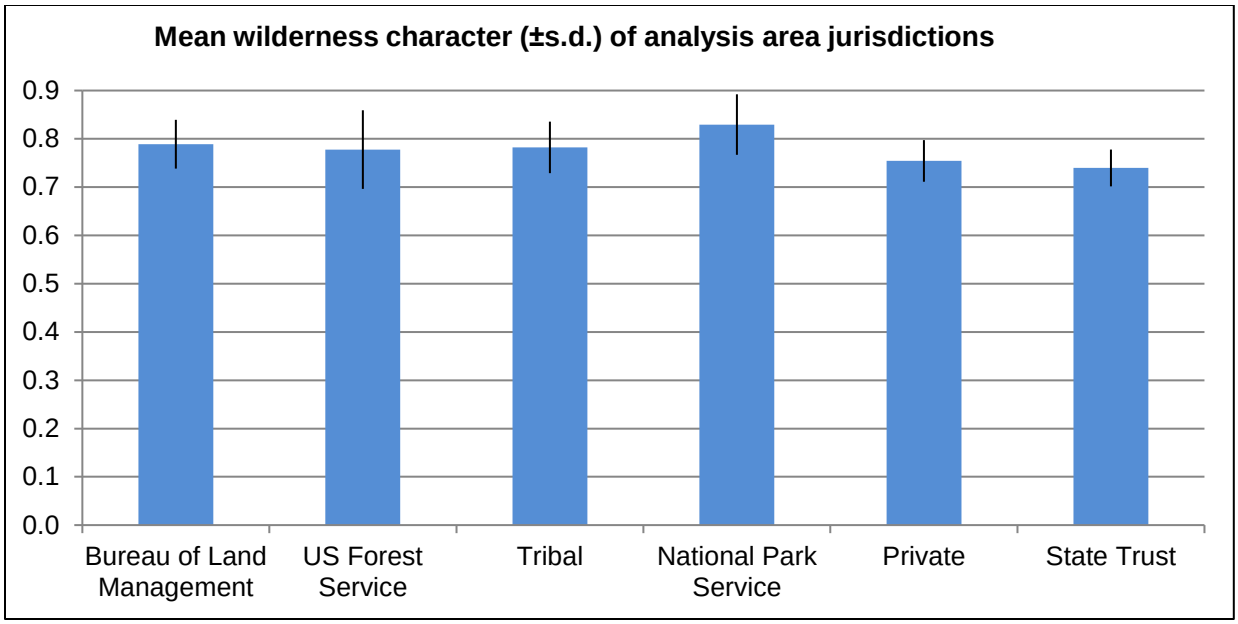


Figure 74. Mean wilderness character values on a 1–10 scale by land owner within the GGCLA study area.

5.30.5. Summary

Wilderness character is relatively high across the GGCLA extent. Pockets of lower quality wilderness character are mostly located near highways and other developed areas, and in areas affected by large, suppressed wildfire. There is significant overlap between areas of high wilderness character quality and designated (Saddle Mountain, Mount Logan, Paria Canyon–Vermillion Cliffs, Mount Trumbull, and Kanab Creek Wilderness), and proposed wilderness (proposed designations within Grand Canyon NP).

This wilderness resource condition assessment can serve as a tool for land managers to plan for and preserve wilderness character within Grand Canyon NP, as mandated by NPS, as well as provide guidance for wilderness-related decisions by other land owners within the GGCLA study area.

5.30.6. Data Needs

- Natural acoustic environment and night sky data specific to the geographic region and at finer spatial resolutions would improve estimates of sound and light pollution, thereby improving estimates of solitude and opportunity for unconfined recreation.
- Targeted surveys of biorichness and improved spatial information on management treatments for all jurisdictions in the study extent would help to improve assessment of natural and untrammeled qualities.
- Tracking of impacts from management actions (negatively affecting untrammeled quality) as related to potential positive effects to biorichness potential and ecological integrity would also be beneficial.

5.30.7. Level of Confidence

The datasets used in this assessment are synthesized, modeled datasets, and are the best available data for the spatial extent and multiple jurisdictions of this analysis area. Thus, these estimates of wilderness character can be treated with fairly high confidence, but do not depict the intricacies or depth of wilderness character as a whole.

5.30.8. Sources of Expertise

This section was prepared by Nicole Shaw. Analysis was performed by Nicole Shaw and Luke Zachmann of Conservation Science Partners with synthesized datasets contributed by the National Park Service, and Christine Albano, Brett Dickson, and David Theobald of Conservation Science Partners.

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5.31. Stressors: Altered Hydrological Regime

5.31.1 Description



Over the course of millennia, the Colorado River has relentlessly carved out the magnificent Grand Canyon, meanwhile forging a landscape that has nurtured plants, animals, and humans, both physically and spiritually, for time immemorial. Central to this has been the provision of life-giving water, following the rhythm of the seasons. However, in the modern era, the hydrological regime of the Colorado River has been significantly altered as a result of the construction and management of Glen Canyon Dam upstream. The resulting transformations have impacted species and visitors alike. In addition, the Colorado's future hydrological regime is expected to be affected by climate change. Photo: Glen Canyon dam viewed from a raft on the Colorado River (Photo by Mark Byzewski, creative commons license CC BY 2.0).

The hydrology of the mainstem Colorado River has changed substantially since the construction of Glen Canyon Dam, but tributary hydrology remains largely in a natural state. Before the construction of Glen Canyon Dam, the natural flow of the Colorado River exhibited enormous variability, with scouring floods sweeping through the lower canyon annually, clearing vegetation from the riparian zone (Schmidt et al. 1998; Schmit et al. 2005). The 2-year recurrence flood between the years 1921 and 1962 averaged 2150 cubic meters per second, and it was common during that period to measure sustained flows exceeding 1250 m^3/sec over 30 days or more (Schmidt et al. 1998). Completed in 1963, Glen Canyon Dam decreased the flow variability throughout the year and eliminated the regular, intense floods and the ecosystems and landscapes they supported (Mortenson et al. 2012). Between the years 1962 and 1996, the 2-year recurrence flood average was 679 m^3/sec (Schmidt et al. 1998).

Sediment load was also transformed dramatically. Average suspended-sediment load prior to the dam's construction was 6.0 x 10^{10} kg/year, but after the dam it was only 0.000013 x 10^{10} kg/year (Schmidt et al. 1998). River temperature before dam construction varied from near-freezing in the winter to 25–30 °C, but with the dam, water temperature holds steady at 8–10 °C (Schmidt et al. 1998).

Vegetation along the Colorado River in the Grand Canyon has also been substantially altered. Pre-dam flooding scoured channel banks, and perennial vegetation was present as a linear band above the flood line (Schmidt et al. 1998; Ralston 2005). Now that the flood effect is substantially moderated, permanent vegetation has established in a marsh zone immediately adjacent to the water, a lower riparian zone occupies formerly barren sandbars, and there is an upper riparian zone where pre-dam vegetation existed (Schmidt et al. 1998).

Although annual flooding largely disappeared with the completion of the dam, greater degrees of daily variability emerged, governed by hydropower needs (Mortenson et al. 2012). Seasonal timing of relative high- and low-flow events has also been altered by river regulation (Graf 2006).

Changes in the riparian and river ecosystem post-dam have included the significant expansion of non-native *Tamarix* populations, now that beaches are rarely scoured. The loss of native riparian areas imperils the southwestern willow flycatcher (*Empidonax traillii*), which depends on riparian habitat. Elevated populations of nonnative invasive fish (Mortenson et al. 2012) threaten two endangered endemic fish that occupy the river (razorback sucker, *Xyrauchen texanus*, and humpback chub, *Gila cypha*). In addition, the cold temperature of the regulated river has been shown to reduce reproduction of both native and certain nonnative fish (Schmidt et al. 1998).

Since the 1990s, river managers have experimented with permitting flood-scale releases from the reservoir with the goals of rebuilding sandbars and improving native fish habitats. Floods have redistributed fine-grained deposits and created new backwaters, but many of these physical changes disappeared relatively quickly after the controlled flood (Schmidt et al. 2001). Furthermore, the timing of such flooding has assisted *Tamarix* to spread when it has occurred during *Tamarix* seed release (Mortenson et al. 2012).

5.31.2. Condition and Trend

In 1996, Glen Canyon Dam's operating regime shifted to modified low fluctuating flow (MLFF), as a response to Environmental Impact Statement findings and concerns about endangered species management (Schmit et al. 2005). Under MLFF, there are maximum and minimum established flow levels, as well as limits on the rate of flow change allowable during a daily period (Schmit et al. 2005).

Predicted climate change impacts that may affect the Colorado River include reduced precipitation throughout large swaths of the arid American West, including much of the Colorado River watershed; increased intensity of precipitation events when they do occur (which will lead to high levels of runoff and thus potentially increased localized flooding); and reduced snowfall relative to rainfall, resulting in faster release of moisture from the watershed (i.e., a lower contribution from

snowmelt). At the same time, increased water consumption and demand throughout the Colorado River watershed is likely, due to a combination of increased human population and higher temperatures. These impacts could reduce the overall amount of water present in the Colorado River reach, while increasing its variability across seasons and even days (Garfin 2013).

5.31.3. Summary

As a result of dam regulation and reduced water throughout the Colorado River system, the incidence of powerful floods is far below natural. Water temperatures and sediment are considerably reduced, but permanent riparian vegetation and the occurrence of nonnative species have increased. A return to unregulated flow is highly unlikely; however, some sort of adaptive management using controlled flooding at various frequencies is likely to continue (Meretsky et al. 2000).

5.31.4. Level of Confidence

Records of historical Colorado River hydrology are fairly complete and include direct measurements, maps, and other sources of data. The changes identified here can be presented with a high level of confidence.

5.31.5. Sources of Expertise

This section was prepared by Clare Aslan.

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5.32. Stressors: Climate Change

5.32.1. Description



Both hydrology and temperature in the Grand Canyon region are expected to be significantly affected by climate change over the next few decades. For this reason, of all the stressors evaluated in this assessment, climate change is likely to have the most widespread and profound effects on ecosystem integrity (USDA Forest Service Photo).

Both hydrology and temperature in the Grand Canyon region are expected to be significantly affected over the next few decades by climate change. Due to the extreme topographic diversity of the region, the GGCLA area is characterized by a broad range of microsites and microclimatic conditions. As a result, many species in the region have finely tuned climatic requirements (e.g. sentry milk-vetch; Monahan and Fisichelli 2014), suggesting that climate change may be a significant stressor in this system. Canyon rim temperatures are projected to increase by an average of 7°F over the next 60 years (Kunkel et al. 2013), and models based on both low- and high-emissions scenarios of greenhouse gas emissions project that some vegetation types currently occurring within the GGCLA may become extirpated from the park over the same time period (Rehfeldt et al. 2012). For this reason, of all the stressors evaluated in this assessment, climate change is likely to have the most widespread and profound effects on ecosystem integrity.

5.32.2. Methods

Observations of historical climate trends in the GGCLA area are based on data from a long-term weather station on the south rim at Grand Canyon Village. These observations reveal that temperatures have increased over the past century, with precipitation varying between wet and dry periods (Fisichelli 2013). Indeed, along with most other U.S. National Parks, Grand Canyon NP is currently experiencing average temperatures typical of the warmest end of historical temperature ranges, suggesting that future temperatures may exceed historical limits (Monahan and Fisichelli 2014).

Regional spatial trends were assessed by acquiring downscaled climate maps from Adapt West (https://adaptwest.databasin.org/pages/adaptwest-climatena). We assessed the difference between the mean annual temperature 1981-2010 average and projections for 2050 temperature and precipitation based on RCP 8.5 ensemble projections, a high emissions scenario (Wang et al. 2016).

5.32.3. Condition and Trends

Species will respond differently to changes in precipitation and temperature. The GGCLA area encompasses a wide diversity of life zones in a compressed geographic region. Species already distribute themselves according to bands of temperature and precipitation in that region. Shifts in these abiotic factors are likely to result in species occupying different parts of the region, or even disappearing locally if suitable conditions no longer exist. Furthermore, formerly associated species may no longer occupy the same ranges under changed climate conditions. For example, pinyon and juniper are expected to respond differentially to climate change and therefore may no longer co-occur in the future (National Parks Conservation Association 2010). Meanwhile, some introduced species, such as tamarisk (*Tamarix* spp.), will likely benefit from climate change, which may cause an increase in suitable habitat (Ikeda et al. 2014).

Climate change is likely to affect the flow of regional seeps and springs and also the Colorado River, which may impact both biorichness and human users of the Grand Canyon. In such an arid region, any reduction in flow could impact the number of species able to utilize the water. Furthermore, water and dam management will have to adjust for needs downstream under a reduced total water volume, with unpredictable consequences (National Parks Conservation Association 2010; Bureau of Reclamation 2012).

Climate change is expected to increase wildfire potential in the greater Grand Canyon landscape and across the Colorado Plateau. Higher temperatures and reduced snowmelt will contribute to drier fuels and longer fire seasons (Fisichelli 2013); the resources needed to fight such fires may make it difficult for stakeholders in the region to meet other resource needs (National Parks Conservation Association 2010). Furthermore, changing fire regimes in this region are propelled by, and also serve to facilitate many introduced species, such as flammable cheatgrass (*Bromus tectorum*; see Exotic Plants section), suggesting that changes in these populations may occur even faster than simple climate models might predict.

Projected temperature and precipitation changes over the next few decades suggest that particularly large increases in temperature will be observed in the eastern half of the analysis area, and

precipitation is likely to decrease in the eastern half of the analysis area, with the largest decreases on on the Kaibab Plateau on the north rim (Figures 75 and 76).

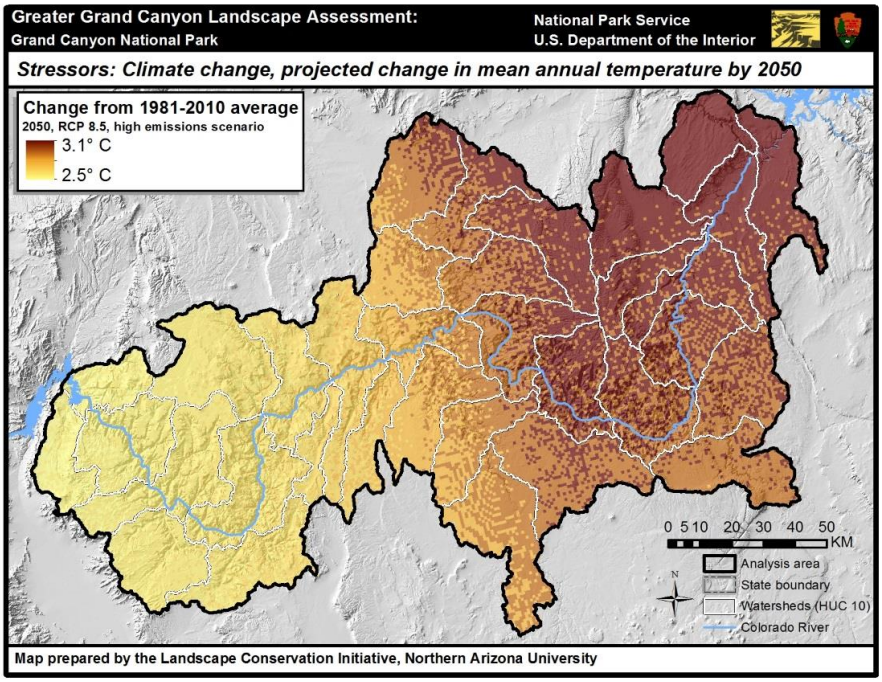


Figure 75. Projected change in mean annual temperature by 2050, compared to 1981-2010 average. Values are based on RCP 8.5 ensemble projections, a high emissions scenario (Wang et al. 2016).

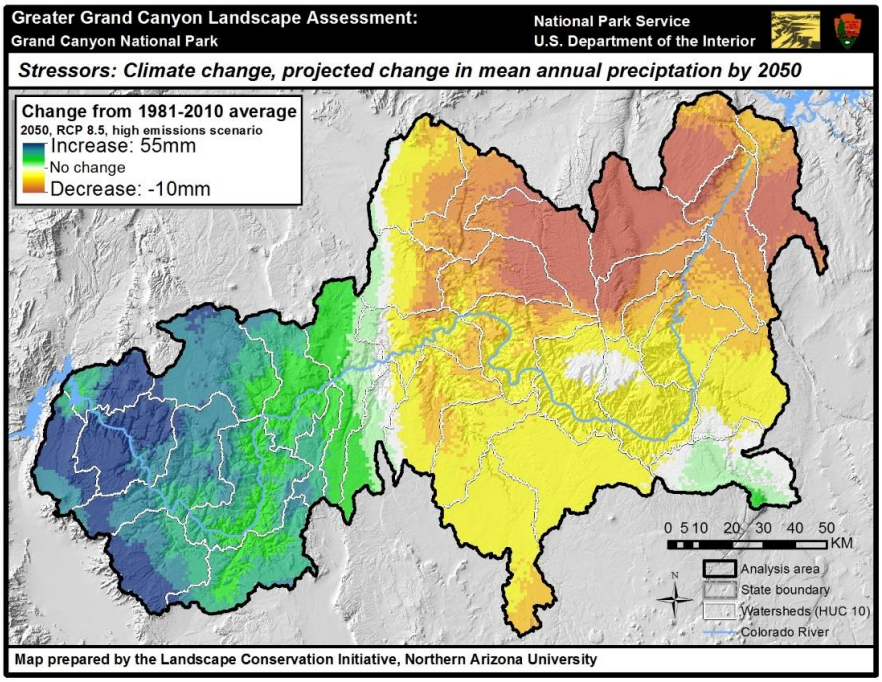


Figure 76. Projected change in mean annual precipitation by 2050, compared to 1981-2010 average. Values are based on RCP 8.5 ensemble projections, a high emissions scenario (Wang et al. 2016).

