



Landscape Dynamics of Saguaro National Park

Natural Resource Report NPS/NRSS/NRR—2013/615



ON THE COVER

Saguaro National Park, Tucson Mountain District, looking west over the Avra valley.
Photo from Flickr by Lars Hammar (Creative Commons).

Landscape Dynamics of Saguaro National Park

Natural Resource Report NPS/NRSS/NRR—2013/615

William B. Monahan¹, Don E. Swann², and J. Andrew Hubbard³

¹National Park Service
Inventory and Monitoring Division
1201 Oakridge Drive, Suite 150
Fort Collins, Colorado 80525

²National Park Service
Saguaro National Park
3693 South Old Spanish Trail
Tucson, Arizona 85730

³National Park Service
Sonoran Desert Network
7660 E Broadway Blvd, Suite 303
Tucson, Arizona 85710

January 2013

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado publishes a range of reports that address natural resource topics of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate high-priority, current natural resource management information with managerial application. The series targets a general, diverse audience, and may contain NPS policy considerations or address sensitive issues of management applicability.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available from the Natural Resource Publications Management Web site (<http://www.nature.nps.gov/publications/nrpm/>).

Please cite this publication as:

Monahan, W. B., D. E. Swann, and J. A. Hubbard. 2013. Landscape dynamics of Saguaro National Park. Natural Resource Report NPS/NRSS/NRR—2013/615. National Park Service, Fort Collins, Colorado

Contents

	Page
Figures	v
Tables	.vii
Photos	.ix
Executive Summary	.xi
Natural Systems	.xii
Human Drivers	.xiii
Conservation Context	.xiv
Future Directions	.xiv
Acknowledgements	.xvii
List of Abbreviations	.xviii
1. Introduction	1
2. Methods	5
2.1 Landscape Indicators	5
2.1.1 NPScape Indicators for I&M Landscape Dynamics Monitoring	5
2.1.2 Landscape Indicators Selected Specially for Saguaro National Park	6
2.2 Ecologically Informative Areas of Analysis	9
2.2.1 Park, Boundary, and Upstream Watershed AOAs	9
2.2.2 Local 30 km and FireScape AOAs	10
2.2.3 Local viewsheds for RMD and TMD	11
2.2.4 Sonoran Desert and Madrean Archipelago Ecoregional AOAs	11
2.3 Data Sources	11
2.3.1 NPScape Data	11
2.3.2 Other Landscape Data	14
2.3.3 AOA Data	20
3. Results and Discussion	23

Contents (continued)

	Page
3.1 Natural Systems	23
3.1.1 Climate	23
3.1.2 Land Cover	24
3.1.3 Hydrography & Connectivity	27
3.1.4 Landscape Pattern	29
3.1.5 Fire	31
3.1.6 Renewable Energy	32
3.1.7 Vulnerable Species	32
3.2 Human Drivers	33
3.2.1 Population	33
3.2.2 Housing	33
3.2.3 Roads	37
3.2.4 Nighttime Lights	38
3.3 Conservation Context	40
3.3.1 Conservation Status	40
3.3.2 Transportation	41
3.3.3 Viewsheds	41
3.3.4 Land Use & Zoning	45
3.3.5 Socioeconomics	48
4. Synthesis	51
4.1 Status and Trend of Human Drivers	51
4.2 Future Directions	52
References	55
Map Appendix TOC	59

