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Monitoring park landscape dynamics through NPScape: Saguaro National Park

By William B. Monahan, Don E. Swann, J. Andrew Hubbard, and John E. Gross

Abstract: Changes in the composition and configuration of different land cover types within and adjacent to national parks can affect a multitude of biological and physical processes, including habitat availability, animal movements, potential for invasion by exotic plants, water quality, and in-stream habitat for fish and other aquatic organisms. Information about the status and trends of landscape-scale indicators in and around parks can help park staffs anticipate, interpret, plan for, and manage associated effects on park resources. NPScape is a landscape dynamics monitoring project that produces and delivers to parks a suite of landscape-scale data sets, maps, reports, and other products to inform resource management, planning, and interpretation at local, regional, and national scales. The target audience for NPScape spans the range from GIS specialists who will benefit from the geospatial data and tools, to network ecologists and park resource management specialists who will be interested in general landscape metrics presented in a local and regional context, to park superintendents who can incorporate the maps and graphics into reports or briefings. Here, we present an overview of NPScape and describe its uses at Saguaro National Park.

Key Words: conservation context, conservation status, GIS, housing, human drivers, human population, inventory and monitoring, land cover, landscape dynamics, landscape pattern, natural systems, NPScape, resource management, roads, Saguaro National Park

Introduction



NPS PHOTO ARCHIVE

A view of Saguaro National Park and residential development beyond park boundaries.

Parks and other protected areas are importatn sources of highly valued ecosystem services that include preservation of

biodiversity, provision of freshwater, detoxification of pollutants, recreation, and scenic enjoyment. When the National Park Service (NPS) was established in 1916, the prevailing thought was that these resources would be retained by simply "building a bigger fence"—that is, by isolating parks from threats and insults that originated outside park boundaries.

We now know that land use changes outside parks have profoundly affected virtually all U.S. national park units, and they will continue to do so in the future (U.S. General Accounting Office 1994; Radeloff et al. 2010; Davis and Hansen 2011; Monahan and Gross 2012). Furthermore, recent land use intensification has occurred at a disproportionately rapid rate near the boundaries of protected areas (Wittemyer et al. 2008; Wade and Theobald 2010). If this trend continues, projections are for an additional 17 million housing units to be constructed within 50 km (31 mi) of protected areas in the United States, with more than 1 million units within 1 km (0.6 mi) (Radeloff et al. 2010). Impacts of external threats on parks are already so prevalent that well-considered essays have questioned the ability of the National Park Service to retain even large wilderness parks in an "unimpaired" condition (Cole et al. 2008; chapters in Cole and Yung 2010).

Our appreciation for the importance of broad-scale influences on park resources has grown more rapidly than our ability to identify and assess the specific locations and magnitudes of risk posed by these factors. Most protected areas are threatened by invasive species, climate-driven changes, habitat conversion, and loss of connectivity. Recognition that the effective scale of these critical threats is much broader than individual management units has motivated actions at local to national scales to form new partnerships, and has stimulated the establishment of the emerging Department of the Interior (DOI) Landscape Conservation Cooperatives and regional Climate Science Centers (DOI Secretarial Order 3289). In concert with these higher-level activities, DOI bureaus are conducting assessments at watershed to ecoregional scales. The broad geographical scope of these assessments is consistent with our current ecological thinking, but it is well beyond the area traditionally addressed in park-based natural resource studies and it far exceeds the data holdings and analytical capabilities of most U.S. land management units administered by the National Park Service or any other U.S. bureau.

NPScape: Landscape dynamics monitoring of national parks

NPScape is an NPS landscape dynamics monitoring project designed to help parks better understand the landscape-level opportunities and challenges they face in protecting park natural resources. To support these needs, NPScape produces and delivers landscape-level data, maps, analyses, and interpretations to inform natural resource management and planning over a range of park-relevant scales. Key NPScape objectives are to provide

- a coherent conceptual and analytical framework for conducting landscape-scale analyses and evaluations that can inform decisions
- useful geographic information system (GIS) data and maps at broad scales not typically available to individual parks
- well-documented methods founded on strong science, and readily repeatable and extensible with local data
- assistance to parks in interpreting results

These objectives are well aligned with needs common to most natural area managers and current DOI directives that address some of the most pressing environmental issues of our time.

NPScape data and analyses are developed from a conceptual framework that links measurable attributes of landscapes to natural resources within parks (fig. 1). This framework articulates key attributes of the greater park environment and relates these attributes to landscape condition and the ecological context of parks. At its core, NPScape is designed to support and enhance conservation of park resources that may be vulnerable to or benefit from landscape-level changes and management. The framework focuses on attributes of (1) the natural systems, (2) human drivers of landscape change, and (3) conservation context of surrounding areas. This framework is derived from and founded on more comprehensive analyses of the mechanisms that link land use intensification outside protected areas to the resources within those areas (Hansen and DeFries 2007).