5.32.4. Summary

Climate change is likely to affect protected areas across the United States over the next century. Projections indicate that only 8% of protected areas nationwide will continue to experience current average temperatures (Hansen et al. 2014). Across the state of Arizona, temperatures in the next 50 years are expected to warm by up to 6 °F (Figure 75), and extreme climatic events (i.e., extreme temperatures and extreme precipitation events) are expected to become more frequent (Seager et al. 2007; National Parks Conservation Association 2010). In addition, average precipitation in the Grand Canyon region is expected to decline by up to 10% over the next 50 years (National Parks Conservation Association 2010), although there is likely to be considerable seasonal variability (Fisichelli 2013). This may in itself impact Colorado River and tributary flows, but additional and perhaps more dramatic effects could result from reduction in snowmelt moisture due to warmer temperatures, more frost-free days, and reduced precipitation (Fisichelli 2013). Since snowmelt maintains steady delivery of water to aquifers and surface flows over much of the year, a loss of snow accumulation could mean that the precipitation that is received by the region will largely be subject to quick runoff, potentially generating flooding, erosion, and drought as well as decreased aquifer recharge (Bureau of Reclamation 2012; Fisichelli 2013).

5.32.5. Data Needs

Climate change models are continually improving, but uncertainty in temperature and precipitation projections remains, particularly at finer scales that are most relevant to resource management. Continued enhancement of models and the emergence of new modeling techniques could reduce that uncertainty somewhat. In the meantime, a better understanding of how species of concern and introduced species respond to projected temperature and precipitation scenarios would help stakeholders across the region prepare for potential future conditions.

5.32.6. Level of Confidence

Our maps of projected climate change are based on differences between current and projected temperature and precipitation using projection data acquired from AdaptWest climateNA and a high greenhouse gas emissions scenario, RCP 8.5 (Wang et al. 2016). Reduction in global emissions would reduce the amount of predicted change.

5.32.7. Sources of Expertise

This section was prepared by Clare Aslan with analytical assistance from Jesse Anderson.

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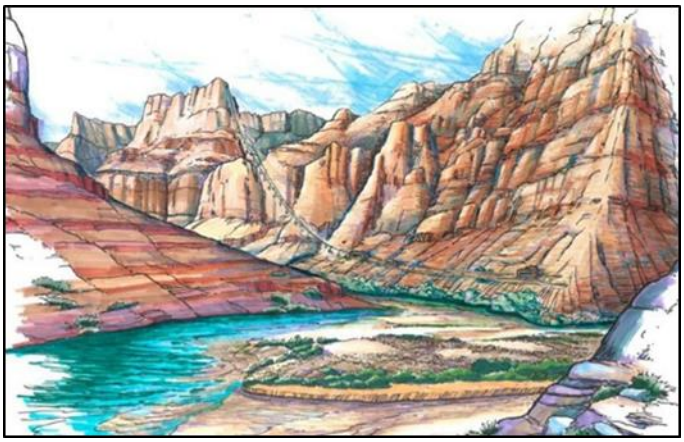
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5.33. Stressors: Development

5.33.1 Description



Current development around the Grand Canyon Landscape Assessment analysis area is concentrated in several areas. New development proposals have created controversy in the region. Photo: Artist rendering of the proposed escalade tramway. (Confluence Partners photo by AP).

Development in the Greater Grand Canyon Landscape Assessment (GGCLA) area is currently concentrated in Tusayan, Grand Canyon Village, North Rim Village, and Jacob Lake. Two major development proposals in the region have potential to impact the condition of GGCLA resources: the Grand Canyon Escalade tourism development near the confluence of the Little Colorado and Colorado Rivers, and a major new housing and commercial development in Tusayan's Kotzin Ranch. Developmental components in the region also include power lines and communication towers. Future placement of additional power lines is planned as part of energy development across the western states.

The proposed new Grand Canyon Escalade tourism development would be built on the Navajo Reservation outside the borders of Grand Canyon NP at the confluence of the Little Colorado River and Colorado River. The development would include a hotel, restaurants, retail shops, and other tourism amenities, and would feature a gondola tramway transporting visitors to a river walk at the bottom of the canyon (outside the park). The Escalade tourism development, which would occupy 420 acres, would impact the eastern end of the GGCLA analysis area (Lee 2014).

Substantial controversy is associated with the Escalade development because the confluence of the Colorado and Little Colorado Rivers is sacred to several Indian tribes. Also, the project has the potential to impact sacred sites, the environment, and the viewsheds of the Grand Canyon region.

In Tusayan, a new 2,200-home development, which would include 3 million square feet of commercial space, was approved by Tusayan voters but easement approval was declined by the Kaibab National Forest. The new development would have increased Tusayan's water demand by 400% (LA Times 2014).

5.32.2. Condition and Trend

Existing development across the GGCLA area includes the towns of Grand Canyon Village and Tusayan, which contain most of the tourism infrastructure (hotels, airport, shops, and restaurants) as well as housing for park employees (Figure 77). Most of this existing development is on the south rim, although the North Rim Village and Jacob Lake contain additional tourism development on the north rim. More broadly, construction of new power lines will result from planned energy development across western states (Holtkamp and Davidson 2009).

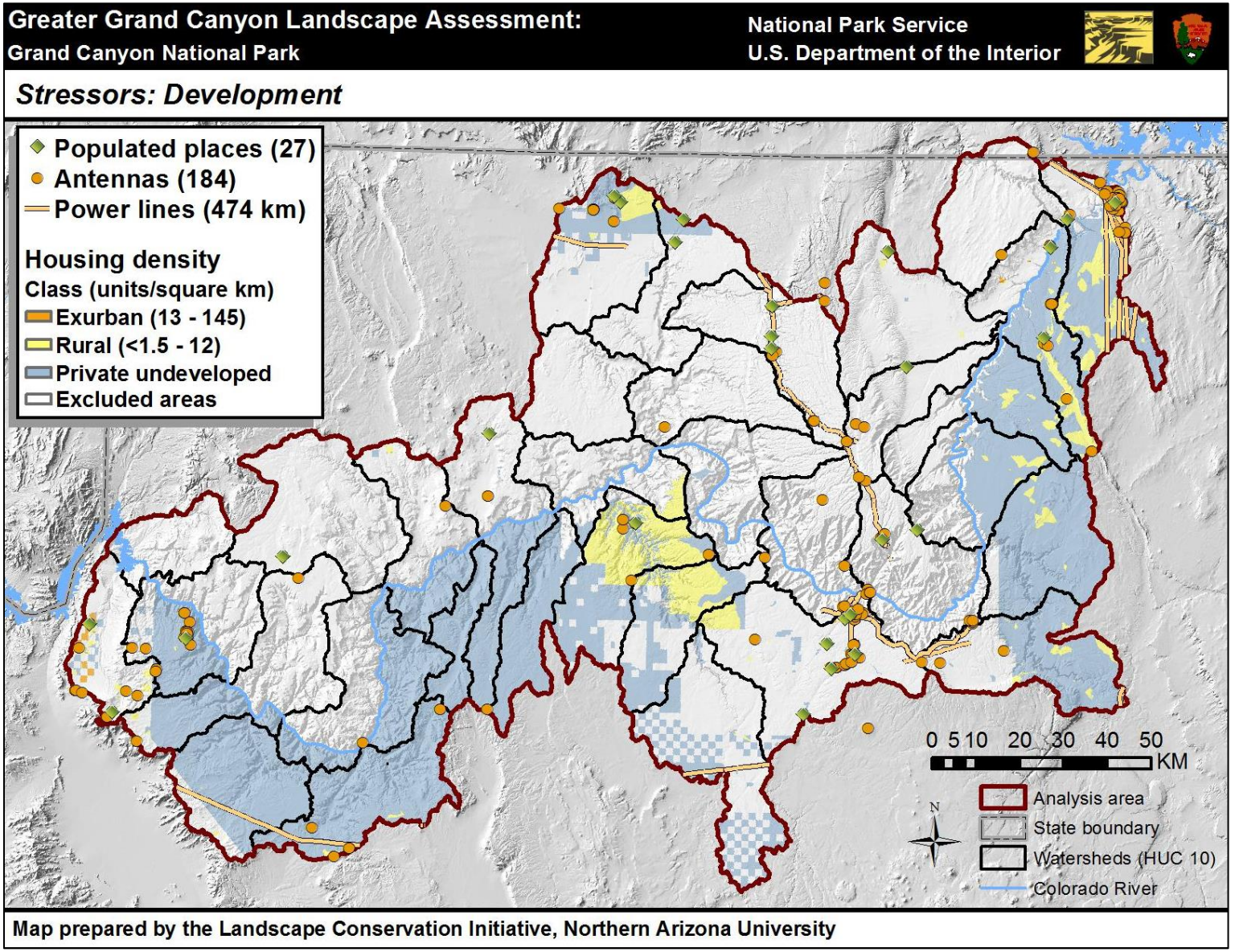


Figure 77. Population and infrastructure density across the greater Grand Canyon landscape.

5.33.3. Summary

Proposed new development would impact regional water sources and viewshed, as well as cultural resources. Both the Tusayan and Escalade proposals are controversial and are meeting opposition from the park itself, with regional stakeholders falling on both sides of the debate (LA Times 2014).

5.33.4. Level of Confidence

Existing development data are derived from the 2011 USGS National Land Cover Dataset. Mapping data for power lines and communication towers were taken from TIGER/Line 2008, FCC, Grand Canyon National Park, and the Kaibab National Forest. The map displaying these planned power lines was produced by Argonne National Laboratory and is available as part of the file "Programmatic Environmental Impact Statement, Designation of Energy Corridors on Federal Land in the 11 Western States" (DOE/DOI 2008).

The extent of open roads is another component of development, because roads channel human activities and can directly impact species by, for example, fragmenting the natural habitat. For spatial analysis, road layers are available from Kaibab National Forest and Grand Canyon National Park. Additional layers depicting roads without an assessment of status (open or not) are available from BLM and TIGER/Line 2012.

5.33.5. Sources of Expertise

This section was prepared by Clare Aslan with assistance from Jill Rundall.

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5.34. Stressors: Introduced Species and Expanding Ranges

5.34.1 Description



Bison grazing at Grand Canyon NP (Photo by R. Warrin creative commons license CC BY-NC-ND 2.0).

Grand Canyon, like much of western North America, supports populations of introduced ungulates that can place additional stress on ecosystem structure and function. Of particular concern are species with expanding populations that degrade or otherwise impact rare habitat types and/or vulnerable native species. Within the GGCLA area of analysis, several species are of concern, primarily because of their impacts on springs, seeps, wetlands and other rare habitat types associated with naturally occurring water. Some large vertebrates also impact archaeological sites and other cultural and biological resources (Brennan 2015). Here we address three species of interest: Bison, Rocky Mountain Elk, and feral Burros. Range expansion of the native Javelina into Grand Canyon NP also presents an emerging concern.

Bison

The bison herd currently expanding across the Kaibab Plateau, including areas within the park, was brought to Arizona in 1906 by Charles “Buffalo” Jones in an attempt to breed a robust cattle-bison hybrid that could survive harsh winters on the Kaibab Plateau. While hybridization was somewhat successful, the operation was not economically viable, and was eventually abandoned. In 1925, the state of Arizona purchased the remaining herd, which is managed by Arizona Department of Game and Fish Department. Until recently, the herd was confined to the House Rock Valley Bison Allotment (now known as the House Rock Wildlife Area), as stipulated in agreements with the Kaibab National Forest, signed in 1950 and 1973. The bison are a prized objective for trophy hunters. Between 1990 and 1997, bison counts were between 69 and 96 animals, following managed hunts within the House Rock allotment. In the late 1990s or early 2000s, the bison began to move from House Rock Wildlife Area, through parts of the Saddle Mountain Wilderness that had experienced

large fires, and onto higher elevation areas atop the Kaibab Plateau, including favorable habitat within Grand Canyon National Park. In 2008, herd numbers were estimated at over 300 head, while today biologists think the number is closer to 600, with the majority of the bison staying within Grand Canyon National Park, where hunting is not permitted, for most of the year (Grand Canyon National Park 2016; Reimondo 2012; Reimondo 2014; Reimondo et al. 2015).

Rocky Mountain Elk

Arizona's Merriam's elk were extirpated in the early 1900s. In 1913 another subspecies, the Rocky Mountain Elk, was introduced to eastern and central Arizona from Yellowstone National Park (Beschta and Ripple 2009). Over the next several decades, the distribution of Rocky Mountain Elk expanded northward, towards the Grand Canyon. The first documented elk sighting inside Grand Canyon National Park occurred in 1965, near the Grandview Trial. Elk populations have been increasing ever since, and today they are commonly encountered throughout the South Rim, including the heavily visited areas and residential neighborhoods of Grand Canyon Village. Elk are attracted to developed areas because of the availability of water and ornamental vegetation, including lawns (Beschta and Ripple 2009), and because the park constitutes a refuge from heavy hunting pressure on surrounding public lands.

Feral Burros

Burros (*Equus asinus*) were originally introduced to the Grand Canyon in the 1800s as pack animals to support mining operations. Over the years, many were set loose or wandered, becoming feral. In the 1970s, studies demonstrated that the ecological impacts of feral burros in Grand Canyon included altered riparian habitat and native plant composition, damage to soil crusts, impacts to native small mammal communities and potential competition for forage with native desert bighorn sheep (Walters and Hansen 1978; Reimondo 2012). The Wild Free-Roaming Horses and Burros Act of 1971 (Public Law 92-195) established protection and management of burros on public lands, but national parks and wildlife refuges were exempted. In the park, managing burros proved to be highly controversial. Following completion of an environmental impact statement in 1980, live burros were removed from Grand Canyon National Park by private organizations, followed by the culling of remaining animals.

5.34.2. Condition and Trend

Bison

Of the introduced fauna described here, bison represent the management challenge most actively studied in recent years. A tri-agency collaborative group, involving Grand Canyon National Park, the Arizona Game and Fish Department, and the Kaibab National Forest worked for several years to coordinate efforts across management jurisdictions and to identify mutually agreeable management options to control bison herd size and location. Under provisions of the National Environmental Policy Act, the park launched an Environmental Impact Statement effort in 2013, to formally develop and analyze management options inside Grand Canyon National Park. The process is currently being restructured as an Environmental Assessment, to allow expedited management efforts to reduce herd size within the park "as quickly as possible" to a target herd size of 80-200 animals. Recent research primarily addresses impacts on park resources and bison behavior. We focus here on research establishing current condition and trend in bison numbers and impacts.

Bison Numbers and Locations

Estimates of bison number vary widely, but there is a consensus that the herd is larger than at any time since its introduction to the region in the early 20th century, and that it is increasing rapidly in size. Simple demographic models used by the Arizona Game and Fish Department annually from 1980-2013 show herd numbers ranging from 88 to 195 individuals (AZGFD 2013). Herds of over 200 individuals were regularly spotted on the Kaibab Plateau in 2014, with total population size estimated at well over 300 (Reimondo 2014), and recent NPS estimates place the size of the herd at 400-600 animals (Grand Canyon National Park, 2016). Aerial observation conducted by several agencies have spotted groups of over 150 individuals in multiple areas, but no statistically informed, systematic survey has been conducted. The complex topography of Grand Canyon, with extensive forested areas, indicates a need for systematic survey efforts that incorporate estimation of detection probabilities, in order to generate sound estimates of bison population size and temporal trends. Bison congregate in larger numbers within the park and on and around its boundary with the North Kaibab Ranger District, particularly during summer months. In the winter months, smaller groups tend to move to the canyon rim, where forage is more easily accessed and temperatures are warmer on south-facing slopes (Figure 78).

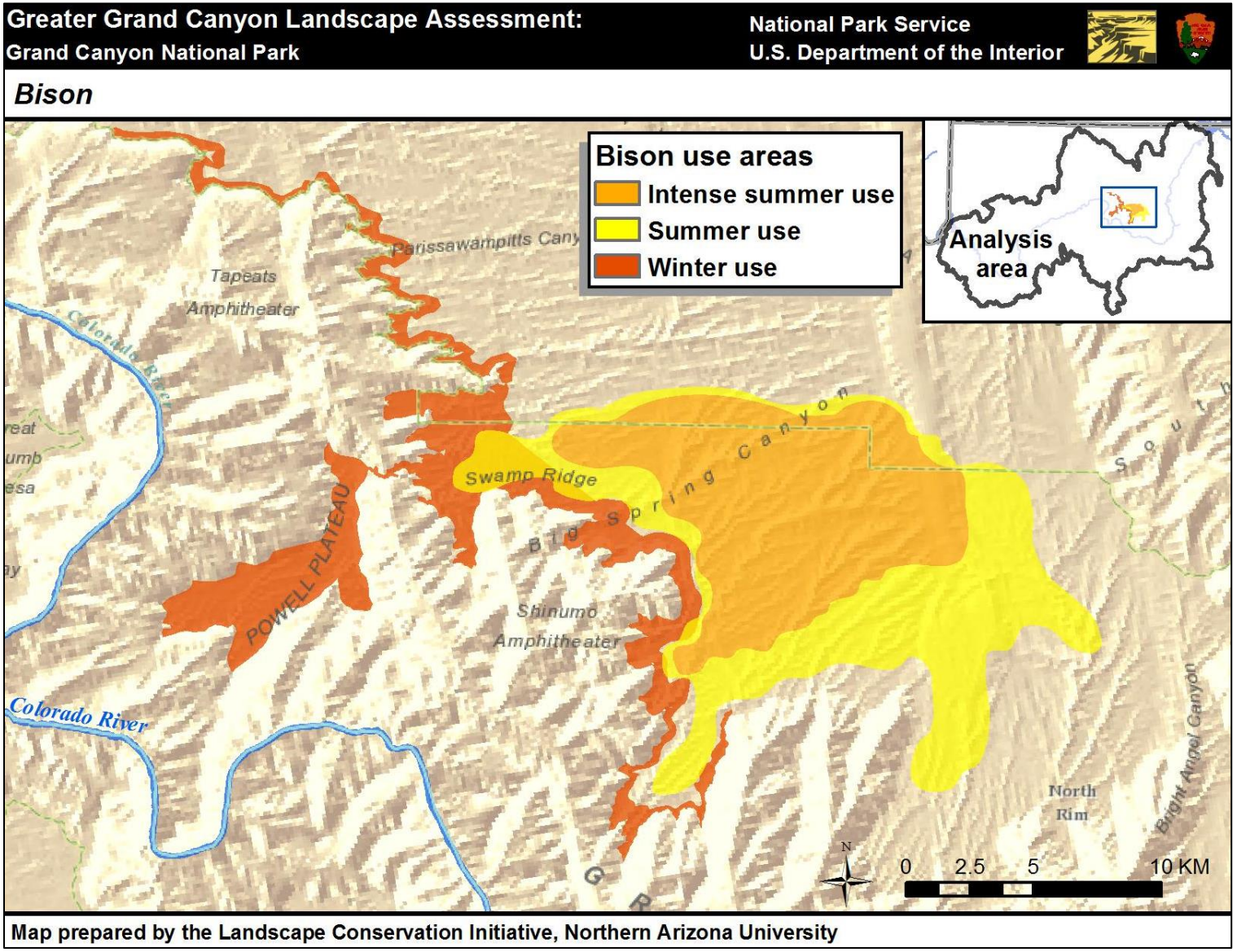


Figure 78. Bison use areas across the greater Grand Canyon landscape were determined using known locations and bison sign (scat and tracks).