Figures

	Page
Figure 1. Conceptual model for addressing landscape dynamics. Image from NPScape.	xi
Figure 2. The Tucson and Rincon Mountain Districts of Saguaro National Park differ dramatically in climate (see Results, Section 3.1.1).	xiii
Figure 3. Past and future changes in human population occurring in Pima County (see Results, Section 3.2.1).	xiii
Figure 4. Major landowners within 30 kilometers of Saguaro National Park (see Results, Section, 3.3.1).	xiv
Figure 5. Location of Saguaro National Park, including its western Tucson Mountain District (TMD) and its eastern Rincon Mountain District (RMD). The TMD is heavily impacted by Picture Rocks Road.	1
Figure 6. Broad categories of measures considered by NPScape, and how they contribute to understanding the landscape context of parks and park resources.	2
Figure 7. A schematic diagram illustrating a few major types of ecologically informative areas of analysis (AOAs), and why it is important to assess landscape indicators across scales	9
Figure 8. Minimum temperature of the coldest month (top), maximum temperature of the warmest month (middle), and annual precipitation (bottom), reported separately for the two districts of Saguaro National Park with 3 km buffer.	23
Figure 9. Seasonal trends in minimum monthly temperature (top), maximum monthly temperature (middle), and monthly precipitation (bottom), reported separately for the two districts of Saguaro National Park with 3 km buffer	24
Figure 10. Anderson level I land cover area (%) by ecoregion, excluding the dominant category of shrub, which comprises 87% of the Sonoran Desert and 73% of the Madrean Archipelago.	25
Figure 11. Ecological units for the Catalina-Rincon FireScape planning region	26
Figure 12. Map of streams and shallow ground water areas in eastern Pima County, obtained from http://gis.pima.gov/	28
Figure 13. Map of urban-rural-wildlife interface, obtained from the Pima Association of Governments (http://www.pagnet.org/RegionalData/Maps/MapsandGIS-Downloads/tabid/902/Default.aspx).	29
Figure 14. Area density of forest (top) and grassland (bottom) land cover types in the Sonoran Desert (left) and Madrean Archipelago (right) ecogenions encompassing Saguaro National Park	30

Figures (continued)

	Page
Figure 15. Estimated flame length based on current ecological conditions in the Catalina-Rincon FireScape planning region.	31
Figure 16. NOAA wind rose statistical summaries (1973-2004) of wind speed vs. wind direction for the Tucson reporting station	34
Figure 17. Housing density (number of units per km ²) computed for 14 decades (1970-2100) and four AOAs: TMD + 3 km buffer (top left), RMD + 3 km buffer (top right), Park + 30 km buffer (bottom left), and the FireScape planning region (bottom right)	36
Figure 18. Road density (length of road in km divided by the size of the AOA in km ²) computed for three density classes (major roads, all roads, and all roads weighted) and four AOAs: TMD + 3 km buffer (top left), RMD + 3 km buffer (top right), Park + 30 km buffer (bottom left), and the FireScape planning region (bottom right)	38
Figure 19. Traffic volume in and around Tucson in the year 1970	39
Figure 20. Traffic volume in and around Tucson in the year 2010.	40
Figure 21. Map of a night sky inventory recorded during the recent Saguaro BioBlitz.. . . .	41
Figure 22 Land ownership (both conservation and non-conservation lands) in the the Catalina-Rincon FireScape planning region. Map obtained from http://www.azfirescape.org/content/catalina-rincon-analysis-area-maps	42
Figure 23. Area managed by major landowners, expressed as a percentage of each AOA: Park + 30 km buffer (top left), FireScape (top right), Sonoran Desert (bottom left), and Madrean Archipelago (bottom right).	43
Figure 24. Protected areas by AOA: Park + 30 km buffer, FireScape, Sonoran Desert, and Madrean Archipelago. Percentage of protected area (left) and mean size of protected area (right)	44
Figure 25. Northern portions of the eastern Pima County trail system master plan	44
Figure 26. Southern portions of the eastern Pima County trail system master plan	45
Figure 27. Estimated travel times from the main University of Arizona campus, near the city center of Tucson (top row), and the University of Arizona Tech Park, located to the southwest of Tucson (bottom)	46
Figure 28. Existing land use (year 2009) in the Tucson metropolitan area. Map obtained from the Pima Association of Governments (http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx).	47