Landscape dynamics is one of the highest-priority "vital signs" identified by NPS Inventory and Monitoring (I&M) networks (Fancy et al. 2009; Fancy and Bennetts 2012). As part of landscape dynamics monitoring, NPScape focuses on a set of information-rich, landscape-scale metrics in six major categories: population, housing, roads, land cover, landscape pattern, and conservation status (table 1). These categories broadly address the human drivers, natural attributes, and conservation context of parks (fig. 1). NPScape data, methods, and results are designed to support decisions at the park level and focus on analyses that rely heavily on GIS. NPScape delivers the landscape metrics listed in table 1 for most parks using published, national-level source data, thereby facilitating use by parks that do not have in-house GIS capabilities or data. In addition to the landscape metrics computed for various areas around parks, NPScape provides a dynamic map viewer, which enables non-GIS specialists to quickly visualize results and save maps for use in reports or briefings (e.g., housing and road density maps, such as those shown in fig. 3 and fig. 4, could be produced by anyone using the NPScape map viewer).

NPScape products also include a series of methodological reports, or standard operating procedures (SOPs), and ArcGIS scripts and toolboxes that enable GIS users to quickly recompute NPScape metrics using other data sources and spatial extents. For example, NPScape relies on relatively coarse-scale GIS data because these are the only suitable data available at

regional to national extents. But some parks have access to finer-resolution data that may only be available (and consistent) at county to state extents, and they generally want to use these data in a decision-making process. Using standardized NPScape methods (i.e., SOPs and GIS toolboxes), GIS specialists can easily and quickly recompute NPScape metrics using, for example, a higher-resolution land cover data set or a customized park planning region. These unusually well-documented SOPs and GIS processing tools are powerful resources to help parks calculate landscape metrics on local data using expert knowledge.

NPScape provides a rich and varied source of basic data as well as a large and sophisticated set of analyses. Few parks, I&M networks, or regional offices have staffs with the expertise to interpret this broad range of results. To help educate users, we developed a guide on how to interpret NPScape data and analyses in relation to park natural resources (Monahan et al. 2012). The NPScape interpretive guide furnishes examples of landscape metrics for particular parks, describes the ecological basis of the metrics, and summarizes scientific literature for how each may influence key resources such as biodiversity, watershed condition, and habitat connectivity. The interpretive guide is intended to help parks and networks use landscape-level data and results to address questions that often arise with little warning. Additional examples of park applications of NPScape include analyses of park upstream watersheds (Monahan and Gross 2012), geospatial analyses of BLM-proposed solar energy program lands (National Park Service 2012), natural resource condition assessments (Stark et al. 2011), and park-focused landscape dynamics reports (McIntyre and Ellis 2011).

Accessing and integrating NPScape products

NPScape products are available for public download through the DataStore of the Integrated Resource Management Applications (IRMA) portal and the NPScape Web site (fig. 2; see sidebar). IRMA is essentially a one-stop shop for park data, and by distributing NPScape products via IRMA they are discoverable using standardized search tools that will also identify other types of park-based information in the form of reports, publications, park species lists, and links to other data sources. Additionally, IRMA DataStore references provide, serve, and archive detailed metadata on the compilation and derivation of NPScape products. The NPScape project Web site provides basic background information and streamlines access via direct links to products in the IRMA DataStore.

Landscape-scale resource management means working with partners, which dramatically increases the need for effective information sharing and integration. IRMA provides basic means to relate NPScape products to other landscape projects, but NPScape goes a step further by sharing its data via Internet map services that may be readily integrated into other GIS-based landscape projects and Web sites. Four other groups and projects that NPScape has been working with in this regard are

- Park Analysis and Landscape Monitoring Support (PALMS, http://science.nature.nps.gov/im/monitor/lulc/palms/index.cfm, Gross et al. 2011), which includes products from NASA Ames' Terrestrial Observation and Prediction System (TOPS, Nemani et al. 2009, http://ecocast.arc.nasa.gov/)
- USGS Gap Analysis Program (http://gapanalysis.usgs.gov/)
- Assessing Socioeconomic Planning Needs, a joint USGS/NPS socioeconomic analysis decision support tool under development (Koontz et al. 2011; Montag et al. 2012)
- Landscape Climate Change Vulnerability Project (LCC-VP), an NPS Inventory and Monitoring and NASA-funded project that seeks to develop and link climate change vulnerability assessments to management in two Landscape Conservation Cooperatives (Hansen et al. 2011, http://www.montana.edu/lccvp/index.html)

Our goal in forging these new connections is to help ensure that NPScape is increasingly able to deliver to parks the information needed to understand resource conservation in a landscape context.