Bison Impacts

Bison impacts have been a focus of recent research and monitoring. Work includes assessing bison impacts to meadows, archaeological sites, springs, wetlands and other water sources. Bison impacts to meadows and wetlands have been studied on the Kaibab Plateau at sites both inside and outside the park, using vegetative sampling and bison scat counts to estimate bison use across a suite of suitable sites (Reimondo et al. 2012; Reimondo 2014). Linear regression was employed to explore the relationship between bison scat counts, vegetation cover and exposed soil. Sampling was done in 2010/2011, and repeated in 2014. Bison impacts documented at sites in 2010/2011 were found to be increasing in scale and intensity when sites were resampled in 2014.

As indicated by scat counts, bison use of areas was found to have a significant ($p<0.05$) positive correlation with exposed soil and a negative correlation with vegetative cover (Figure 79). Bison use also had a significant negative correlation with the height of forbs and graminoids (Figure 79). At 11 of 16 sites assessed, vegetation cover decreased from 2011 to 2014 (Table 63). Wetland sites that received moderate or high use by bison in 2010 or 2011 appeared to continue to receive heavy summer use over time. However, wetlands that were dry in 2014, following a winter with low precipitation, appeared to have older signs of bison use, as indicated by scat and wallows, suggesting that bison utilize sites with greater frequency and longer duration when water is present. Trends in bison impacts are difficult to assess because of high spatially variability, due in part to the seasonal variation in water availability.

Reimondo (2014) established GPS locations of bison wallows for monitoring the possible spread of invasive plants into heavily disturbed areas. A separate park effort in 2014 estimated the average size of bison wallows to be about 150 sq. ft. per wallow in the areas of Lower Park, Little Lower Park and Basin meadows. An additional field campaign assessing vegetative impacts was conducted in fall of 2014, and data are currently under analysis.

Rocky Mountain Elk

The Grand Canyon elk population has not been consistently monitored or studied by the park and, therefore, population size and trends cannot be estimated quantitatively. The general understanding is that elk herds inhabiting the south rim of Grand Canyon National Park and adjacent lands have been increasingly consistently over the past decade (Stroud-Settles pers. com.). In 2014, a pilot ungulate count was initiated with the goal of developing an annual effort to monitor elk densities within Grand Canyon Village and inform an elk management plan for the park. The pilot effort attempted to obtain a complete census of all elk in the count area, using volunteers to walk closely spaced transects. In 2015, Grand Canyon National Park began an effort to estimate elk population size by identifying individuals and determining sex ratios via DNA extracted from fecal pellets. Analysis will employ mark-recapture estimation techniques.

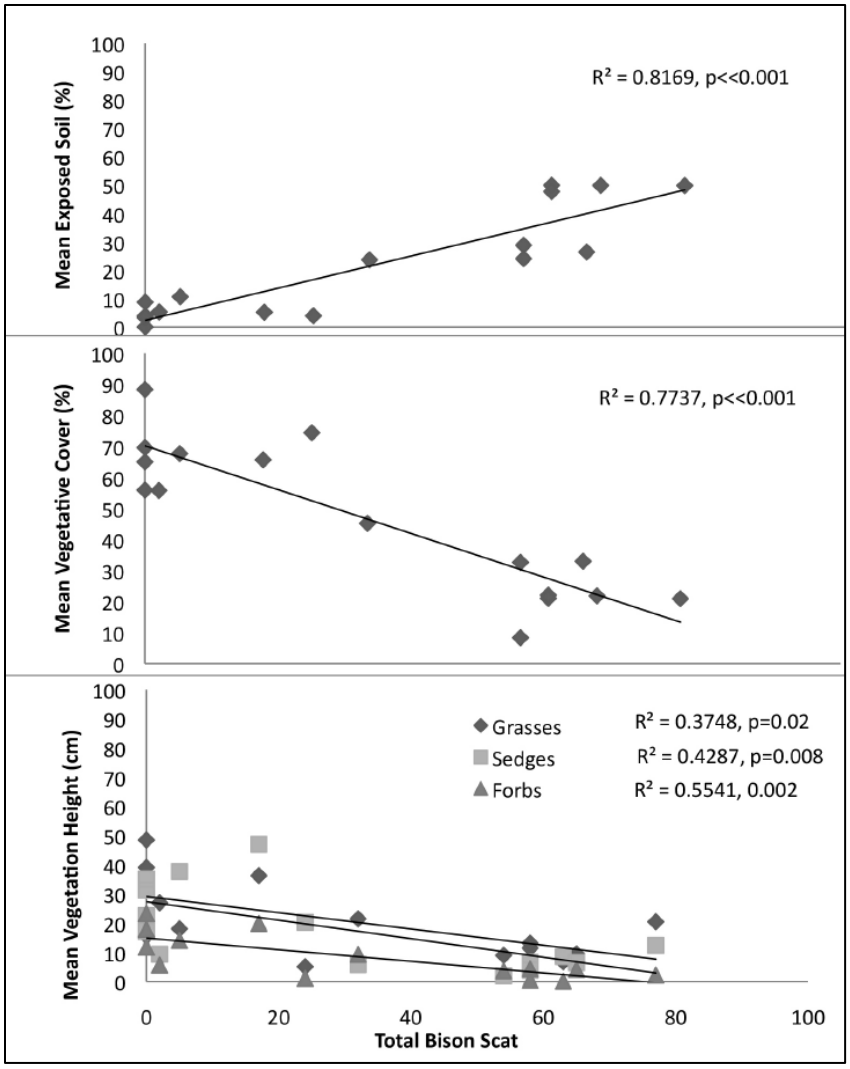


Figure 79. Linear regressions of 2010 comparative study sites show significant trends ($p > 0.05$) of increased exposed soil (top), decreased vegetative cover (middle), and decreased vegetation height (bottom) as a function of increasing bison use. Figure used with permission from Reimondo 2014.

Table 63. Trends in mean vegetative cover and total bison scat between 2010 and 2014 at 16 sites on the Kaibab Plateau. Eleven of 16 sites had lower mean vegetation cover and higher scat counts in 2014 (Table used with permission from Reimondo 2014).

Site	2010 Mean Veg Cover	2014 Mean Veg Cover	Veg Cover trend (+/-)	2010 total Bison Scat	2014 Total Bison Scat	Scat Count Trend (+/-)
FAWN	8.4	59.8	+	54	21	-
HADES	65.0	45.7	-	0	0	=
BASIN	67.7	66.6	-	5	24	+
LPL	74.4	44.8	-	24	61	+
UN38	88.3	58.6	-	0	4	+

Table 63 (continued). Trends in mean vegetative cover and total bison scat between 2010 and 2014 at 16 sites on the Kaibab Plateau. Eleven of 16 sites had lower mean vegetation cover and higher scat counts in 2014. (Table used with permission from Reimondo 2014.)

Site	2010 Mean Veg Cover	2014 Mean Veg Cover	Veg Cover trend (+/-)	2010 total Bison Scat	2014 Total Bison Scat	Scat Count Trend (+/-)
GLOR	32.7	42.9	+	54	17	-
MILK	65.7	85.3.	+	17	24	+
SPR03	22.1	40.0	+	58	21	-
SPR02	21.9	2.0	-	65	50	-
COFFEE	21.1	10.4	-	58	80	+
POND42	21.0	39.2	+	77	88	+
KANA	69.6	41.4	-	0	6	+
CPOND	55.8	30.6	-	2	50	+
CSPRING	33.0	13.0	-	63	80	+
RROOST	55.9	48.7	-	0	29	+
BARREL	45.2	11.7	–	32	37	+

Feral Burros

Feral burros have largely been removed from Grand Canyon National Park. Small herds of burros still exist in the Grand Canyon region, including in BLM Herd Management Areas in the western portion of the GGCLA analysis area (BLM 2014). The park uses fencing at potential access points to restrict burro re-entry (Reimondo 2012) and receives occasional anecdotal reports of burro presence around Great Thumb Mesa and the redwall layer along the Sinyella Fault. Burros continue to impact areas around Olo and National Canyons. Pilot efforts to study burro impacts in 1997 were revisited in 2003, and the trails created by feral burros were still visually apparent.

5.34.3. Summary

The presence of the large, introduced ungulates described here present complex management challenges. They may be valued as game species hunted outside the park, while seen as a stressor to natural and cultural resources within. Elk and bison also generate significant impacts to visitors, in the form of human-wildlife conflicts and vehicle collisions. Greater understanding of the specific locations and numbers of these animals may help to address whether and where they have an appropriate place within the park and across the Greater Grand Canyon Landscape. Because these species are viewed and managed differently within and outside the park, greater clarity in management policy is needed to guide collaborative field efforts to reduce impacts to native species and ecosystems.

In addition to the historic, current and emerging management issues addressed here, a possible future species of interest for the Grand Canyon region is the javelina. Javelina are native to central and southern Arizona, but they are a recent newcomer to Grand Canyon National Park, likely arriving

during the past decade. While no efforts to introduce javelina to the Grand Canyon region are known to have taken place, their natural range expansion has the potential to introduce a novel stressor, in the form of soil and vegetation disturbance caused by their foraging for roots and tubers, and human-wildlife encounters on trails. Javelina movements and range expansion are currently understood through anecdotal evidence, but more targeted efforts could be an important area for future research to inform management, both of the javelin and the species impacted by their presence.

5.34.4. Level of Confidence

Of the metrics discussed here, bison impacts to vegetation and soil have been most systematically monitored, with repeat measures showing trends over 4 years. These data present a high level of confidence. Bison population and growth rate estimates have lower confidence. They are based on aerial observation and observed cow:calf ratios, or on "best guess" estimates from wildlife specialists. Systematic surveys accounting for detection probability in the rugged North Rim landscape are advised. Elk and burro numbers and impacts have not been regularly monitored in recent years, and estimates of population size and distribution have lower confidence.

5.34.5. Sources of Expertise

This section was prepared by Sasha Stortz and Tom Sisk, with assistance from Brandon Holton, Janice Stroud-Settles, and Greg Holm.

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5.35. Stressors: Exotic Plants

5.35.1. Description



Out of more than 1,750 plant species found in Grand Canyon NP, 198 are exotic (Grand Canyon NP 2014). The vast elevational and topographic variability of the Grand Canyon enables a wide variety of exotics to find a foothold in the park. Photo: Exotic cheatgrass (Bromus tectorum) (NPS photo by Robb Hannawacker).

Across the GGCLA area, exotic plant species of primary concern include those that carry fire and transform fire regimes, and those that may alter riparian habitat. According to the National Parks Conservation Association (2010), species of particular concern in the park include tamarisk (*Tamarix* spp.), Russian olive (*Elaeagnus angustifolia*), camelthorn (*Alhagi maurorum*), Asian mustard (*Brassica tournefourtii*), ravennagrass (*Saccharum ravennae*), spiny sowthistle (*Sonchus asper*), date palm (*Phoenix dacylifera*), Himalayan blackberry (*Rubus discolor*), Dalmatian toadflax (*Linaria dalmatica*), bull thistle (*Cirsium vulgare*), Scotch thistle (*Onopordum acanthium*), musk thistle (*Carduus nutans*), rush skeletonweed (*Chondrilla juncea*), puncturevine (*Tribulus terrestris*), houndstongue (*Cynoglossum officinale*), foxtail barley (*Hordeum jubatum*), and cheatgrass (*Bromus tectorum*).

One of the best-studied invasive plant species in the Grand Canyon region is the shrub tamarisk, which invades riparian areas and establishes monocultures along waterways. Tamarisk is the subject of much controversy. Although some studies identify its benefits to wildlife (e.g., as nesting habitat for the endangered southwestern willow flycatcher), other studies indicate that the shrub supports a low diversity of wildlife species relative to native shrubs (Lovich and Melis 2007). It remains uncertain whether sensitive bird species, such as the yellow-billed cuckoo, are widely able to use tamarisk for nesting (Sogge et al. 2008). Managed water releases from Glen Canyon Dam have

contributed to the spread of tamarisk throughout the region—consistent and moderate water flows allow tamarisk to establish and dominate riverbanks whereas more natural, variable flows are more conducive to native species establishment (Lovich and Melis 2007). Predicted climate change in the region in the future is likely to promote tamarisk establishment still further (Ikeda et al. 2014).

In the broader GGCLA region, cheatgrass (*Bromus tectorum*) is widespread on the canyon rims and across the Kaibab Plateau. Cheatgrass is of particular concern because it produces large amounts of biomass that become fine fuel, carrying fires that are hotter and more frequent than natural fire regimes. In addition, the invasive grass responds positively to burning, returning in greater densities than had existed pre-fire. Research on the Kaibab Plateau and elsewhere in the region strives to identify management techniques that can reduce cheatgrass prevalence and populations (Neal et al. 2009), and many such efforts are currently focused on the seeding of native species to outcompete cheatgrass (Shinneman and Baker 2009).

5.35.2. Condition and Trend

Regions that show high occurrence of exotic species include Kaibab National Forest tracts both north and south of the park, where cheatgrass is particularly prevalent (Figure 80), and the Colorado River riparian areas invaded by tamarisk.

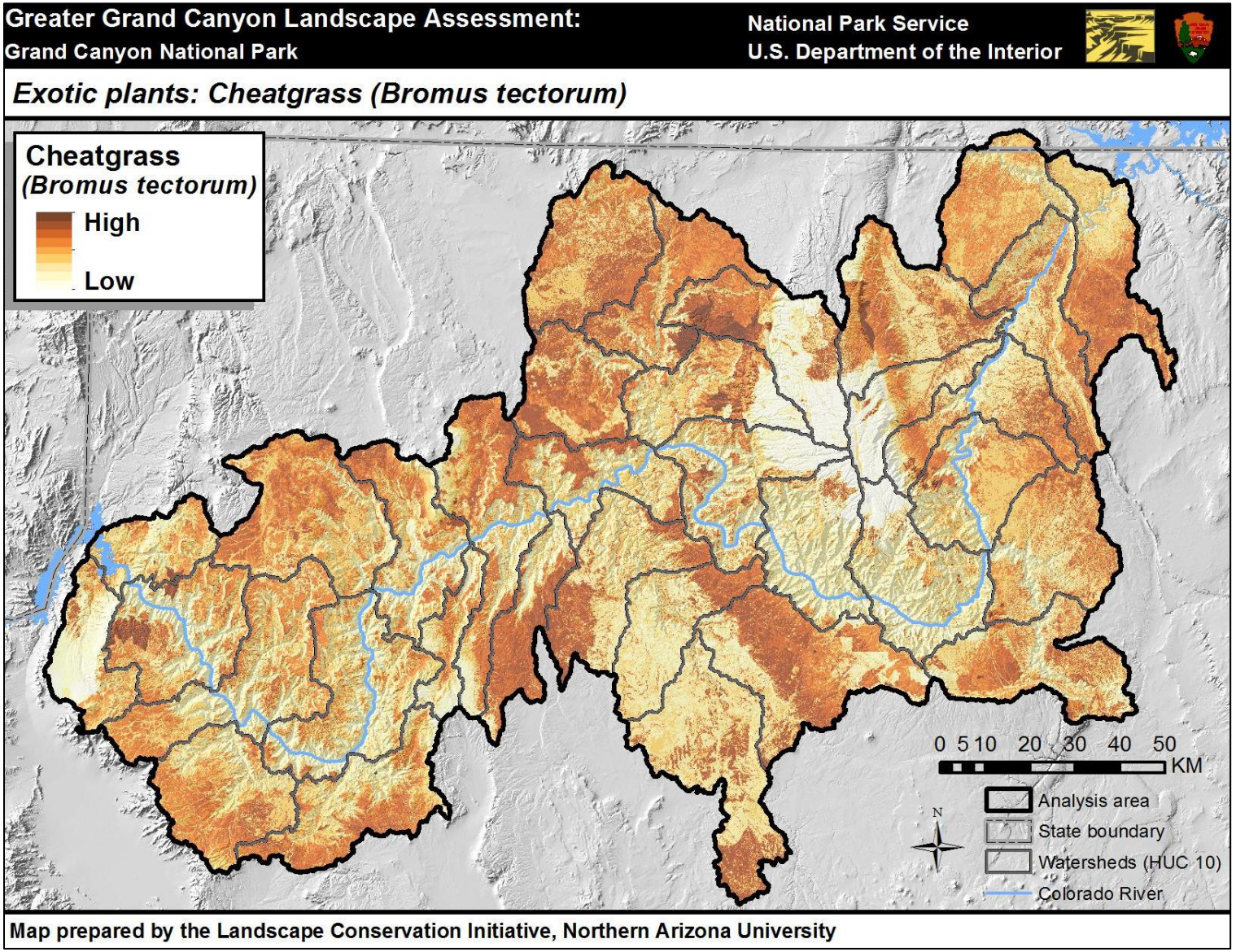


Figure 80. Distribution of cheatgrass across the landscape.