Tables

	Page
Table 1. Landscape indicators selected by Saguaro National Park and the Sonoran Desert Network to form the basis for foundational I&M landscape dynamics monitoring.	5
Table 2. Other landscape indicators related to natural systems, human drivers, and conservation context that complement the core I&M indicators listed in Table 1.	6
Table 3. Summary of AOAs considered in this report and why they are ecologically relevant.	10
Table 4. Data used to estimate the NPScape indicators considered in this report. Data sources cross reference the indicators in Table 1.	12
Table 5. Data used to estimate other landscape indicators that are of special importance to Saguaro National Park. Data sources cross reference the indicators in Table 2.	14
Table 6. Data for AOAs considered in this report. Data sources cross reference the AOAs in Table 3.	20
Table 7. Status and trend of human drivers according to the Park + 30 km AOA.	52

Photos

	Page
Photo 1. A view of Saguaro National Park and residential development beyond Park boundaries. Photo from NPS photo archive.	x
Photo 2. Washes and riparian habitat provide important connectivity for wildlife. Photo of Rincon Creek by Don Swann.	.xii
Photo 3. Development occurring around park boundaries poses distinct challenges to managing Saguaro natural resources. Photo from NPS photo archive.	xiii
Photo 4. Ponderosa pine forest in the high elevation wilderness area of the Rincon Mountain District, Saguaro National Park. Photo by Don Swann.	xiv
Photo 5. Saguaro National Park and the surrounding city of Tucson. NPS photo archive.	1
Photo 6. Buffelgrass invasion of saguaro habitat. NPS photo archive.	2
Photo 7. A desert tortoise enjoys fruit from a prickly pear cactus. NPS photo archive.	3
Photo 8. Most precipitation tends to fall in late summer with monsoonal rains. Summer storm over Sabino Canyon, viewed from the Rincons, with Tucson in the distance. Photo by Jim Malusa, courtesy of FireScape.	22
Photo 9. On rare occasions, snow falls on the desert floor of Saguaro National Park. Photo by Joshua Boles (NPS photo archive).	22
Photo 10. Desert scrub is the dominant land cover type throughout the Sonoran Desert and Madrean Archipelago ecoregions. Photo by Joshua Boles (NPS photo archive).	25
Photo 11. Looking downstream on Big Wash towards the Tangerine Road Bridge, with SR-77 and the Santa Catalina Mountains	27
Photo 12. Forest pattern on Heartbreak Ridge from Rincon Peak Trail. Photo by Laura Bolyard (NPS photo archive).	32
Photo 13. Bell's Vireo (<i>Vireo bellii</i>) utilizes riparian habitats	32
Photo 14. Tucson and surrounding communities have experienced rapid human population growth, and projections suggest that these trends will continue through at least 2030.	33
Photo 15. Picture Rocks Road is a major road that bisects Tucson Mountain District	37
Photo 16. Tucson at night	38
Photo 17. Senita Valley Elementary School, located at 10750 E Bilby Road in Tucson, is about 5 miles (estimated 12 minute drive time) from the entrance to RMD.	48



Photo 1. A view of Saguaro National Park and residential development beyond Park boundaries. Photo from NPS photo archive.

Executive Summary

Like many protected areas in the western United States, Saguaro National Park has experienced rapid urban growth outside of 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 distant along poorly developed dirt roads. Today, Tucson has nearly 1 million residents, and a multitude of human pressures associated with this growth and development pose distinct challenges to Park natural resources. Roads carve up natural landscapes and impede connectivity for wildlife, urban and agricultural development further fragment and erode the remaining natural areas, and housing proximate to the Park enable residents and pets to transgress its boundaries (Figure 1). Hence, despite the best possible resource management practices being implemented inside the Park, external anthropogenic landscape stressors originating from such sources as population, housing, and roads require Park managers, planners, and interpreters to confront the tricky questions of how such landscape dynamics affect the status and trend of key defining Park resources.