The value of NPScape to Saguaro National Park

By way of introduction, consider the example of the desert tortoise (Gopherus agassizii) in Saguaro National Park, Arizona. Within the park, the attributes of the natural system that support tortoise populations are areas of suitable habitat, and integrity and connectedness of the habitats. The capacity of the natural system to maintain tortoise populations must be evaluated in the context of landscape changes and threats, including human population, housing, roads, and other land cover conversions. Tortoise populations in the park were historically connected to populations outside, but this connectivity is being disrupted by habitat loss because of urban development and barriers that include roads and residential developments (Edwards et al. 2004a, b; fig. 3 and fig. 4). The overall assessment and evaluation of conservation potential rely on the stewardship of the park and surrounding natural systems. Conservation potential depends on current land condition, landownership, level of protection, and the spatial (geographical) context of lands suitable for conservation. NPScape describes and illustrates these essential landscape elements and provides a framework and methods to quantify, analyze, and interpret results. In turn, these customized park products enhance planning and management of natural resources such as the desert tortoise.

Saguaro National Park, like many parks in the western United States, has experienced rapid urban growth outside its boundaries. When the park was first established as a national monument in 1933, the nearby city of Tucson had fewer than

40,000 residents, and the city was more than 20 miles (32 km) distant along poorly developed dirt roads. Today, Tucson has nearly 1 million residents, and according to state projections compiled by NPScape the population in Pima County is expected to increase to more than 1.4 million by the year 2030.

The park comprises two districts: the Rincon Mountain District, approximately 100 square miles (259 sq km) on the east side of Tucson, and the Tucson Mountain District, approximately 40 square miles (104 sq km) west of Tucson. Housing developments flank both districts and housing densities have rapidly increased in recent decades (fig. 3). In addition, a major commuter road (Picture Rocks Road, fig. 4) cuts through the Tucson Mountain District. These landscape-level changes have profoundly affected the park's resources, especially wildlife such as javelina, deer, coyote (McClure et al. 1996), and desert tortoise (Edwards et al. 2004a, b). An estimated 29,000 animals are killed annually by cars on the 76.6 miles (123.2 km) of roads that run through the park or along the park's boundary (Gerow et al. 2010). Park resources are also affected by nonnative species, particularly domestic dogs and buffelgrass. The city concentrates urban heat near the park, raises ozone and particulate pollution, profoundly alters night skies, and contributes sound pollution from increasing air traffic over the park's interior.

Landscape dynamics also affect visitation to the park. Seventy-eight percent of Saguaro is classified as wilderness (National Park Service 2007). The East and West Saguaro Wildernesses—along with the U.S. Forest Service Pusch Ridge Wilderness north of Tucson—anchor the larger network of protected areas in the region. Some areas, especially in the Rincon Mountain District, are quite remote, but others that were remote when the wilderness was designated are now adjacent to high-density housing (fig. 3) and roads with high traffic volume (fig. 4). Whereas visitation to the park once was primarily by out-of-town tourists, the vast majority of current visitors are local recreationists, with the number of bicycles now approaching the number of cars on the Rincon Mountain District's Cactus Forest Loop Road (Saguaro National Park, unpublished data).

NPScape products are of considerable value to Saguaro's managers, who have come to recognize that the park can no longer be managed in isolation from its neighbors. One simple but important application for landscape-level maps is to illustrate the significant changes the park is experiencing, and to interpret those changes for park staff, partners, and the public. NPScape maps of Tucson's explosive urban growth (fig. 3) tell the story of landscape change more profoundly than any words. They help explain the park's issues in protecting resources to partners, who can then help carry that message and work forward.

These maps also create opportunities for working with new partners. Saguaro is currently developing a wilderness management plan, and NPScape products have the potential to illustrate how landscape-level changes outside the park can influence aspects of wilderness character, especially visitor experience. For example, nighttime light pollution may be assessed in relation to viewsheds from key observation points inside the park (fig. 5). Insights gained from these analyses may suggest ways to mitigate such influences or work with partners who are grappling with similar issues.

While the focus on profound landscape-level changes (such as the increases in human population) is usually on the negative effects of these changes on park resources, NPScape also provides maps and analyses that can help parks achieve other goals. An important goal at Saguaro is to increase the park's relevance to the surrounding community, particularly among youth. NPScape has developed customized maps for the park that use U.S. Census data to identify such attributes as age and economic status in communities that are currently underserved by the park (fig. 6). For the NPS–National Geographic Society BioBlitz, Saguaro's major event in 2011, park staff connected schoolchildren with biological diversity and reached out to schools that have not traditionally visited the park. NPScape maps show where the two Saguaro districts are in relation to these opportunities, and provide educational materials for teaching how its natural resources—saguaro cacti, birds, water, and dark skies—both contribute to Tucson and are influenced by the actions of all who live nearby.