5.35.3. Summary

Exotic species are present in all habitat types in the GGCLA area (Table 64), but are of particular concern where they impact riparian communities and fire regimes. Efforts to restore natural fire and flow conditions have the potential to benefit native species that might outcompete exotics, but future climate change could impede these restoration efforts and result in increased species assemblage transformation.

Table 64. Exotic species with spatial records in Grand Canyon NP.

Family	Species
Amaranthaceae	*Amaranthus albus; Amaranthus retroflexus; Chenopodium album; Chenopodium murale; Corispermum nitidum; Kochia scoparia; Salsola tragus*
Apiaceae	*Apium graveolens; Conium maculatum; Foeniculum vulgare (L.) Karst*
Apocynaceae	*Vinca minor*
Arecaceae	*Phoenix dactylifera*
Asteraceae	*Acroptilon repens; Carduus nutans; Centaurea biebersteinii; Centaurea diffusa; Centaurea melitensis; Chondrilla juncea; Cichorium intybus; Cirsium arvense; Cirsium vulgare; Conyza canadensis; Hieracium aurantiacum; Lactuca serriola; Leucanthemum vulgare; Onopordum acanthium; Pseudognaphalium luteoalbum; Scorzonera laciniata L.; Senecio vulgaris; Sonchus asper; Sonchus oleraceus; Taraxacum laevigatum; Taraxacum officinale; Taraxacum officinale ssp. officinale; Tragopogon dubius*
Boraginaceae	*Cynoglossum officinale*
Brassicaceae	*Alyssum minus; Brassica tournefortii; Camelina microcarpa; Capsella bursa-pastoris; Cardaria draba; Chorispora tenella; Descurainia sophia; Erysimum repandum; Lepidium latifolium; Lepidium perfoliatum; Malcolmia africana; Rorippa nasturtium-aquaticum; Sisymbrium altissimum; Sisymbrium irio; Thlaspi arvense*
Cannabaceae	*Cannabis sativa*
Convolvulaceae	*Convolvulus arvensis*
Eleagnaceae	*Elaeagnus angustifolia*
Fabaceae	*Alhagi maurorum; Lathyrus latifolius; Medicago lupulina; Medicago sativa; Melilotus alba; Melilotus indicus; Melilotus officinalis; Trifolium hybridum; Trifolium repens*
Geraniaceae	*Erodium cicutarium*
Lamiaceae	*Lamium amplexicaule L.; Marrubium vulgare; Mentha spiccata L.; Nepeta cataria; Prunella vulgaris; Salvia aethiopis*
Malvaceae	*Alcea rosea; Malva neglecta; Malva parviflora*
Plantaginaceae	*Linaria dalmatica; Plantago lanceolata; Plantago major; Veronica anagallis; Veronica anagallis-aquatica*

Table 64 (continued). Exotic species with spatial records in Grand Canyon NP.

Family	Species
Poaceae	*Aegilops cylindrica; Agropyron desertorum; Agrostis stolonifera; Bothriochloa ischaemum (L.) Keng; Bromus berterianus; Bromus catharticus; Bromus diandrus; Bromus inermis; Bromus japonicus; Bromus rubens; Bromus tectorum; Cenchrus spinifex; Cortaderia selloana; Cynodon dactylon; Dactylis glomerata; Elymus repens; Eragrostis cilianensis; Hordeum jubatum; Hordeum marinum; Hordeum murinum; Lolium arundinaceum; Lolium perenne; Phleum pratense; Piptatherum miliaceum; Poa annua; Poa compressa; Poa pratensis; Polypogon interruptus; Polypogon monspeliensis; Polypogon viridis; Saccharum ravennae; Schismus arabicus; Schismus barbatus; Secale cereale L.; Setaria pumila (Poir.) Roem. & Schult.; Setaria verticillata; Setaria viridis; Thinopyrum intermedium; Triticum aestivum*
Polygonaceae	*Polygonum argyrocoleon; Polygonum aviculare; Rumex acetosella; Rumex crispus*
Portulacaceae	*Portulaca oleracea*
Ranunculaceae	*Ceratocephala testiculata*
Rosaceae	*Rubus discolor*
Rubiaceae	*Galium aparine*
Scrophulariaceae	*Verbascum thapsus*
Simaroubaceae	*Ailanthus altissima*
Solanaceae	*Solanum elaeagnifolium*
Tamaricaceae	*Tamarix aphylla; Tamarix chinensis; Tamarix ramosissima*
Typhaceae	*Typha angustifolia*
Ulmaceae	*Ulmus pumila*
Zygophyllaceae	*Tribulus terrestris*

5.35.4. Level of Confidence

Park personnel collect extensive data on exotic plant populations as they are encountered and removed. Much of the location data used for this analysis comes from these data collection efforts. This results in high confidence in information for sites that are frequently visited by park personnel.

5.35.5. Sources of Expertise

This section was prepared by Clare Aslan with assistance from Jill Rundall.

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5.36. Stressors: Groundwater Withdrawal

5.36.1. Description



Groundwater is a critical resource for the canyon and surrounding area. Complex regional aquifers are not well understood, and well operators are not required to report pumping rates. Projected increasing regional population and groundwater withdrawal coupled with climate change depleting groundwater recharge means that future ground water withdrawal poses a high risk of reducing spring flows and shifting local groundwater divides. Photo: Water pipeline in Grand Canyon NP (NPS photo).

Groundwater is a critical resource across the greater Grand Canyon landscape, where surface water is often scarce. It supplies water to the region and also feeds springs—the places where groundwater meets the surface of the earth (Springer and Stevens 2008). Spring ecosystems provide important habitat for wildlife and backpackers, they have significant cultural value, they contribute base flow to the Colorado River and all of its perennial tributaries in the region, and their biorichness is high compared to the surrounding desert landscape.

The Grand Canyon sits on two aquifers—areas saturated with groundwater that provide water through wells and springs. The Coconino (C) aquifer is relatively shallow, consisting of sandstone and limestone units of the Kaibab, Toroweap, and Coconino formations. The Redwall-Muav (R) aquifer is a limestone layer about 3,000 feet below the surface (Pool et al. 2011). The R-aquifer, the primary aquifer for the region which extends across much of northern Arizona, is bisected by the Colorado River and the Grand Canyon. The R-aquifer is the source for most springs in the Grand Canyon on both the north and south rim, as well as the water source for most water supply wells, particularly south of the canyon (Arizona Department of Water Resources 2009, 2012; U.S. Bureau of Reclamation 2006).

The hydrogeology of the region is complex and not well understood (Rice 2012). Precipitation typically drains into sinkholes and surface fractures, flows downward through the Coconino aquifer

and into the karstic R-aquifer below, and ultimately emerges at springs at the regional base level. Faults and folds in the rock layers affect groundwater movement at both the regional and local scale (ADWR 2009). These folds and faults are important in directing groundwater movement and likely are a determining factor in the location of springs (Rice 2012). Overall, the regional dip of the aquifer is south, away from the Grand Canyon's south rim and towards the north rim. Near the south rim, the R-aquifer is about 3,000–3,400 feet below surface level, but the water table rises away from the canyon to around 2,500 feet below the surface (Rice 2012; U.S. Bureau of Reclamation 2002). On the south rim, the residence time of groundwater, as determined using isotope analysis, is between 50 and 3,400 years, and water discharging from most studied springs is a mixture of young and old water, suggesting that groundwater in the aquifer follows multiple flow paths, and that recharge occurs in multiple areas (Monroe et al. 2005), as is typical of most karst systems. On the north rim, groundwater residence times are unknown, but spring discharge is also likely a mixture of younger precipitation and older waters (Brown 2011). Ross (2005) and Brown (2011) have characterized groundwater paths for Roaring Springs, but broader behaviors of the north rim aquifer system are unknown. Current work and work planned for 2015–2017 will better describe groundwater flow direction and travel time on the North Rim (Springer and Tobin, personal communication, 2015).

A major concern for groundwater in the area is that increasing withdrawal will lead to depleted water availability, a reduction in spring flow, or shifts in local groundwater divides that will completely shut off water supply to springs. As the area's climate becomes warmer and drier, as projected by models, precipitation and subsequent aquifer recharge have the potential to decline. At the same time, population in the region is projected to increase, leading to unmet water demands before 2050 (U.S. Bureau of Reclamation 2006, 2012). Potential increases in development and groundwater withdrawal, therefore, are a substantial concern for managing regional water systems and springs. Although the complexity of the aquifer poses challenges in predicting how specific wells might impact specific springs in the water system, a review of groundwater models notes that they consistently show that some level of spring flow decline will result from groundwater withdrawal south of the canyon on the Coconino Plateau (Rice 2012). Furthermore, if annual groundwater withdrawals exceed annual groundwater recharge, groundwater depletion will result in a number of significant impacts: land subsidence, aquifer compaction, and declining water tables (Galloway et al. 1998; Konikow and Kendy 2005). These impacts, over time, would result in decreased available storage and at a minimum substantially reduced spring flow. It is therefore important to improve our understanding of the aquifer system and to develop an understanding of how current and future projected rates of groundwater withdrawal will affect the hydrogeology of the region.

5.36.2. Condition and Trend

Wells in Arizona are registered by the Arizona Department of Water Resources (ADWR). As of 2012, their Groundwater Site Inventory identified 248 wells in the GGCLA analysis area, with 150 actively in use. Wells range in depth from 0 to 4,663 feet. Most are used as stock tanks or as domestic or public water supply (Figure 81). Most active wells in the region are on BLM, private, and tribal land (Figure 82). ADWR does not require well operators to report pumping rates (Rice 2012), so information on rates of water use is largely uncertain.

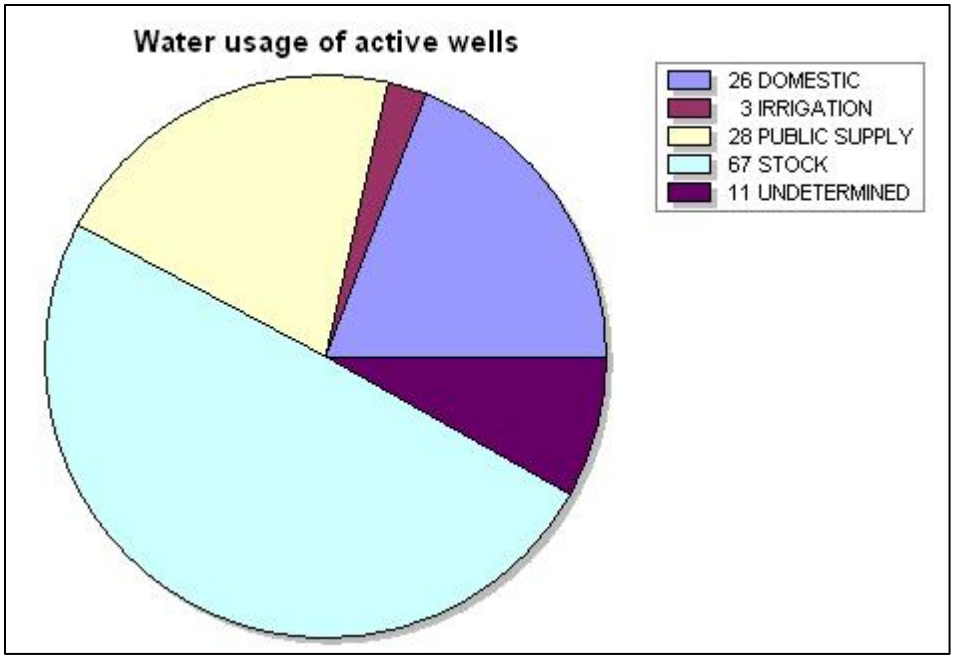


Figure 81. Most wells are used as stock tanks or as domestic or public water supply.

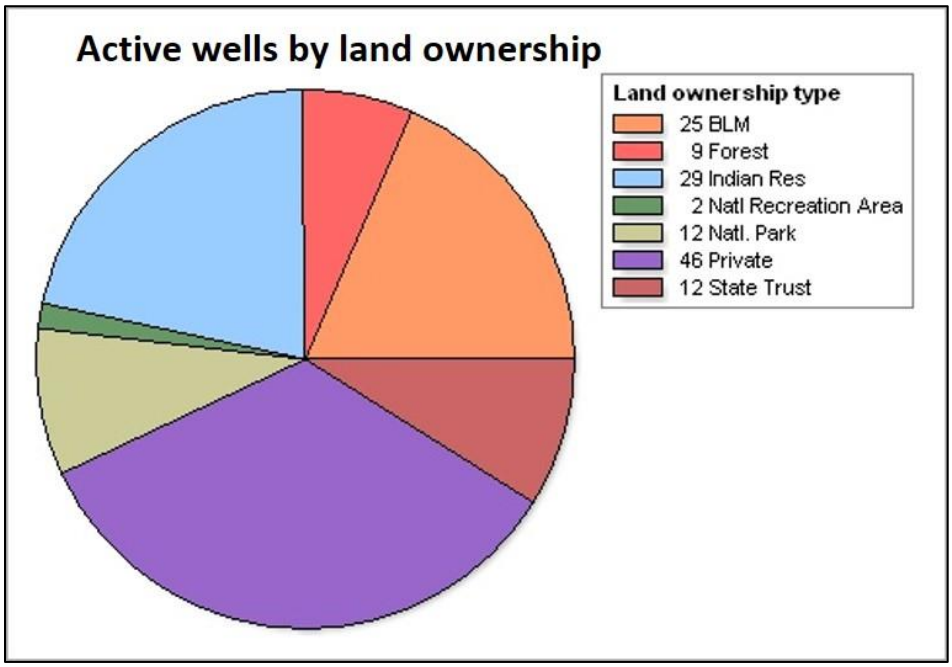


Figure 82. Most active wells in the region are on BLM, private, and tribal land.

Grand Canyon National Park is fully supplied by groundwater from Roaring Springs on the north rim. A pipeline diverts about 700 gallons per minute from Roaring Springs to Phantom Ranch, across the river to Indian Gardens, and up to the south rim (Rice 2012). Estimated water use in the park was about 194 million gallons, or 596 acre-feet annually in 1994; work is currently underway to meter water usage and develop a more recent figure. Trends for increased visitor use also suggest increased

water consumption, and the water need is projected to double by 2050 to 1,255 acre-feet per year (U.S. Bureau of Reclamation 2002).

Development is another stressor affecting the GGCLA in large part because of its potential for increasing groundwater use in the region. Of particular concern is the development being considered by the city of Tusayan. This would add 2,200 homes and about 3 million square feet of retail space to the town. The developers are considering multiple options for water, including tapping into the aquifer through local wells, as well as a water pipeline (Cart 2014; Yerian 2015). Studies suggest that south rim spring flows will be affected if there is an increase in groundwater withdrawals from either the C- or R-aquifer (Rice 2012).

Although there are no studies of groundwater supply specific to the GGCLA area, projections of future water supply and demand suggest unmet needs for water in both north-central Arizona and the entire Colorado River basin by 2050 (U.S. Bureau of Reclamation 2006, 2012). Regional projections for population growth and predictions of increasingly drier and hotter climate together suggest a trend towards increasing groundwater withdrawal and decreasing groundwater availability.

5.36.3. Summary

The combination of regional population growth and demand for water, and an increasingly dry and hot climate, lends urgency to concerns over groundwater withdrawal in the GGCLA region, which could affect local water supply and lessen spring flow, impacting biorichness and cultural values alike. In addition to concerns about withdrawal—currently focused on developments south of the canyon—contamination of groundwater is also a possible stressor in the region. Development south of the canyon lends itself to increased risk of contamination from chemical spills, changes in land use, and other potential stressors. North of the canyon, development is less of an immediate stressor, but rapid discharge of springs there suggests that land use and potential contamination issues north of the park boundaries could also influence ground and spring water quality (Ross 2005).

Surface activities such as chemical spills, poorly maintained septic systems, and disturbances due to mining can rapidly impact karst aquifers because recharge is not filtered through soils, takes unknown flow paths, and can move at high velocities (Kacaroglu 1998). For example, breccia pipes are geological features that can cause depressions and sink holes. These collect precipitation and shuttle it underground to recharge groundwater in karst aquifer systems such as those in the GGCLA region. Breccia pipes are also areas where minerals of interest for mining, such as uranium, are found (Huntoon 1996); thus, uranium mining poses a threat to groundwater quality. The recent decision to withdraw new uranium mine claims in the Grand Canyon area lessens future risk, but existing, or grandfathered, claims were exempt from the withdrawal. One such mine, the Canyon Mine, was recently cleared at the U.S. District Court level to proceed with operations near the south rim (Yerian 2015).

As with many public lands, major stressors to groundwater and springs in the park come from actions outside the park boundaries. Increased understanding of the groundwater basin extents, aquifer recharge patterns, and localized behaviors will improve understanding of the impacts of specific well locations. Increased monitoring within and adjacent to the park can improve knowledge of current

condition and trends within a complex system. Additional research is needed if we are to understand the cumulative and interactive effects of alterations to hydrological systems in the region (Pringle 2000).

5.36.4. Data Needs

- Greater understanding of the hydrogeology of the aquifer, including flow paths and dominant recharge sites is essential.
- Tools are needed that will permit a greater understanding of groundwater availability, including a network of monitoring wells to assess aquifer levels, general properties, and changes over times.
- A system of springs and stream gages would be very helpful to monitor spring discharge and water quality.