Fortunately, beyond the human drivers of landscape change, Saguaro also has opportunities to manage its natural systems in a broader conservation context (Figure 1). By considering park resources over a range of ecologically relevant scales, Saguaro can evaluate where and how important habitats are distributed, the degree to which they are connected to the Park, who owns the intervening lands, and the extent to which they are managed for conservation. Such information is critical when developing and strategizing landscape-level conservation partnerships, and indeed Saguaro already considers factors such as these when it engages in collaborative partnerships like FireScape (<http://www.azfirescape.org/>) and the Rincon Institute Urban Interface Project (<http://rinconinstitute.org/>). Where possible this report encompasses existing partnerships and seeks to provide the Park with additional landscape-level data and analysis that may help it further strategize new/future partnerships. In this context the report delivers an extensive set of socioeconomic indicators, which may be used by Saguaro to strategize where and how to engage in education and outreach with local communities.

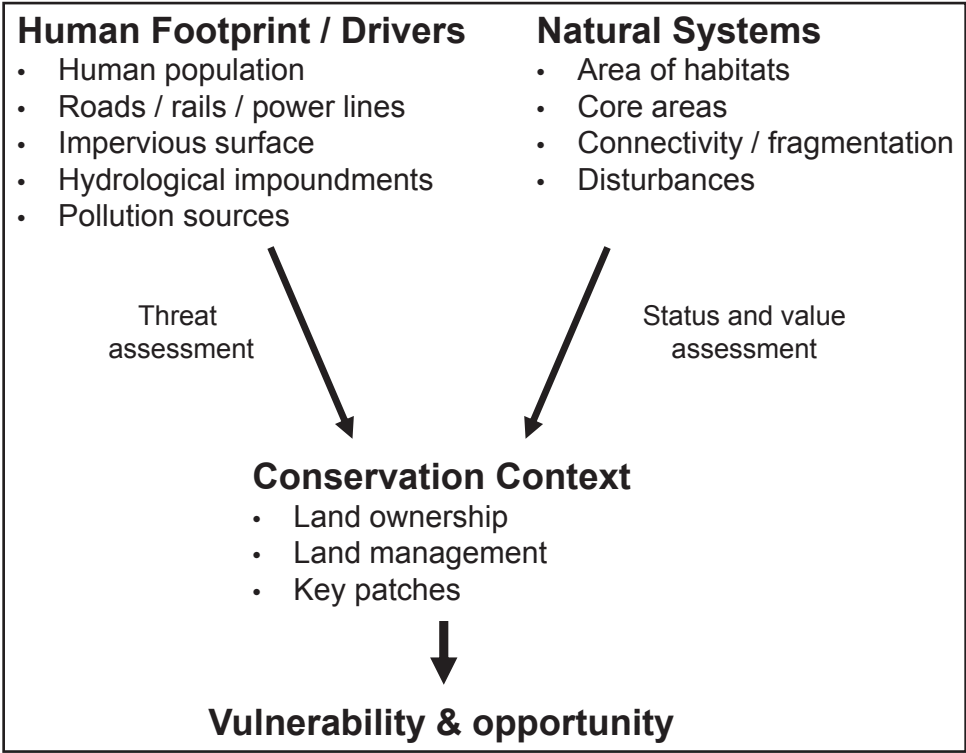


Figure 1. Conceptual model for addressing landscape dynamics. Image from NPScape.

This landscape dynamics report endeavors to provide Saguaro National Park with:

- Data and methods for ongoing inventorying and monitoring of landscape dynamics
- A detailed analysis of existing landscape data for areas within and surrounding the Park
- Interpretation of the results in the context of key defining park natural resources

Data and methods are described in sufficient detail to enable replication of the calculations and procedures, particularly as they relate to I&M landscape dynamics monitoring, so that results can be updated for Saguaro over time as new source data become available (typically every 5 to 10 years). A summary of key findings related to natural systems, human drivers, and conservation context is provided here.

Natural Systems

Beyond the management decisions and actions made inside park boundaries, the natural systems surrounding Saguaro are what enable many park natural resources to persist for future generations. Other natural areas afford opportunities for maintaining connectivity with the Park, hydrography facilitates the bi-directional flow of materials and energy, and both climate and climate change determine broad-scale patterns of biodiversity. Below we summarize key observations related to Saguaro's natural systems considered at landscape scales:

Climate: Saguaro National Park is located on the transition between the Sonoran Desert (West) and Madrean Archipelago (East) ecoregions. Due to this geographic positioning, the temperature, precipitation (Figure 2), and seasonality gradients around the Park are quite pronounced. Recent changes in climate (1980-2010) suggest that annual precipitation has declined in most areas, while minimum winter and maximum summer temperatures are characterized by complex spatial patterns of temperature change.