Changes in the landscape surrounding Saguaro National Park are now part of the park's story, no less than ecological changes in the saguaro forest (Swann et al. 2012). NPScape maps of human drivers changing over time—housing density, human population, road density—can be used to illustrate this story by interpretive staff. Ultimately, the data and maps can help to illustrate the story about the relationship between human society and the "natural" world, and the role of national parks within it.

> "Changes in the landscape surrounding Saguaro National Park are now part of the park's story, no less than ecological changes in the saguaro forest."

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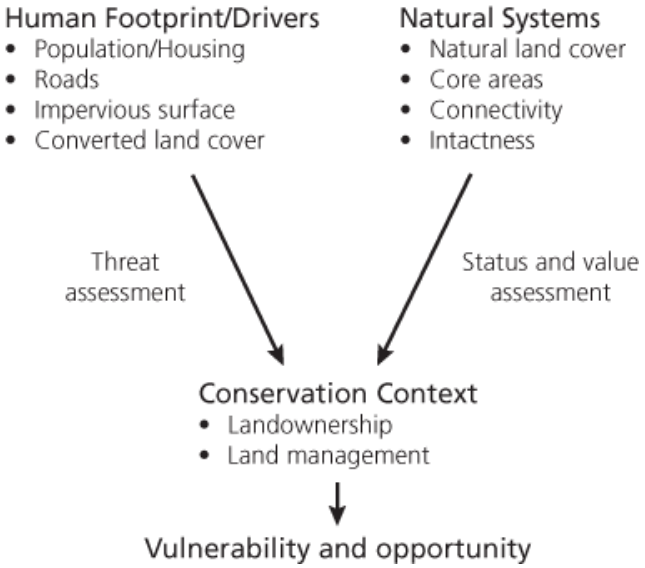


Figure 1. Broad categories of measures evaluated by NPScape and how they contribute to understanding the landscape context of parks and park resources.