5.36.5. Sources of Expertise

The section was prepared by Sasha Stortz, with assistance from Dr. Ben Tobin, hydrologist for Grand Canyon NP, and Dr. Abe Springer, Northern Arizona University.

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5.37. Stressors: Overflights

5.37.1. Description



The number of air tour flights over Grand Canyon NP increased by 37% between 1987 and 2005. The increased noise from aircraft can disrupt wildlife behavior and fitness and also detracts from the wilderness character of the area, including opportunities for solitude and the experience of natural sound (NPS Photo).

The first recorded air tour flight over the Grand Canyon occurred in 1919, and air tour companies began formally operating in the park in 1927. In 1975, the Grand Canyon Park Enlargement Act required the secretary of the Department of the Interior and the responsible agency to protect park and visitors from "significant adverse effects on natural quiet and experience of the park" caused by aircraft or helicopter activity. Throughout the 1980s and up to the present, Grand Canyon NP, the Federal Airways Administration, air tour companies, and other relevant groups have worked through negotiations, rules, and actions to regulate and manage noise, flight corridors, and numbers of flights. Air tour flights over the canyon nevertheless grew by 37% between 1987 and 2005 (Bell et al. 2009), and in 2011, air tours carried more than 400,000 visitors over the canyon (NPS 2011).

Air tours attract visitors who are drawn to the opportunity to experience the canyon from the air. Yet air tours create visual and noise-related impacts that detract from the experiences of visitors on the ground. Wilderness character, which includes opportunities for solitude and natural sound, is affected by the path and frequency of air tours, and noise from overflights can also affect wildlife and alter animal behavior related to feeding, breeding, and socializing (NPS 1994). Changes in behavior, particularly when combined with other stressors, can decrease wildlife fitness (Barber et al. 2009). Species of concern in the greater Grand Canyon region that are especially affected by mechanical noise include raptors and bighorn sheep (NPS 1994).

Sound is described by the frequency and amplitude of waves, and can be measured in a number of different ways. Sound exposure levels can be reported in terms of dBA, which is a logarithmic unit with adjustments based on human response to sound. The logarithmic nature of the unit means that an increase of 10 dB is 10 times the sound energy, and double the perceived loudness of a sound. In other words, 50 dBA is experienced as twice as loud as 40 dBA, but 60 dBA is experienced as four times louder than 10 dBA. Note also that the difference in energy from 40 dBA to 60 dBA is a factor of 100. For reference, the sound of leaves rustling is about 20 dBA, and the sound of thunder is about 100 dBA (NPS 2014).

5.37.2. Methods

As part of an initiative to develop and incentivize quiet technology for aircraft, the Volpe National Transportation Systems Center began modeling sound exposure levels of commercial air tours overthe Grand Canyon in 2012. A variety of scenarios were modeled, including the baseline sound exposure condition for 2012. Using flight reports provided to the FAA by the individual operators, NPS created a noise map of all reported 2012 commercial air tour flights—not including large planes traveling higher overhead—by calculating the sound exposure level of the 55,215 commercial air tours flown that year.

The sound exposure level of each aircraft and route combination was first modeled by the Department of Transportation's Volpe Center using an Integrated Noise Model (INM). Any aircraft model not found in the INM database was represented by the closest available model, as chosen by Volpe. To create a model of all aircraft sound, the NPS then stacked the grid data from each flight and summed the data at each point. Sound exposure level (SEL), or total amount of sound energy in a given unit in a year, was calculated per 2 kilometer pixel. A single, map-wide sound exposure level was also calculated through logarithmic sum by simply summing all the data from each individual point. This is the total amount of sound energy from overflights in the study area in a year. A simple analogy is to treat each sample point as a bucket. Each time an aircraft flies over the study area, it deposits sound into the bucket. The SEL is the total amount of sound in all the buckets.

To summarize sound exposure at the watershed and landownership level, we calculated the equivalent continuous sound level, LEQ, of each unit. The SEL is the total amount of sound energy a unit is exposed to in a given amount of time, and the LEQ is the mean amount of sound exposure, thus taking into account the differing sizes of HUCs and land jurisdictions in the analysis area. We used natural breaks to identify watersheds with the highest LEQ.

Because the Hualapai Tribe is exempted from reporting flights, the Volpe model did not include the sound exposure contributed by the frequent commercial air tours flown over Hualapai lands. In addition, air tours in the canyon employ several different flight paths, but allocated flights are not associated with a specific flight route; a commercial air tour company simply has a certain number of allowable flights. Therefore, Volpe extrapolated intensity of use of a given flight path based on fractions of total flights flown. The map extent for this model did not fully cover the GGCLA analysis area, but the highest-intensity sound exposure areas—those that most contribute to overall sound exposure levels—are captured within the analysis area.

5.37.3. Condition and Trend

Predicted sound exposure due to commercial air tours in 2012 ranged from 50 dBA to 120 dBA total SEL (Figure 83). The total SEL across the study area was 138.3 dBA. We used spatial analysis to examine the mean sound exposure by land management jurisdiction (Table 65) and HUC 10 zones by calculating the LEQ. HUC zones with the highest LEQ were concentrated in the east and the southwest of the analysis area. Watersheds in the highest quartile LEQ (96.7–111 dBA) were Grapevine Wash and Burnt Springs Canyon–Colorado River in the east; and Heather Wash, Shinumo Creek–Colorado River, Bright Angel Creek–Colorado River, Tatahatso Wash–Colorado River and Lee Canyon–Little Colorado River in the southwest.

Although the model has not been re-calculated for other years of commercial air tour flight data, the number of actual flights has increased annually since 2012, indicating that there could be an increasing trend in sound exposure since 2012. However, quiet technology changes to some aircraft means that total flight increases do not have a consistent relationship with changes in sound exposure level.

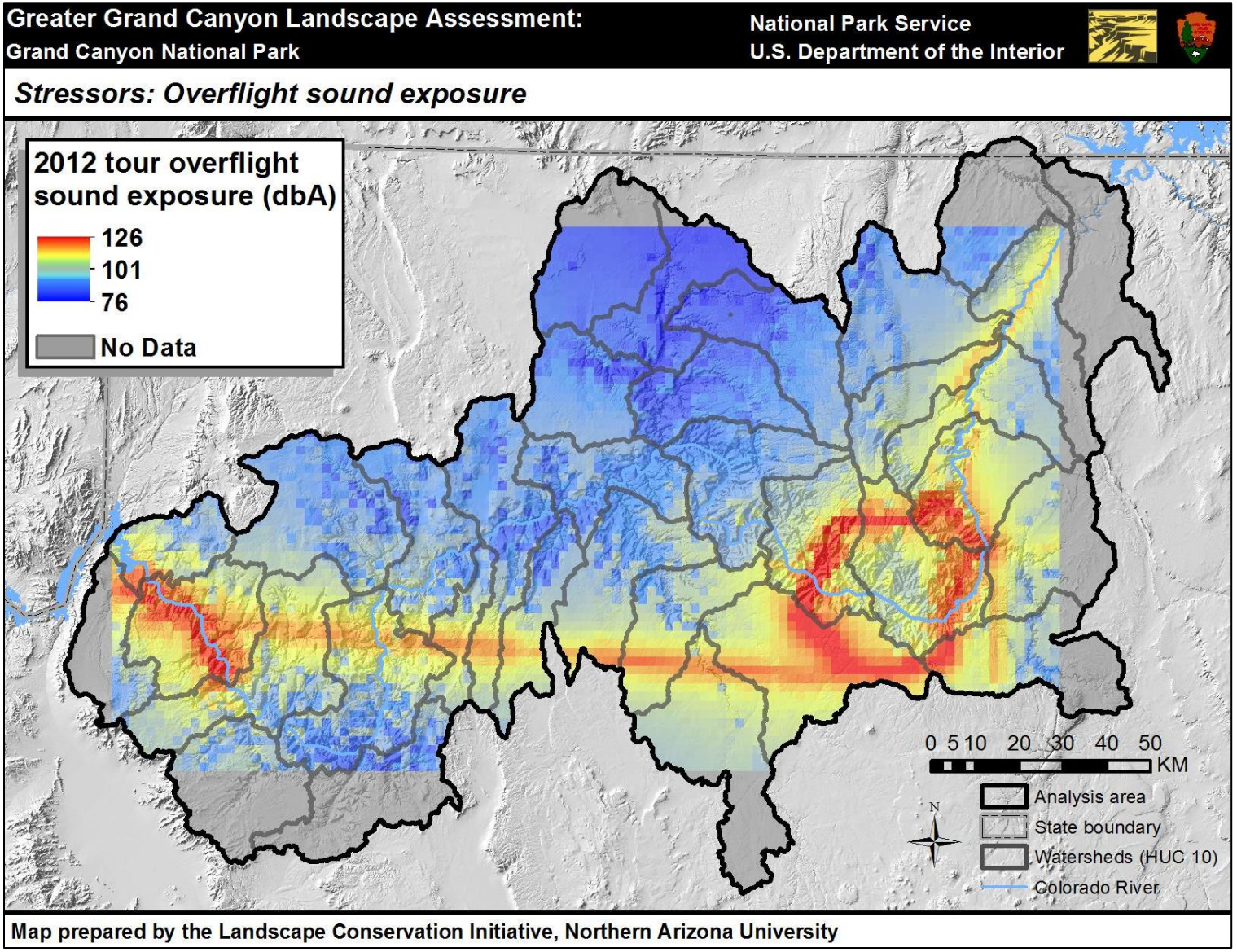


Figure 83. Overflight sound exposure levels ranged from 50 to 120 dBA across the greater Grand Canyon landscape study area in 2012.

Table 65. Sound exposure levels by jurisdiction in 2012. LEQ was highest on USFS and NPS lands.

Sound Exposure Level	BLM	USFS	Tribal	NPS	Private	State Trust
LEQ (dBA)	77.48	105.49	95.22	103.78	101.07	95.10

5.37.4. Level of Confidence

The model used to map sound exposure did not integrate commercial air tour flights originating from tribal lands, which are not required to report flights. Tribal lands with local overflights include Hualapai, where air tours are offered and river passengers are flown out from the Whitmore helipad. Because information about flights in these areas was not incorporated into the models, sound exposure in this area is an underestimated and the confidence level for this area is lower than for the surrounding area.

Because the sound exposure model used a study area different from the GGCLA analysis area, sound exposure values are missing for some parts of the analysis area. However, the extent of the model does capture areas known to have the highest level of overflights and we can assume that wider coverage would not significantly add to the total sound exposure value across the study area.

5.37.5. Sources of Expertise

This section was prepared by Sasha Stortz with analysis and review provided by Damon Joyce, NPS Natural Sounds and Night Skies Division.

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5.38. Stressors: Resource Extraction

5.38.1. Description



Although historical mining in the GGCLA was targeted toward placer gold, copper, asbestos, and lead, modern mining has been focused on extraction of uranium, which has attained high value in markets and thereby driven the establishment of more than 3,700 uranium claims in the watersheds surrounding Grand Canyon National Park. These claims are concentrated north of the canyon, south of Highways 89A and 389, with 556 additional claims south of Grand Canyon near Desert View. Photo: The Orphan Lode Mine lies within Grand Canyon NP (Photo by Alan Levine, creative commons license CC BY 2.0).

Mining in the GGCLA was historically targeted toward placer gold, copper, asbestos, and lead (Anderson 2010), but modern mining has been focused on extraction of uranium, which has attained high value in markets and thereby driven the establishment of more than 3,700 uranium claims in the watersheds surrounding Grand Canyon NP. These claims are concentrated north of the canyon, south of Highways 89A and 389, with 556 additional claims south of Grand Canyon near Desert View (Figure 84; Payne et al. 2010).

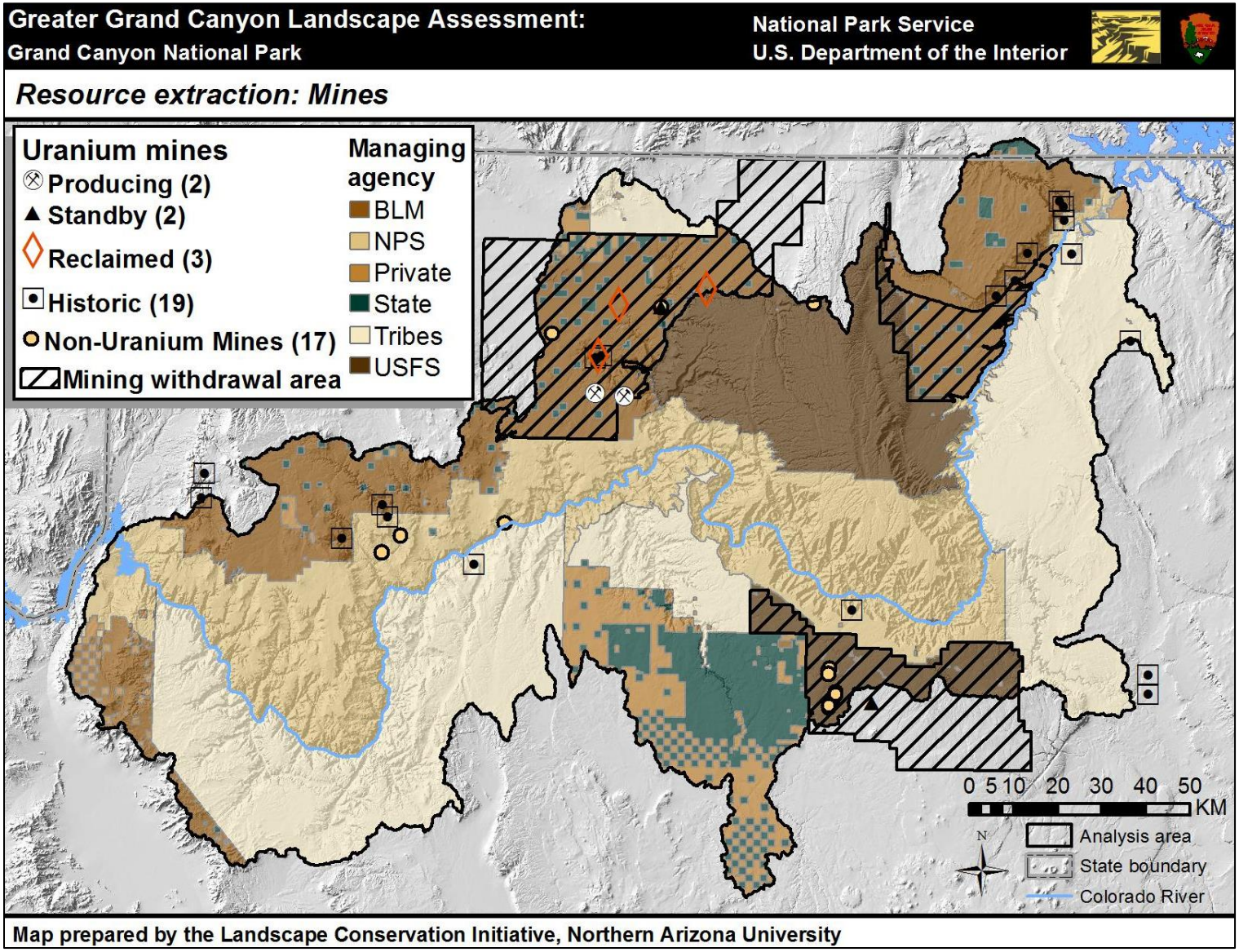


Figure 84. Uranium mines in the GGCLA analysis area.

A 2-year moratorium on all uranium claims "subject to valid and existing rights" in the Grand Canyon region, pending investigation of impacts, was extended in 2012 to 20 years by President Obama. This moratorium, which excludes four existing uranium mines in the region, followed the publication in 2012 of a Uranium Withdrawal Environmental Impact Statement identifying concerns that uranium extraction would result in adverse effects on the Grand Canyon watershed (BLM 2012). Legal challenges to extraction by those existing mines are ongoing (Burnett 2015).

Potential impacts of uranium mining in the Grand Canyon watershed include terrestrial, aquifer and groundwater contamination; surface water contamination and sedimentation; damage or degradation of cultural resources; and localized concentrations of ozone (National Parks Conservation Association 2010).

If existing claims are mined, new road construction (totaling an estimated 866 km) to provide access to mines will be one of the most prominent and visible impacts on the landscape (Payne et al. 2010; Uranium Withdrawal EIS 2012). Initial land clearing associated with the mines will directly impact another 160 km^2 of habitat, affecting bats, small mammals, birds, invertebrates, elk, and other species that inhabit these locations (Payne et al. 2010).

5.38.2. Condition and Trend

The uranium extraction moratorium was founded on concerns that watershed quality would be impacted by uranium withdrawal (Uranium Withdrawal EIS 2012). In particular, the USGS (Alpine 2010) identified uncertainties in subsurface water movement due to lack of groundwater data, resulting in an unacceptably high level of risk of radionuclide migration. Impacts to tribal resources are also a concern (Uranium Withdrawal EIS 2012). Contamination of surface water may degrade habitat critical for sensitive species, such as the Kanab ambersnail and southwestern willow flycatcher (Payne et al. 2010), as well as for amphibians that absorb environmental toxins through the skin (Payne et al. 2010). Other threatened species that might be affected include the Fickeisen plains cactus (*Pediocactus peeblesianus* var. *fickeiseniae*), which occurs within a short distance of existing claims (Payne et al. 2010) and was listed under the Endangered Species Act in 2013. Endangered California condors have been introduced to the Grand Canyon region and have demonstrated a propensity for drinking from surface water close to human disturbance—putting them in danger of drinking waters close to, and perhaps contaminated by uranium mines (Payne et al. 2010). The top carnivore in the park, the mountain lion, may also be impacted by the development of mining infrastructure, as both lions and their prey will shift their territories to avoid roads and other human developments (Payne et al. 2010).