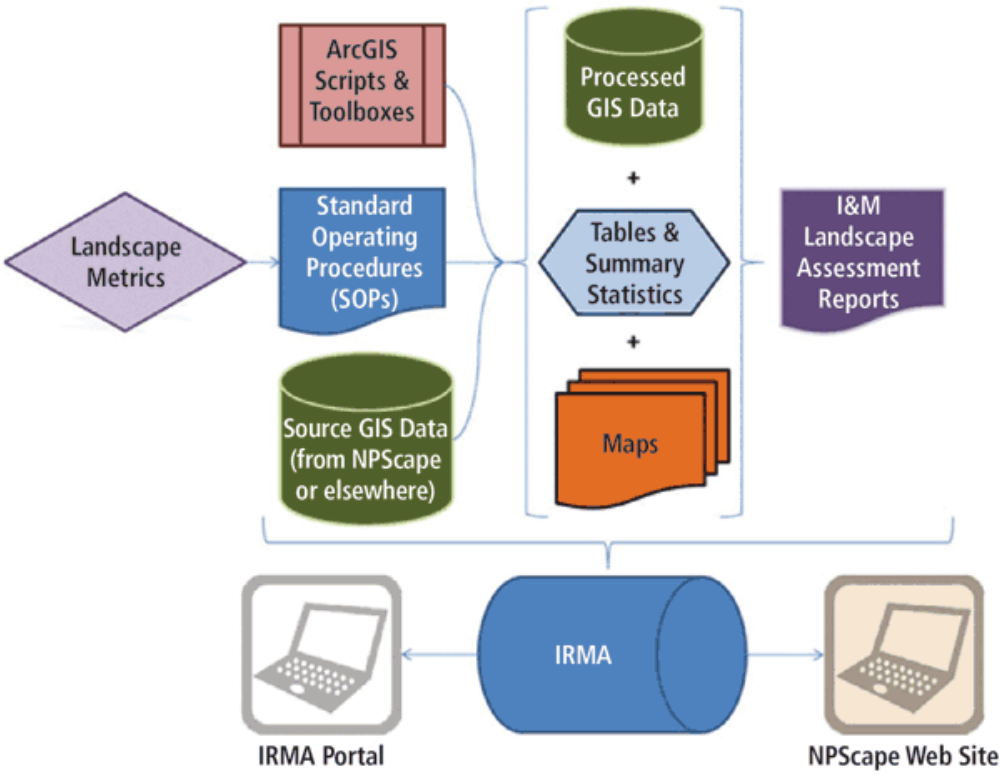


Figure 2. Overview of processing steps and products delivered by NPScape to I&M networks, parks, and others. We begin by defining a core set of landscape metrics that are of fundamental value to all or most parks (see table 1). We then document in great detail the GIS methods (SOPs) needed to quantify the landscape metrics, including the source GIS data inputs and ArcGIS scripts and toolboxes to assist with computations. Importantly, these methods enable others to recompute the landscape metrics using local source data, where available. Primary outputs from our methods include processed GIS data, tables with summary statistics, and maps to assist visualization by non-GIS audiences. These outputs are then used to generate I&M assessments and reports. All NPScape products are managed through the Integrated Resource Management Applications (IRMA) system and are available for public viewing and download through either the IRMA portal or the NPScape Web site (see sidebar).

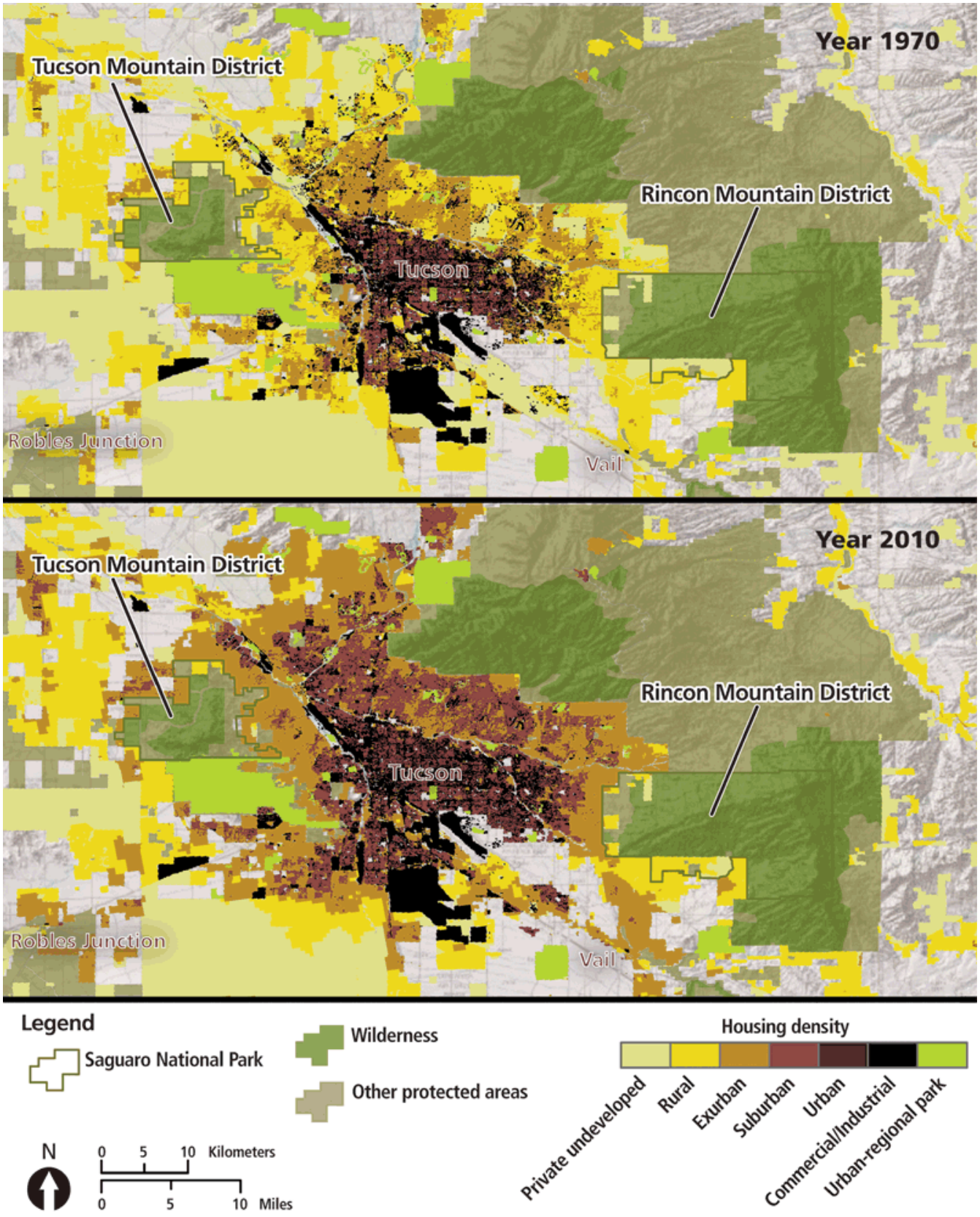


Figure 3. Housing density around Saguaro National Park in the recent past (1970, top map) and present (2010, bottom map). Housing density categories are defined by Theobald (2005): rural (< 0.0618 housing units/ha [< 0.1527 units/ac]), exurban (0.0618–1.47 units/ha [0.1527–3.63 units/ac]), suburban (1.47–10.0 units/ha [3.63–24.7 units/ac]), and urban (> 10.0 units/ha [> 24.7 units/ac]).

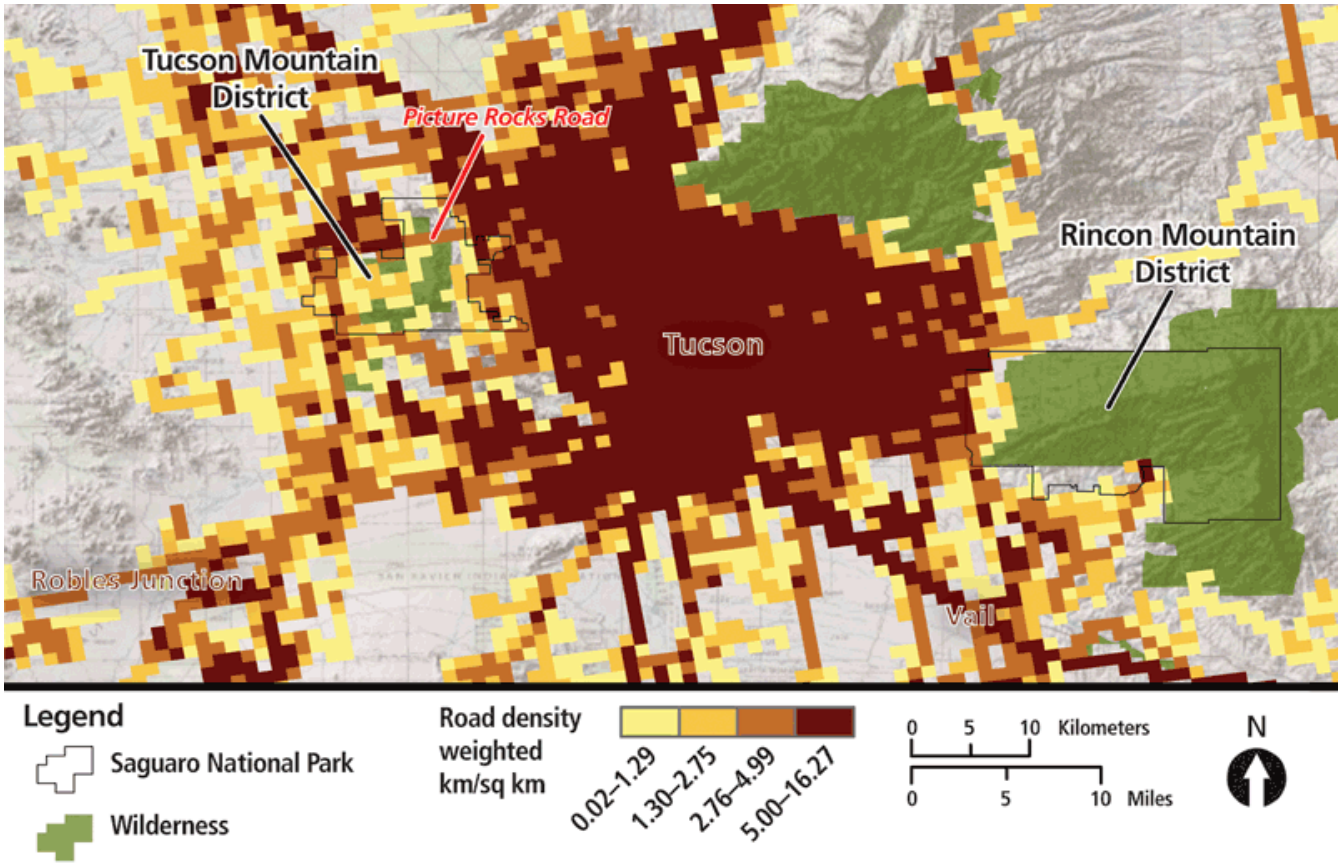


Figure 4. Weighted road density in the local area surrounding Saguaro National Park. Higher road densities are often associated with higher traffic volumes and larger areas of road clearings.