A study of ecological impacts conducted at the Canyon Mine near Tusayan, which was developed in two phases between 1986 and 2012, and was slated to begin uranium production in 2015 (subject to the fluctuating price of uranium), appears to be the first field study examining the impacts of uranium on biodiversity in the Grand Canyon region (Hinck et al. 2014). Because full-scale extraction has not yet begun, the contamination and radiation levels detected in this study can be considered baseline and will be revisited over time as uranium production continues (Hinck et al. 2014). In a few days of sampling in 2013, the study detected more than 200 species of plants, invertebrates, and vertebrates in the immediate mine area, including the vulnerable Tusayan flameflower (*Phemeranthus validulus*)

and the long-legged bat and Arizona bat (both species of concern; Hinck et al. 2014). The researchers observed that the detention pond constructed for the mine, in particular, attracted a large number of species (Hinck et al. 2014).

Species occurring in close proximity to the mine may be subject to radiation from the uranium itself, but also to associated toxic contaminates including arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, thallium, and zinc (Hinck et al. 2014). Sampling of organism tissues over the next few years will allow researchers to ascertain whether these toxins are accumulating in the food chain (Hinck et al. 2014).

5.38.3. Summary

It is possible that existing uranium mining will deliver toxins and radiation to the groundwater and broader environment, although the moratorium has limited new mining in the Grand Canyon region. A shift in policy allowing new uranium extraction or active initiation of mining in existing claims not subject to the moratorium could impact sensitive species adjacent to mines, such as species sensitive to decreased water quality and wide-ranging species that may be impacted by roads and traffic increases.

5.38.4. Level of Confidence

Our understanding of the impact of uranium mining on species relies on baseline characteristics and our basic understanding of species responses to environmental toxins. Data specific to impacts in the Grand Canyon region are not yet available.

5.38.5. Sources of Expertise

This section was prepared by Clare Aslan with assistance from Jill Rundall.

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5.39. Stressors: User Impacts

5.39.1. Description



A much higher number of users visit Grand Canyon NP (approximately 4.5 million people per year) than surrounding lands. However, user impacts within the park itself are concentrated near specific attractions. In the GGCLA area, user impacts are distributed across a wide network of routes and thus permeate the landscape (NPS photo).

Resources that may be particularly sensitive to high user impact include wildlife, caves, ethnographic and archaeological resources, riparian areas, soil crusts, and fragile desert plants (National Parks Conservation Association 2010; National Park Service 2015). In total, 94,159 user nights were spent in the backcountry of the park in 2012, evidence of the high potential for use impact in this park, in spite of extensive regulation. Meanwhile, the number of river user-days per year averages above 200,000 (National Park Service 2014).

High user impacts concentrated around campsites can damage soil crusts and native plants and increase the extent of exotic annual grasses in the immediate vicinity of those campsites (Cole and Hall 1992). However, research on recovery from user impacts demonstrates that soil crusts can be severely damaged or even destroyed by hiker trampling, but, depending on local geology, they may recover in 5 years of non-disturbance (Cole 1990).

5.39.2. Condition and Trend

Information relevant to user impacts is highly variable across the GGCLA region. To develop the map of user impacts for the analysis area, trails (routes), backcountry campsites, and visitor attractions were considered high-impact areas within the national park itself (National Park Service 2013). For non-park lands, open roads, routes, and trails were considered high-impact areas on USFS, tribal, state, BLM, and private lands and were incorporated into the map from multiple jurisdictional sources (Figure 85; Bureau of Land Management 2007, 2014; National Forest Service

2012). However, it is unclear whether the information in that layer is up to date or complete. Furthermore, day use within the park is largely unmonitored and unregulated, resulting in a limited understanding of the number of people in any particular use area on any particular day (National Park Service 2015). A few overarching generalizations can nevertheless be drawn.

The park itself has a markedly lower density of routes than the surrounding lands, but a higher density of known user "attractions." Campsites and attractions are clustered near the main corridor of the inner canyon and along the eastern half of the river. Additional campsites are located along both the south and north rims, within the boundaries of the park.

Outside the park, but within the analysis area, Forest Service land just west of the Vermillion Cliffs has an extremely high density of routes. High densities are also present on tribal lands in the extreme east of the analysis area, and on BLM land in the far north of the analysis area.

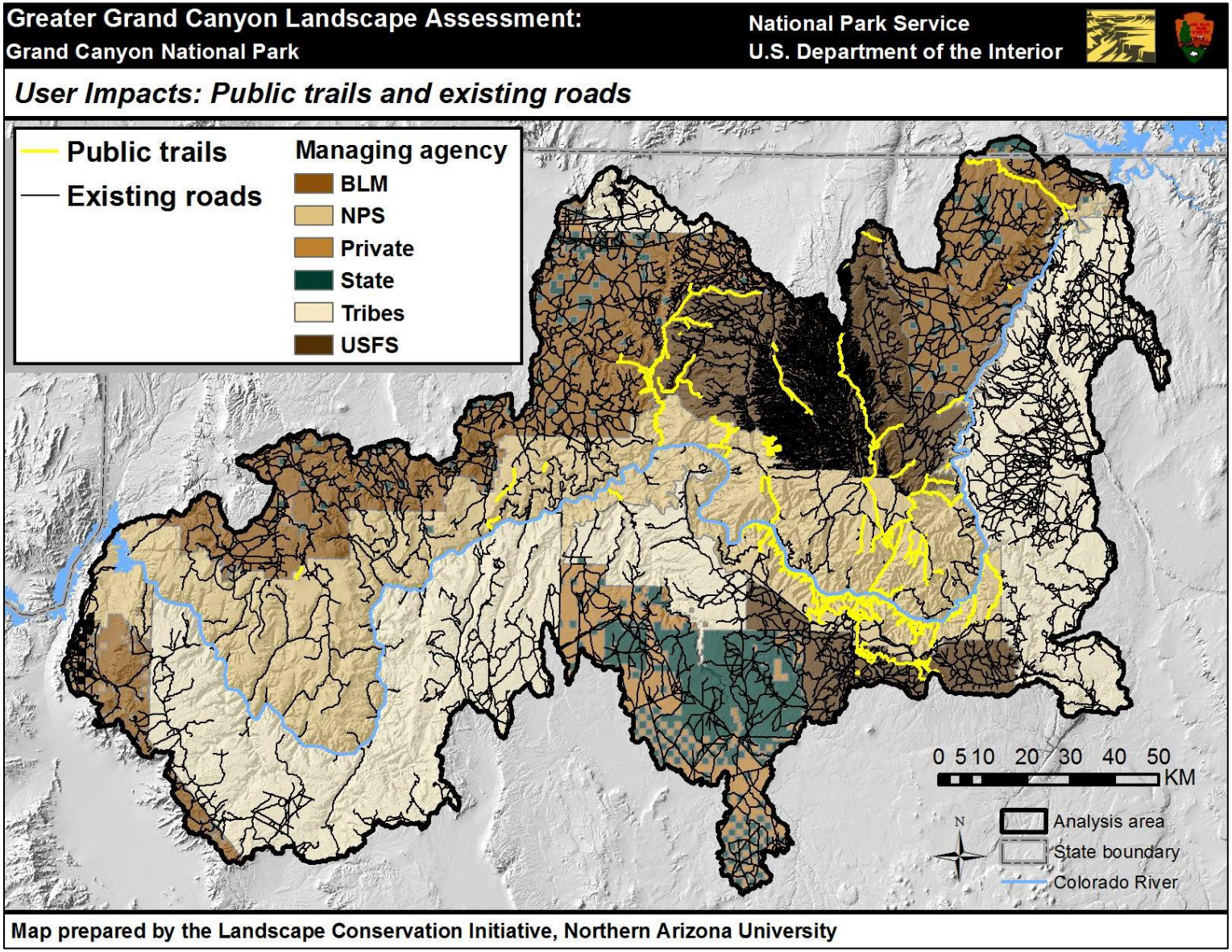


Figure 85. Public trails and existing roads in the greater Grand Canyon area.

5.39.3. Summary

Many more visitors use the park itself than the surrounding lands, but their use is likely concentrated near trails, campsites, and attractions. Outside the park, the region is clearly crisscrossed by visible routes. A better understanding of which routes are open, how often they are traveled, where the paved roads are, and the locations of campsites and attractions in the broader analysis area could inform a spatial assessment of habitat connectivity and the determination of restoration requirements.

5.39.4. Level of Confidence

Confidence in the information about user impacts within the park is moderately high. Backcountry and river users are permitted and tracked carefully, giving the park a high level of understanding about the number of people entering the park and the locations they frequent, but day use is mostly unmonitored. Confidence about impacts beyond the park boundary is low to medium, with poor records of indicators in many places.

5.39.5. Sources of Expertise

This section was prepared by Clare Aslan with assistance from Jill Rundall.

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Chapter 6. Discussion

6.1. Summary

The assessment of resources in Grand Canyon, one of the worlds' most compellingly diverse and inaccessible landscapes, might seem to be a nearly impossible task. Yet from the perspective of those dedicated to managing the Grand Canyon during a time of rapid ecological change and increasing human demands, the task is essential because it provides the integrated perspective needed to inform sound decisions and implement efficient management strategies. As we enter the National Park Service's second century, this landscape perspective, drawing on the best available science and newly available spatial data and analytical tools, places science firmly in the hands of decision makers who will guide the next phase in America's grand experiment in public lands management (Soukup 2015). Meeting the challenge of safeguarding the nation's most cherished places, while creating opportunities for public recreation and education and leading the way in adaptation to a warming climate, requires a new orientation for park science, where effort and capacity are focused squarely on management challenges, and scientists and resource specialists work hand-in-glove with decision makers and the public. The Greater Grand Canyon Landscape Assessment provides a living example of how this can be accomplished, serving as a "pivot point" for realigning the linkages between science and management so that science illuminates and informs the evolving relationships between natural and cultural resource management, between NPS staff and neighboring landowners, and between a cherished National Park and its broad and dispersed community of stakeholders.

The size and scope of the GGCLA shifted over a several-year period, as a diverse group of collaborators sought to carry out the Resource Condition Assessment for Grand Canyon National Park. The initial group of scientists and managers quickly recognized that the Grand Canyon was too vast and too heterogeneous to be comprehensively characterized through an exhaustive enumeration of its natural resources, and that for this park the distinction between natural and cultural was fuzzy at best, with these resources co-occurring and subject to many of the same stressors. Furthermore, many of the stressors to park resources, including the spread of fire and introduced species, and the ubiquitous and increasing influences of climate change, emerged from outside the park. And while the status and trends of many resources demanded an expansive, landscape perspective, efforts to address the sources of stressors and other challenges facing Grand Canyon National Park required work by leaders and landowners, experts and the public, to find effective and socially acceptable pathways for minimizing stressors and capturing management opportunities, usually in the form collaborative efforts to reach common objectives.

What has emerged after over three years of effort is an integrated, focused resource assessment, one that conveys the status and trends for a set of purposefully selected focal resources, while at the same time surfacing the shared values and priorities of stakeholders. In the following sections, we

summarize resource condition and review spatial priorities, discuss opportunities and challenges in this process, and identify key next steps for carrying the findings of this assessment forward into future planning and management for Grand Canyon NP and the surrounding landscape.

6.2. Overview of Findings: Spatial Priorities

Time and resources are limited, so prioritization is always essential. The GGCLA carried out the first landscape-level, science-based prioritization effort for the Grand Canyon region that considered natural and cultural resources, stakeholder values, and expert opinion. The effort, detailed in Chapter 4, followed a transparent, iterative participatory analysis, involving a diverse group in a process drawing on the scientific synthesis described in Chapter 3, and resulting in the detailed assessments of Chapter 5. Stakeholders accessed shared data resources and analytical support to express their values and identify the stressors that put those values at risk. Following several stages of analysis, interpretation, refinement and negotiation, overarching priorities emerged that reflected not only the current understanding of resource condition and trend, but the experience and insights of dozens of informed and engaged stakeholders, from National Park Service staff and tribal representatives, to researchers, ranchers, recreationalists and environmentalists.

Several trends stand out. First, while many unique and high-value resources occur throughout the inner canyon, many of the perceived stressors that put them at risk are strongest above the rim. As the landscape perspective highlights the connectivity of the entire area of analysis, the upper reaches of the GGCLA watersheds, many outside the park boundary, emerge as high priorities, due to the potential for fire, water extraction, mining and development to degrade below-the-rim resources in the intricate, remote, and seemingly well protected incised canyons downstream. While many efforts to prioritize involve drawing lines on maps and highlighting favorite places, water sources, or areas of high biodiversity, the spatial mapping and overlay process, informed by resource attributes and the stressors that put them at risk, highlights areas truly in need of management attention. It is a shift in understanding to recognize that the most treasured places or highest valued resources might not be the appropriate targets for management, if stressors can be better controlled or mitigated in upstream locations.

The priority maps from Ch. 4 reveal the high value locations for the entire Kaibab Plateau, outside of the park, and the North and South Rims. Interestingly, these high ranks came not from the great popularity of this heavily visited portion of the park, but from the value- and stressor-based analysis. Several lower profile areas of the Greater Grand Canyon Region emerged as equally important areas for management attention, due to the overlay of stakeholder-defined values and stressors. The Shivwits Plateau and Parashant watershed is one of these, and the upper reaches of the adjacent Mohawk-Whitmore watersheds another. Somewhat surprisingly, the higher portions of several watersheds in the eastern portion of the analysis area also emerged as high priorities, as did the northern portion of the Kaibab National Forest's Tusayan Ranger District. The strong collaboration between the fire managers in the Kaibab National Forest and Grand Canyon National Park provides an effective response to the challenges facing these areas from elevated fire hazard, while demonstrating the value of collaborative efforts to address high priority management challenges at

the landscape level. The high-priority portions of Havasu and Kanab Creeks might benefit from a similarly collaborative effort among park, tribal, and private interests.

Also apparent from the GGCLA prioritization effort is the fact that particular side canyons rise in priority rank because of the co-occurrence of focal resources. While these results are subject to the selection of resources included in the prioritization exercise, the results presented here are derived from a clearly structured public dialog that involved multiple meetings, expert input, public discourse, over a period of almost two years. Thus, while admittedly only one of many such possible outcomes, it represents the most comprehensive effort to date, one that not only produced spatially explicit results, but did so in a science-based manner. The participatory analytical techniques used here can be repeated and refined as new data become available, and additional stakeholders choose to engage.

6.3. Overview of Findings: Resource Conditions

Chapter 5 analyzed resource condition, by indicator, for 25 focal resources selected by park staff, subject matter experts, and the public. Each of these resource assessments can stand alone as an informative, individual essay, but the compilation of these vignettes is likely to prove equally powerful to planners and decision makers, as it reflects the complex interrelationships among many key elements of a rich and varied landscape. Here we describe key findings about resource conditions and trends, areas of particular concern, and future data needs for strengthening science and addressing current uncertainties in existing data sets. A full list of data needs are accessible via Appendix C.

6.3.1. Landscape

Focal resources under the Landscape category in this NRCA include biorichness, ecosystem integrity, and fire. For these resources, indicators relevant to water availability (e.g., net primary productivity for biorichness) suggest vigilance and protection of surface waters and restoration of seeps and springs wherever possible due to ongoing and predicted worsening of drought events associated with climate change. Sensitivity to disturbance indicators also indicate caution or significant concern due to increased human population and development in the region. For fire, departure from historic fire regime varies across the analysis area, with roughly a third of the region in poor condition, a third in fair condition, and a third in good condition.

For Landscape category resources, the indicator with the lowest confidence in reported condition is availability of future surface water, which is highly relevant to biorichness. Climate change will strongly influence future water availability, and climate models, although continually improving, carry their own levels of uncertainty. Additional uncertainty, however, stems from a limited understanding of the hydrology in the GGCLA analysis area. A better knowledge of spring and stream flow rates and aquifer dynamics, including contributing and recharge areas, within the region would enable improved modeling of the interaction between future climate conditions and surface water features.

6.3.2. Vegetation

Limited data on trends in plant community composition and structure preclude a comprehensive assessment of trends in vegetation resources throughout the park, so the assessment effort focused on unique species and assemblages. Focal resources in the Vegetation category include rare and endemic plant species and riparian vegetation communities. For these resources, occurrence of rare and endemic plant species warrants particular caution because a variety of stressors, including groundwater withdrawal, uranium extraction, commercial and residential development, user impacts, and climate change, may impact such plants. Due to altered river flow regimes as a result of the construction and operation of Glen Canyon Dam, xero-riparian communities are in decline. Additionally, increased occurrence of exotic plant species, in riparian communities in particular, is cause for concern (Stromberg et al. 2004).

The lack of survey data for rare and endemic plants in many regions, including jurisdictions outside the park boundary and particularly inaccessible regions within the park itself, also makes it challenging to evaluate the likely impact of stressors on focal species and communities in the analysis area. In riparian systems, uneven sampling of communities throughout the analysis area results in limited certainty and general knowledge gaps across indicators. Leveraging the recently completed vegetation map for Grand Canyon National Park with repeated, systematic sampling of a carefully selected set of representative plant communities across ecosystems in all jurisdictions of the analysis area is needed.

6.3.3. Wildlife

Focal resources in the Wildlife category include bighorn sheep, mountain lion, mule deer, northern leopard frog, California condor, eagles, Mexican spotted owl, Northern goshawk, the avifauna of the river corridor, Northern Leopard frog, and invertebrates. Indicators relevant to connectivity and movement for wildlife warrant caution due to future increases in human disturbance, transportation infrastructure, and development. Indicators relevant to climate change, such as future availability of water and some forage types, also warrant caution, due to the likelihood of decreased precipitation and altered temperatures in the region, affecting wildlife food, water, and habitat. Resources subject to unique stressors include California condors, whose reintroduced population is dependent on intensive active management, due to poisoning from lead and other environmental contaminants; bighorn sheep, for which disease transmitted from domestic livestock is a source of significant concern; sensitive avifauna along the Colorado River (particularly the Southwestern willow flycatcher), for which habitat has declined due to drought and loss of riparian vegetation; Northern Leopard frog; and aquatic invertebrate taxa, which experience novel competition and predation regimes as a result of dam-driven environmental changes.