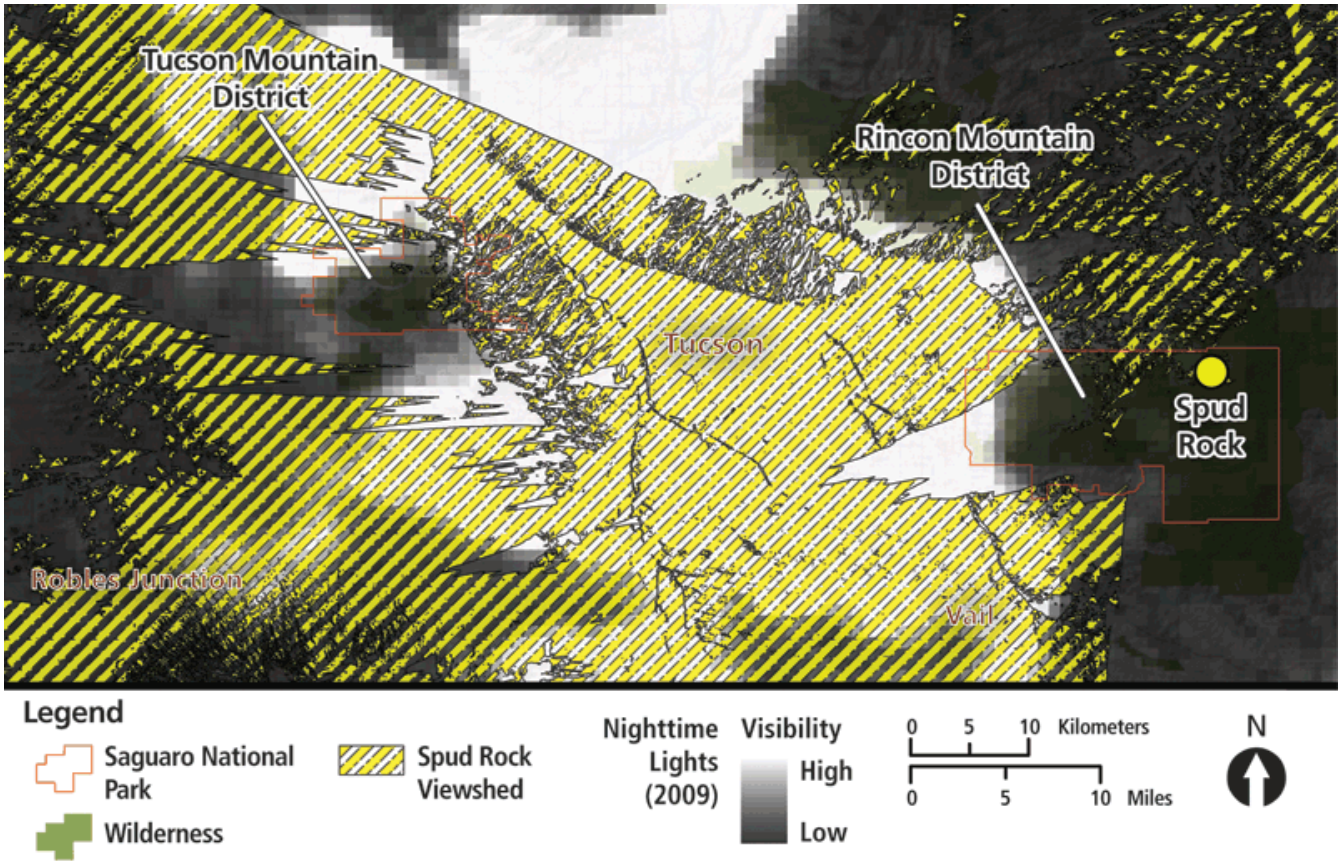


Figure 5. Viewshed from Spud Rock in the Saguaro Wilderness of Rincon Mountain District, considered in relation to nighttime light pollution (year 2009). Lighter areas (white and light gray) have more light pollution than dark areas (dark gray and black). Yellow hatching identifies all areas visible from Spud Rock; some of these areas are more challenged by nighttime lights than others. Saguaro is able to use maps such as this in wilderness planning.