Lack of up-to-date, systematic, and replicated surveys hinder accurate assessment of Mexican spotted owl occurrence across the analysis area. Invertebrate diversity and population trends, bighorn sheep genetics and population structure, and mountain lion abundance are also indicators for which there is limited information and need for additional data. Metrics associated with climate change, such as an anticipated reduction in precipitation and increased evapotranspiration, have the potential to

dramatically impact habitat quality, but estimates of these variables carry inherent uncertainty, due to limitations to current climate change models.

6.3.4. Fisheries

The construction of Glen Canyon Dam resulted in the extirpation of three endangered fish species, while the remaining species have experienced considerable declines. Distribution and abundance of remaining populations of at-risk species, however, generally demonstrate stable or increasing populations at this time. Native fish populations have been sampled in most major creeks and rivers, but are little known in other parts of the analysis area. Continued monitoring of well-studied populations, and expansion of these efforts to geographically dispersed populations would enhance understanding of population trends by geography and sensitivity to regional stressors.

6.3.5. Physical Resources

Focal physical resources include caves and seeps and springs. For caves, hydrological and biological resources both warrant greater inventory and monitoring efforts. Climate warming is likely to reduce water resources in the future, while the possibility of increased groundwater withdrawal could impact cave hydrology. Cave biota are poorly known and trends little understood. Increased frequency, extent, and replication of surveys of geological, biological, and hydrological resources within caves are necessary in order to better understand their condition and trend. Data are currently restricted enough to limit assessment confidence. For springs, only a few individual springs have received the repeated surveys necessary in order to evaluate trends in flow and quality. Those few, however, have generally exhibited declines in flow over the past few years, and this trend is consistent with regional drought and climate change predictions.

6.3.6. Cultural Resources

Focal resources in the cultural resources category include archaeological and ethnographic resources. For archaeological resources, the large majority of those that have been surveyed repeatedly are in good condition, but only a small portion of the analysis area has been surveyed, and many sites are unidentified or their condition undetermined. For ethnographic resources, existing known sites are preserved in stable condition, with measures in place to limit human disturbance. However, past disturbances have reduced the number and condition of existing sites. For both archaeological and ethnographic resources, limited documentation of cultural resources outside the park itself makes it difficult to verify that resources are being appropriately preserved in the face of current stressors.

6.3.7. Visitor Experience

Visitor experience resources include night skies, daytime viewsheds, recreational resources, the natural acoustic environment, and wilderness character. Current artificial light levels are low in the analysis area, and management efforts to bolster dark night skies are actively being implemented. The daytime viewshed is a crucial value for many visitors to the region, and the monitoring of air quality has been a major long-term priority for the National Park Service. While air quality has improved or stabilized in recent years, projected future decreases in air quality due to increased development across the Southwest could impact this resource. Most recreational resources are carefully managed and maintained, although some sites and buildings face disrepair and a backlog of scheduled maintenance due to budget shortfalls. The acoustic environment is most impacted on

private and state lands, and over large areas of the park, as a result of aircraft overflights. Increasing demand for flight-seeing could increase the already significant impacts on this resource in the future. Wilderness character is currently most impacted by dispersed recreation and management activities across the region. Increased motorized use outside the park may require ever more management intervention, while management of ever-increasing numbers of visitors jeopardizes the visitor experience within the park.

Continued monitoring of the acoustic environment and artificial light at night will provide a more robust capacity for evaluating the impacts on the visitor experience of an increasing human population and the development that accompanies it. Projected trends related to increasing human density and decreasing air quality are based on model predictions that carry unquantified but significant uncertainty.

6.4. Challenges and Opportunities of Landscape-Scale Assessment

6.4.1. Stakeholder Engagement

The GGCLA was designed to provide a pro-active, participatory approach to landscape-level planning. Rather than inviting engagement and feedback through a NEPA process and on a decision document, the project provided an opportunity to step back, think at a more expansive spatial scale, and collectively identify those areas where management attention is particularly needed. In a world where busy schedules and limited resources mean that we are often reacting to the next crisis, it was heartening to see the interest in this process. The results, both in terms of the identification of priorities and in demonstrating the utility and practicality of engaging a broad constituency in complex collective efforts demonstrate the value of sustaining a forum to periodically address the many issues that transcend administrative boundaries in this region.

The GGCLA was, from beginning to end, a collaborative effort that integrated perspectives and information from many land managers and interest groups across the region. Feedback and review incorporated throughout the process are described in Ch. 3 and full documentation of collaborative meetings can be accessed via Appendix A. Overall, representatives from over 35 organizations engaged in the GGCLA through workshops, technical meetings, or both, and considerably more entities provided feedback through open houses and during public presentations. While GGCLA participants represented many interests and perspectives, some representative interest groups were invited but did not participate. Participation in the process required a significant commitment of time and resources on the part all individuals and organizations.

Given the importance of the Grand Canyon to many traditionally associated tribes, and the effort to fully integrate natural and cultural resources into a single resource condition assessment, an intensive tribal outreach effort was implemented as part of the project. This included convening of tribal meetings, travel to present to tribal councils, and presentations at inter-tribal gatherings. Some tribal representatives attended GGCLA workshops. Those who chose to participate reviewed and provided feedback on report language related to the cultural importance of natural resources, as well as on the condition assessments for ethnographic resources. While tribal participation greatly enriched GGCLA process and products, not all traditionally associated tribes were able to participate.

6.4.2. Transboundary, Multi-Jurisdictional Coordination and Analysis

For any given RCA, evaluation of condition and trend across the heterogeneous GGCLA landscape requires identifying, evaluating, and integrating relevant data from various jurisdictions. Throughout the GGCLA effort, this carried its own challenges. For many resources, data availability was inconsistent across the region—that is, data were available for certain jurisdictions and absent for others, and availability of existing data for this project understandably differed dramatically among individual scientists, agencies and jurisdictions. Within and between jurisdictions, existing data were often inconsistently collected, with lack of replication, gaps in sampling, both in time and space, and differences in response variables and the scales and resolutions at which they were collected. In many cases, painstaking cross-walking between data sets and across the study area were necessary. For multiple RCAs, relevant data were reported to exist for certain jurisdictions, but either the data could not be located, were not made available for analysis, or were of insufficient quality for landscape-scale analysis.

As a result of these combined challenges, lengthy efforts to assemble and develop data were required for almost all RCAs, sometimes resulting in the identification of insurmountable problems or small information benefits. Some analyses of some RCAs had to be limited to Grand Canyon NP itself. In other cases, we were unable to assess resource condition at all. The overarching goal of the GGCLA is to extend analyses across the full watershed-delineated landscape and move beyond jurisdictional boundaries and single-resource or single-site approaches.

Despite these challenges, the recent increase in publicly available remotely sensed data products, coupled with advanced spatial analysis and modeling, allowed the development of new spatial data products. These spatial data supplemented previously available resource data and drove much of the assessment and prioritization efforts. By combining existing resource data with new spatial data products, the GGCLA was able to engage multiple stakeholders and demonstrate that information from different management jurisdictions could be complementary and effective across landscape scales for target resources. The GGCLA experience and outcomes stand as guideposts for future NPS science approaches. These should prioritize efficient protocols for collecting cross-boundary data sets to complement single-species approaches and inform landscape-level management efforts.

6.5. Recommendations and Lessons Learned

From the outset of the GGCLA, there was a sense from Grand Canyon NP managers and stakeholders involved in the project that it held the potential to integrate data and diverse perspectives, reframe management perspectives and priorities, and build the collaborative relationships needed to manage strategically and improve resource conditions. In a time of limited resources and increasing challenges, there is hope that this and similar efforts to assess resource conditions and prioritize management needs will serve to avoid the tendency of ambitious new efforts to “start from scratch”, ignoring and possibly duplicating previous and ongoing efforts. By drawing people together to compare efforts, share data, and jointly drive analytical efforts to address shared challenges, participatory efforts provide new perspective on emerging issues and help ensure that managers leverage opportunities to work together to direct management effects more strategically, and more effectively improve conditions on the ground. Furthermore, the GGCLA

effort was seen as a departure from previous park engagement efforts; a wider opening of the door to neighboring landowners and engaged citizens and a deliberate transitioning from "park as island to park as neighbor" as one participant put it (Stortz 2014). Ultimately, participants' expectations for the GGCLA ride on the hope that it is used: that the outcomes guide future planning and actions. Given the hope and expectations of those involved in the GGCLA, and the results of compiling, assessing, mapping, and prioritizing data for the effort, there are several specific ways the outcomes and lessons from this effort can affect management going forward:

Focus future work where it is needed most: A landscape scale assessment can create a sense of overwhelming need; more issues, more acres, more challenges. But the purpose of conducting a spatial prioritization is to identify those specific areas on the landscape where attention might be focused. In Chapter 5, maps of many resources and stressors show where management may be most needed for a single resource. But too often, specialists plan and manage for outcomes based on single-resource assessments, leading to competition among programs for limited resources, inefficiencies in the allocation of resources, and missed opportunities for collaboration and cooperation. In Chapter 4, multiple values and landscape stressors are mapped together, identifying shared areas of interest, where targeted conservation actions can be undertaken to achieve multiple goals, with landscape-scale effect. The next step in this process is to determine the suite of management actions that might be deployed in particular priority areas to most effectively address identified needs. Likewise, the types of partnerships that can efficiently address transboundary management challenges must be cultivated.

Maintain and build partnerships: The GGCLA heavily invested in stakeholder outreach and engagement at the earliest stage in the assessment process. The willingness of stakeholders to attend meetings, contribute data, and participate in a pre-NEPA, non-decisional planning effort illustrates the broad interest in this valued region (e.g. Walters et al. 2004). Building and maintaining social capital through participatory analysis and informed discourse is also a powerful way to build support for ambitious management actions in those areas deemed in greatest need of attention.

Prioritize research needs: Work with park staff, regional subject matter experts, researchers, and resource managers revealed a shared sense that information needs were profound, and that ongoing research, resource inventory, and monitoring efforts were needed in virtually all areas. This finding was not surprising, particularly for specialists working in the highly diverse and difficult-to-access Grand Canyon. However, efforts to obtain and integrate existing data also revealed that ongoing data collection was sometimes intermittent or limited, to the extent that investment in field science was inefficient. Often different agencies, organizations and individuals were collecting similar data using different protocols, or a history of frequent revision of standard protocols had led to data sets that were incompatible or for which analytical options were limited. At times, a multitude of pressing information needs led to the common situation of pursuing too many different data collection efforts, such that each resulting data set was constrained in scope and statistical power, limiting their quality and value to resource managers. A clearer prioritization of research, based on the needs of managers, is needed. The GGCLA effort identified three avenues for addressing this need:

- For each program area, clear priorities for data collection and analysis should be established, based on the information needed to guide established resource management objectives. Clear priorities would allow scientists to develop robust data sets capable of addressing multiple questions, and focus field and analytical efforts accordingly. The research needs that emerged through the GGCLA process are accessible via Appendix C. This list should be posted to the park's research website and shared widely with research partners and institutions.
- Scientists conducting research within the park should work with science and resource management staff to insure that field efforts are aligned with management needs whenever possible, and that opportunities for data integration are recognized and incorporated into the research design, prior to the beginning of each project. Current efforts to coordinate through the Grand Canyon NP research permitting process are well conceived, and could be strengthened to insure that technical attributes of the data collection and analysis are designed to maximize value for future applications, and that permitted research contributes directly to meeting park priorities to the greatest extent possible. Permit applications that demonstrate that they meet one or more of these research needs should be incentivized through expedited permitting or other means.
- Wherever possible, research should be conceived and executed with an eye toward informing inference across the Greater Grand Canyon Landscape. In many cases, narrowly targeted field data can be collected in a manner that facilitates their inclusion into broader Grand Canyon NP or regional data bases. For example, site-specific data on plant distributions helped inform the development of the vegetation map for Grand Canyon NP. Adoption of compatible field methods for areas outside the park could allow eventual extension of the mapping effort beyond the park boundaries. In this way, research efforts designed to address specific, often narrow research questions, might also contribute to shared data resources designed to guide responses to emerging management challenges.

Target research and monitoring: There is always a desire for more information, and a reluctance to act when information is limited. This always has been, and always will be, the case. Yet while we should not pursue resource management actions that are unsupported by science, we cannot afford to wait to manage until we have more data. One solution is to make better use of existing data, and to link future research efforts directly to desired information for management. By acknowledging established priorities and anticipating future management decisions, robust experimental design can insure that future field efforts lead to powerful analytical approaches, and that more actionable information is obtained from the data collected.

For many resources considered in this assessment, quantitative data suitable for incisive analysis were often available for only a few locations. The scale at which data have been collected often does not match the landscape scale of this type of assessment. Designing research and monitoring to target identified management questions and leverage existing data through well considered statistical analysis and modeling can help avoid such data mismatch in the future.

Integrate GGCLA outcomes into the Grand Canyon NP Resource Stewardship Strategy: An important next step for Grand Canyon National Park, following completion of this NRCA, is the Resource Stewardship Strategy (RSS). The RSS is a plan to protect and maintain desired condition of the park's natural and cultural resources through science-based stewardship. The GGCLA should expedite development of the park's future RSS by informing current condition and information needs for establishing effective strategies to protect and monitor resources. Linking the integrated landscape data and assessments of GGCLA to the outcome-driven objectives of the RSS offers a powerful approach for minimizing overlap and redundancy in planning exercises, so that available resources can be focused on the unique purpose of each effort.

Address emerging stressors: As drivers of environmental change continue to accelerate, landscape-scale management challenges are increasingly important and urgent. The stressors evaluated in the GGCLA process, including climate change, exotic plant species, introduced ungulates and those with expanding ranges, development, and resource extraction, occur across scales from specific springs or soil types to the greater landscape. Like resources, stressors should be addressed at multiple scales. Regional climate models, ground-based monitoring, and integrated spatial models all play importing parts in developing the scientific capacity to understand individual stressors and how their interactions are likely to be felt across the GGCLA area of analysis. Monitoring changes and their anticipated effects will put managers in a stronger position to develop resource management plans that address emerging stressors and mitigate their impacts on natural and cultural resources (Holling 1978).

6.6. Conclusions

Through the expansive GGCLA effort, much about the Grand Canyon region was laid open to view: the isolation of its uplifted plateaus, the down-cutting of water on stone, the adaptations of plants and animals to a highly variable, but extremely arid climate. Biologically, the region is diverse, with high levels of endemism, and high beta diversity – a measure of the turnover in species composition across the varied landscape. Culturally, it is rich, with a deep human history, represented by many cultures, from ancient roots that predate written records to recent arrivals drawn to the region from around the world. All Americans, including those stakeholders who live a great distant but constitute a large and committed community of interest, have a central place in determining the region's future (Ostrom 1990).

Looking out over the Plateau's dramatic landscapes, one sees a wedding of geology and life forms that, on a human time scale, appear solid, stable, and unchanging. Yet two centuries of scientific inquiry and an oral history that extends back over a thousand years tells us that this sense of permanence is far from the reality (Wilkinson 2004). Continuous change sculpts the physical environment—uplift and erosion, recent volcanism, and the interaction of climate with the varied topography. Responding to these dynamic conditions, biological communities are distributed in complex patterns along ecological gradients created by changes in elevation, exposure, soil type and a host of other natural and anthropogenic forces. More recently, the modern impacts of mining, cattle, dams, and urban growth have been superimposed on these complex ecological gradients, and

our warming climate, and its uncertain repercussions on precipitation patterns, is reshaping the Grand Canyon Region in ways that we are only beginning to appreciate (Sisk 2006).

This legacy of science and exploration, and the unrivaled traditional knowledge that spans millennia, put today's stewards of Grand Canyon in a strong position to address the emerging challenges represented by the stressors that have been identifies, studied, mapped, and interpreted in this assessment (Maffi et al. 2002). Yet this data-driven understanding is not sufficient for achieving sound stewardship or "doing the right thing", as many GGCLA participants have put it. An informed social dialog, infused with science and guided by thoughtful, structured deliberation, is needed to inspire collective action. Developing the social capital to sustain bold and informed management is an essential aspect of leadership; finding the common ground is a social endeavor that, when wedded to sound science, will lead to the greatest benefits, as we mobilize limited resources in pursuit of the common objectives during this time of global change (Jasanoff 2004).

Much of our work as land stewards is motivated by rapid environmental change, but many of its causes are poorly appreciated and the consequences incompletely understood. We can point to heroic efforts with successful outcomes, like the reintroduction of the California condor and efforts to conserve the regions endangered native fishes, but without broad, landscape level efforts to curtail the forces that put these species at risk, such lead poisoning in scavenging birds and thermal stress and predation on aquatic organisms, these successes will prove to be short-lived (e.g., Finkelstein et al. 2012). It is clear that conservation in the 21st century requires addressing specific challenges such as these, while pursuing approaches that confront the forces that continue to place resources at risk. Stewardship involves targeted management intervention in specific ecosystems, while long-term success involves connecting with people, expanding the scale and scope of science, and developing a transparent and adaptive process for setting priorities, planning management actions, and allocating effort in a manner that maximizes the efficiency and efficacy of stewardship efforts, including our ability to learn as we go.

The GGCLA has highlighted what we have to lose, but also how we can sustain it. The region's geological, biological, and cultural resources are increasingly well understood, valued, and accessible. Yet the pace of change is quickening; even over the course of the GGCLA the dynamic nature of resource conditions and the social context that shapes our ability to respond to them, is evident as staffing levels, politics, policies, news stories, and budgets change as well.

Ultimately, of course, the canyon will persist. The history we see exposed in Grand Canyon reveals over a billion years of the Earth's response to changing conditions. What depends on our intelligent action is the future of valued resources that we, as a pluralistic, open and democratic society have pledged to protect for future generations: the Greater Grand Canyon, its biodiversity, its solitude and open spaces, and it cultural, aesthetic and biological significance. This Resource Condition Assessment, and the prioritization and integration of current science and future needs for the region demonstrates that a long-term, landscape perspective on stewardship need not be bigger, harder, or more complicated. By gathering what we know into more accessible and usable data bases, and by identifying priorities and focusing future efforts on them, we leverage existing information, generate public support and ongoing engagement, and make it easier to guide science and management as a

unified endeavor; a single pursuit of knowledge and understanding to guide stewardship and safeguard the Greater Grand Canyon Landscape.



Appendix A. Collaborative Planning and Stakeholder Engagement

Collaborative planning and stakeholder engagement were an integral component to the Greater Grand Canyon Landscape Assessment. Multi-stakeholder interactive planning components are outlined below. Further documentation, including meeting summaries, handouts and presentation slides, available at: https://irma.nps.gov/DataStore/Reference/Profile/2252541

Workshop 1: Oct. 11, 2012

On October 11, 2012, approximately 45 participants met at Northern Arizona University to kick off the Greater Grand Canyon Landscape Assessment (GGCLA). Objectives of this workshop, the first of a proposed three, included 1) sharing background on GGCLA context, process, and roles; 2) identifying focal resources, threats, and information sources; and 3) discussing stakeholder participation and next steps.

- The group supported the project approach and timeline.
- The participants developed a list of resource values and threats prioritized based on importance.
- Participants discussed the relevance of the project products to management decisions beyond park boundaries and as a tool for Grand Canyon National Park (GRCA) as well as other organization's decision making processes.
- Participants provided input on the extent of the analysis area.
- Participants shared additional data sources that might be relevant to the landscape assessment, and volunteered for technical workgroup participation.

GGCLA Technical Work Group Meetings

- Vegetation TWG: March 26, 2013
- Caves TWG: April 2, 2013
- Springs and Seeps TWG: April 2, 2013
- Cultural TWG: April 23, 2013
- Wildlife TWG: May 9, 2013
- Landscape Metrics TWG: June 12, 2013

- Fire Ecology TWG: June 12, 2013
- Visitor Experience TWG: March 5, 2014

For each Technical Work Group, outcomes included guidance from work group participants on ideas for resources and stressors of concern, appropriate indicators for assessing resource condition, analytical frameworks for assessing resource condition, existing research, and data gaps. These ideas were used to further research existing analytical frameworks for assessing resource condition and to develop frameworks appropriate for the Grand Canyon region, given data availability.

Workshop 2: June 10-11, 2014

Workshop 2 of the Greater Grand Canyon Landscape Assessment was held at the Health and Learning Center on the NAU Campus on June 10 and 11, 2014. The purpose of the workshop was to review and explore the spatial data developed for the stakeholder prioritization process identified in Workshop 1, using stakeholder-identified values and threats.



Appendix B. Tribal Outreach

Background

The Greater Grand Canyon Landscape Assessment (GGCLA) project commenced in 2012. This project went further than traditional National Park Service (NPS) Natural Resource Condition Assessments in that it encompassed an area larger than Grand Canyon National Park (GRCA), it addressed cultural as well as natural resources, and it involved other stakeholders in the region, American Indian tribes traditionally associated with Grand Canyon, nonprofit organizations and other state and federal agencies. This appendix to the GGCLA report summarizes the efforts to involve the traditionally associated tribes in the GGCLA process, describes the outcomes, and provides recommendations moving forward.

Summary of Tribal Outreach Activities

Initial point of contact with Tribes

In August of 2012, GRCA sent a letter to the leadership of the 12 American Indian tribes traditionally associated with Grand Canyon. Key staff within the tribes were also sent copies. The letter, signed by park superintendent David Uberuaga, explained the GGCLA project, described the collaborative process to be used, invited the tribal leadership to participate in the process, and suggested that they contact GRCA Tribal Program Manager Janet Cohen to set up a meeting.

GGCLA Tribal Outreach Coordinator activities

The GGCLA project, through the Landscape Conservation Initiative, hired Jean Palumbo as the Tribal Outreach Coordinator in June 2013. The purpose of her outreach was to inform the tribes about the GGCLA project and to enlist their participation. The following outreach activities were conducted:

- Outreach materials were developed to use in outreach to tribes and other stakeholders, including a GGCLA fact sheet and newsletter, as well as a tribal outreach statement of purpose and PowerPoint presentations.
- A follow-up letter was sent out on August 13, 2014, reiterating the invitation extended previously by Superintendent Uberuaga.
- Follow-up phone calls were made to all that were sent the letter. Meetings, either by phone or in person, were conducted.
- As a result of the initial phone calls, the following presentations were scheduled and made:
    - Open House at the Hualapai Tribe on 7/25/13
    - Presentation to Council of the Paiute Tribe of Utah on 10/3/13

- Presentation to Kaibab Band of Paiute Indians Council on 10/17/13
- Presentation to Hopi Tribe Cultural Preservation Dept. on 10/23/13
- Presentation to Hopi Tribe Cultural Resources Advisory Task Team on 11/21/13
- Presentation to Hopi Tribe Land Team on 2/18/14

- Follow-up letters from Martha Hahn were sent in March 31, 2014 to representatives of tribes that had participated to some degree in the project asking for more specific involvement. Representatives of tribes were invited to the GGCLA Open House on 9/16/13 at Northern Arizona University.
- All tribes were invited to attend the GGCLA Technical Work Group meetings.
- All tribes were invited to the Stakeholders' Prioritization Workshop, June 10 – 11, 2014.

Ethnographic Resources of Grand Canyon: Drafting and Review of Documents

Preparation of draft of GGCLA report sections related to cultural and ethnographic resources

The GGCLA report assesses condition of both natural and cultural resources. Based on a review of the existing literature, documents provided by Grand Canyon NP and the Hopi Tribe, and personal interviews with tribal representatives, the following drafts were prepared by the GGCLA tribal outreach coordinator for the GGCLA report, and reviewed by tribal representatives.

- An introduction to *Chapter 5: Focal Resource Conditions* recognizing that all natural resources in the Grand Canyon region have ethnographic value for the American Indian tribes traditionally associated with Grand Canyon.
- An introduction to the Cultural Resources category, which includes the ethnographic and archeological focal resources.
- A resource condition assessment for the Ethnographic Resources of the GGCLA area.

Review of GGCLA draft documents by participating tribal representatives

On October 20, 2014, the tribal outreach coordinator sent the drafts of the aforementioned documents to the representatives of the tribes that had participated in the GGCLA project by attending meetings and contributing information (the Hopi Tribe, the Hualapai Tribe, the Kaibab Band of Paiute Indians, and the Navajo Nation, see Attachment 5). All comments received were addressed in the final versions of the document. The completed draft of the report was sent to these same individuals as a courtesy before publication.

Further documentation, including detailed narrative of all tribal outreach activities, and copies of correspondence available at: https://irma.nps.gov/DataStore/Reference/Profile/2252621



Appendix C. Data and Research Needs

Data needs identified in each Resource Condition Assessment were compiled into a single document, which was reviewed by the Grand Canyon NP Research Coordinator and Chief of Science and Resource Management to further refine the list. This list will be posted on the Grand Canyon NP science, research, and permitting website to encourage outside research and partnerships to submit research permitting requests that are directly applicable to park management issues.

Category 1: Landscape

Biorichness

- Data on species richness or occurrence including comprehensive species inventories targeted at different taxonomic groups across the analysis area response of threatened and endemic species to changes in climate, groundwater availability, and fire

Ecological integrity

- Outside of GCNP boundaries:
    - Data on human use patterns and trends to enhance understanding of ecological integrity across the Greater Grand Canyon Landscape

Fire

- Improved estimates of higher-elevation forest fire return intervals

Category 2: Vegetation

Riparian communities

- Database Management:
    - Integration of disparate datasets to generate usable, comparable data to determine long-term trends in the mainstem and tributaries
- Changes in vegetation along tributaries
- Data on tamarisk removal using consistent methods
- Tamarisk beetle effects on the hydro-riparian areas along the mainstem and tributaries
- Trends in tamarisk mortality along the mainstem and tributaries using consistent methods
- Current status of marshes along the river corridor
- Riparian woodlands - historical (pre- and post-dam) and current extent and status, including groundtruthing known areas

- Quantification of the beaver population and population growth rate
- Regular surveys for exotic species at springs, especially on rim areas subject to impacts from ungulates and inner canyon areas with high human visitation

Rare and endemic plant species

- Spatial data for at least 3 special-status plant taxa known to occur in the analysis area (*Ipomopsis tridactyla*, *Phyllodoce empetriformis*, and *Silene menziesii*)
- Sampling surveys across less-visited areas of the park for special-status species to improve understanding of spatial distributions

Category 3: Wildlife

General

Data collection of wildlife range expansion (or contraction) due to climate-induced changes

Mountain Lions

- Mountain lion abundance and density estimates through mark-recapture studies or other methods
- A better understanding the effects of mountain lions on bighorn sheep of inner canyon

Bighorn Sheep

- Identification of lambing areas and determination of lamb survival to provide a better indication of potential stressors (i.e. human disturbance) affecting lamb survival
- Reliable population estimates, including juvenile survival and recruitment rates.
- the degree of genetic mixing between translocated and Grand Canyon bighorn sheep
- Assessment of forage selection using consistent and precise methods to predict the impacts of climate change on forage availability
- Understanding how pathogen transfer is occurring across the population
- Accurate assessments using consistent methods of:
    - Surface water availability and quantity
    - Availability of preferred forage
    - Fine-scale habitat suitability models including the influence of:
        - mountain lion movements
        - epizootic disease spread
        - Bighorn population genetic structure and diversity
- A better understanding of backcountry recreationists' effects on sheep movements and behavior

Javelina

- Information on the trend and distribution of javelina in GRCA, and about their effects on other park resources
- Evaluation of their movements and causes of range expansion

Mule Deer

- Population status and trend for the south rim mule deer population within the park along the un*i*t 9 boundary
- Direct and indirect interactions between south rim populations of mule deer and elk.
- Identification of techniques used to establish baseline mule deer populations in the inner canyon, and to assess their status and trend over time
- Determination of the inner canyon population's isolation from north and south rim populations A better understanding of the effects on mule deer to predict future conditions of the following:
    - species interactions
    - invasive species
    - climate change

Bison

- More information about the population abundance and distribution of bison on the Kaibab Plateau, including the north rim in GRCA, and their effects on other natural and cultural resources
- Information about disease prevalence in the bison herd

Elk

- The history and current status of and trends in the north and south rim elk populations
- Elk habitat use patterns and interactions with other ungulates, predators, and humans

Burros

- Information on the numbers and distribution of non-native burros in the Grand Canyon

Eagles

- Nest surveys within park boundaries to determine the condition and trend of this species
- Long-term monitoring of known nests in the GGCLA study area to determine reproductive success Banding and/or transmitted GPS/radio marking to determine long-term survival of individuals and dispersal of juveniles

Condors

- Social science research to develop new, more effective ways to convince hunters to reduce or eliminate the use of lead-based ammunition in carcasses available to scavengers

- Continued testing, in cooperation with other investigators, of lead levelsor other contaminants in birds and their prey

Mexican Spotted Owls (MSOs)

- Determine via genetic sampling and/or telemetry the dispersal patterns of Grand Canyon MSOs
- Determine the relatedness of MSOs in Grand Canyon to surrounding forest-dwelling and canyon-dwelling MSOs
- Identify and investigate dispersal habitat and determine if this habitat is a sink (e.g., North Kaibab forest)
- Determine the MSO occupancy status and population size in Grand Canyon NP
- Abundance and diversity of small mammal communities in rocky-canyon habitat with and without owls, and what key habitat features are important to sustaining a robust prey base for MSOs
- A comparative study of North Kaibab Forest's MSO recovery habitat and forested habitat that support breeding MSOs in order to determine potential limiting factors on North Kaibab MSO populations (e.g., prey, shelter, climate, water, predation, competition)

Northern Goshawk

- Systematic, long-term monitoring of goshawk populations (and associated habitat characteristics) across all potential habitat in the GGCLA analysis area to provide a more accurate assessment of population trends
- Goshawk occupancy and abundance over large spatial extents through the bioregional monitoring protocol described in USFS GTR WO-71 (Woodbridge and Hargis 2006)

River Avifauna

- Additional site level-information on vegetation type and other habitat type variables, such as dominant vegetation and patch size, slope and elevation to improve understanding of the drivers of difference between sites, and its connection to visitor use levels during RM&P surveys (Zachmann et al. 2012)
- Migrant and wintering bird surveys
- Consistent and longer periods of surveying for river avifauna to establish long-term trends
- Surveys for southwestern willow flycatchers using consistent methods to provide statistical assessment of trends

Northern Leopard Frog

- Validation of the habitat quality model by field-checking sites for suitable habitat elements

Invertebrates

- Data on the specific mechanisms causing reduced aquatic invertebrate richness in the Colorado River and investigation of or modeling for whether potential management solutions can generate an upward trend in riverine aquatic invertebrate diversity
- Development of appropriate metrics that have greater capacity to distinguish natural from anthropogenic stressors in Grand Canyon tributaries
- Acquisition and analysis of existing data related to invertebrate occurrences for invertebrate biodiversity investigations, especially rare species/taxa and pollinators
- Systematic and comprehensive invertebrates inventories across a variety of soil, vegetation, stream, cave, and spring types to establish reference conditions and allow evaluation of condition and trend
- Assessment of the present status of non-native species and the known and potential effects on natural and cultural resources and human values
- The development of a strategic information management plan for archiving and reporting invertebrate distribution data for Grand Canyon NP

Category 4: Fisheries

Native Fish Species

- A comprehensive "stock assessment" for most fish species
- Park-wide trend in abundance or catch per-unit effort (CPUE) for Colorado River humpback chub aggregations outside of the Little Colorado River
- Continued research and monitoring of razorback sucker population dynamics (spawning, recruitment, and mortality sources) in Grand Canyon
- Natal origin of high-risk predatory non-native species
- Continued native sucker (bluehead and flannelmouth) population assessment in tributaries, and the Colorado River if feasible (see Walters et al. 2012)
- Modeling of stream channel sensitivity to watershed disturbance data to assess overall trend in species composition and determination of overall condition and trend of the fish community
- Trend data for fish in tributaries (in addition to Shinumo, Havasu, and Bright Angel Creeks and the Little Colorado River) to provide assessment of overall condition and trend at the landscape or watershed scale

Category 5: Physical Resources

Caves

- Continued study of caves within and surrounding Grand Canyon NP to amass reliable, standardized, long-term data to be used to evaluate trends and establish indicator conditions for caves and cave-obligate species

- Visitation data for caves in and surrounding Grand Canyon NP
- Impact studies that evaluate indicators other than speleothems
- Development of an inventory and monitoring plan for cave resources, to include photo monitoring GIS mapping of established cave routes and resources, and monitoring of humidity and microclimates (such as through use of multiple HOBO loggers)
- Collection of data to assess cave sediments, microbiota, drip water, and pools
- Increased research on speleothem fragility and significance as well as impact of cave visitation on the features and evaluation of individual cave stressors
- Improved techniques for bat counts
- Annual, standardized bat population counts
- Macroinvertebrate inventories and abundance estimates in individual caves
- Studies of individual cave energy chains and stressors to the cave ecosystem
- Mapping of suitable macroinvertebrate habitat and possible threats
- Data on paleontological specimen conditions and artifacts

Springs and Seeps

- Spring inventories during both high and low flow conditions in both dry and wet years to include data on water chemistry, field water quality parameters, flow, biological contaminants, flora, and fauna
- Continuous monitoring of temperature, specific conductance, and stage (with enough discharge measurements to calculate flow) to provide sufficient data to inform water quality assessments
- For karst aquifers, use dye traces to determine the extent of groundwater recharge areas associated with springs in the study area
- Establishment of a network of monitoring wells to allow assessment of changes in water level within the groundwater system for both karst and non-karst systems at a regional scale (Fetter 2001)
- Biannual water sampling for biological contaminants to assess impacts related to aquifer contamination at selected locations

Category 6: Cultural Resources

Archeological Resources

- Repeated condition assessments of documented sites are necessary for trend analysis
- Continued cross-referencing of existing data sources to align assessments and interpretations should continue for evaluation of trend data
- Baseline condition assessments are needed for more than a quarter of documented sites

Ethnographic Resources

- Conduct ethnographic resource condition assessments, and work with tribes to identify stressors and effects on those resources and to define site conditions

Category 7: Visitor Experience

Recreational resources

- Improved understanding of the density of users and activities in the Greater Grand Canyon landscape beyond the boundaries of Grand Canyon NP , and evaluation of how stressors may impact the broader recreational landscape

Soundscape

- Monitoring of the acoustic environment and how it is affected by current and proposed residential and tourism developments

Daytime Viewshed

- A better understanding of likely future drought and fire patterns and frequency and how they could affect the immediate GGCL region

Night Skies

- Repeat measures of sky quality indices to monitor and track trends in data across the landscape

Wilderness

- Data on anthropogenic sound and dark sky specific to the geographic region at finer spatial resolutions, to improve estimates of sound and light pollution
- Targeted surveys of biodiversity, improved spatial information, and information on the effects of management actions and treatments for all jurisdictions in the study extent as related to wilderness qualities and objectives



Appendix D. Spatial Data

The GGCLA included the development of novel spatial data developed to inform management questions in the region, and the compilation of existing information into maps. In order for stakeholders and the interested public to view, interact, and use these data, a subset of spatial data layers developed for the GGCLA are posted on Databasin, an online map-viewer and data repository. Data can be viewed at: https://databasin.org/galleries/8ce8106a09d7492fb491667358512b1d or by going to www.databasin.org and typing Greater Grand Canyon Landscape assessment in the search bar.

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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