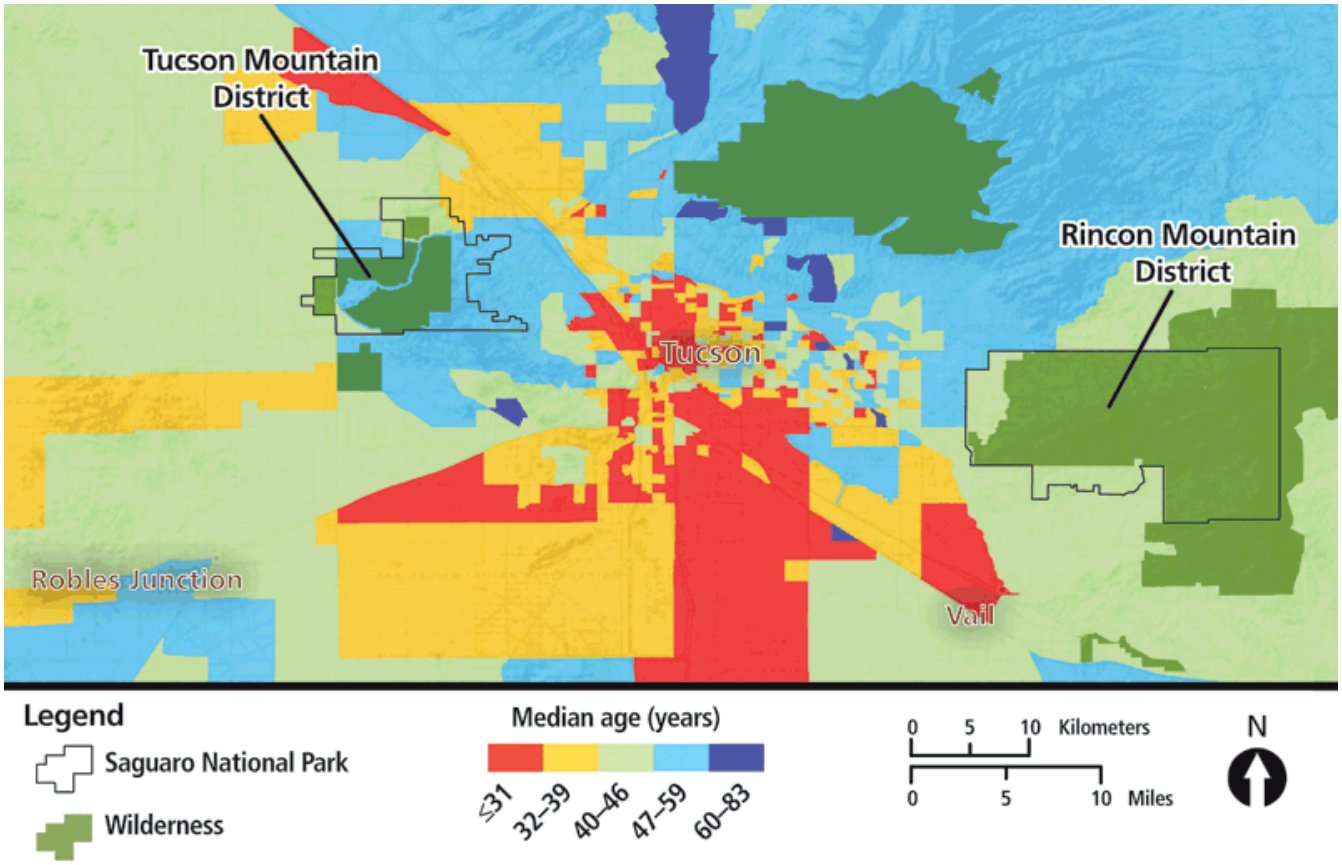


Figure 6. Median age of residents based on data from the 2010 U.S. Census for areas surrounding Saguaro National Park. Census-based demographic maps and analyses such as these provide important insights on where and how best to engage local communities as park recreational visitors. NPScape coordinates with the Social Science Branch of the Environmental Quality Division on the production and distribution of these metrics.

Table 1. Core NPScape measures, metrics, and key data attributes

Measure	Metric	Years	Resolution	Geographic coverage					
				Alaska	Lower 48	Pacific	Caribbean	Mexico	Canada
Population	Current: total and density	1990, 2000, 2010	Census block groups	X	X	X	X		
	Historical: total and density	1790–1990, by decade	County		X				
	Projected: total and density	2010–2050, by decade	County	X	X				
Housing	Housing density	1970–2100, by decade	100 m cells		X				
Roads	Road density	Varies, up to 2005	Varies	X	X	X	X		X
	Distance from roads	Varies, up to 2005	Varies	X	X	X	X		X
	Area without roads	Varies, up to 2005	Varies	X	X	X	X		

Land cover	Natural vs. converted	Varies, 1996–2006	30 m or 250 m cells	X	X	X		X	X
	Anderson Level I & II	Varies, 1996–2006	30 m or 250 m cells	X	X	X		X	X
	Impervious surface	2001, 2006	30 m cells		X	X			
Pattern	Patch size	2001 or 2005	30 m or 250 m cells	X	X			X	X
	Morphology	2001 or 2005	30 m or 250 m cells	X	X			X	X
	Area density	2001 or 2005	30 m or 250 m cells	X	X			X	X
Conservation status	Area protected	Varies	Varies	X	X	X	X	X	X
	Ownership	Varies	Varies	X	X	X	X	X	X

Note: Where possible, metrics are provided with coverage extending into Canada and Mexico for the benefit of parks located near these international boundaries.

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