Photo 2. Washes and riparian habitat provide important connectivity for wildlife. Photo of Rincon Creek by Don Swann.

Hydrography & Connectivity: Water is a key limiting ecosystem factor for many Saguaro resources. Hence, washes, groundwater, basins, watersheds, and springs are critical natural features that influence landscape connectivity. Meanwhile, human modifications like impoundments and development associated with Tucson and surrounding communities carve up these natural features. Despite these challenges, Saguaro is still able to maintain connectivity for certain species – between the Tucson and Rincon Mountain Districts, and also at broader landscape scales.

Fire: Park habitats vary dramatically along an elevational gradient in their adaptation to fire. Lightning is an important natural source of fire ignition that reaches a peak in frequency in the month of August. Once ignited, fires are driven in part by wind, which exhibits complex seasonal and diurnal variation in both magnitude and direction.

Vulnerable Species: Saguaro provides important habitat for a wide variety of plant and animal species of conservation concern,

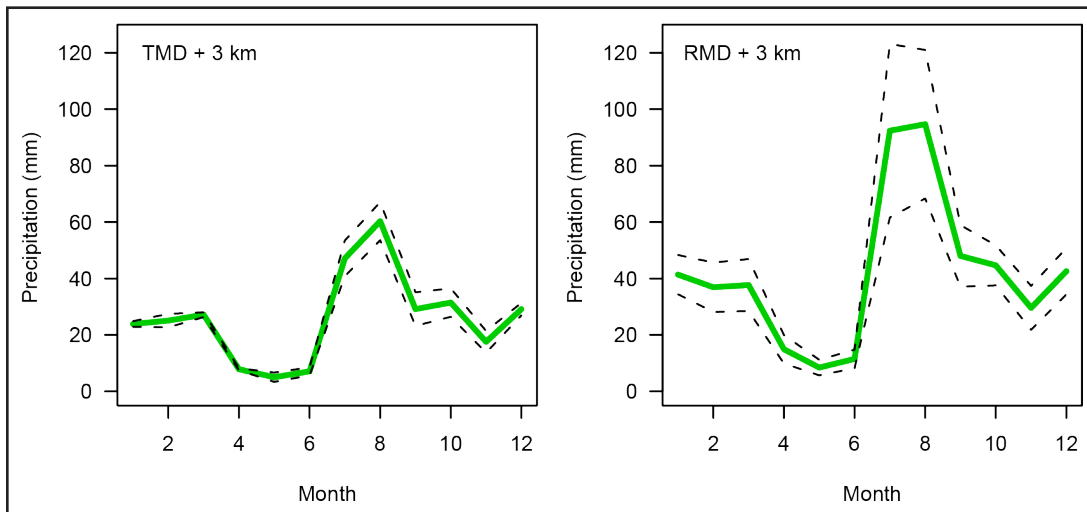


Figure 2. The Tucson and Rincon Mountain Districts of Saguaro National Park differ dramatically in climate (see Results, Section 3.1.1). Solid lines denote spatial averages in each district; dashed lines denote corresponding standard deviations.

and several others are noteworthy in a landscape context. The broad-scale distributions of many of these species are shaped by the climatic gradients summarized above, and at more local scales by the distribution of available habitats and human drivers of landscape change.

Human Drivers

Human drivers of landscape change are important because they represent external factors that can transcend park boundaries and negatively impact park resources. Below is a summary of major human drivers, how they have changed around the Park in the recent past, and how we expect them to change in the coming decades:

Population: Human population around Saguaro has increased dramatically since the Park was first established as a National Monument in 1933 (Figure 3). This growth is expected to continue into the future, especially in areas along the I-10, I-19, and Highway 77 corridors.



Photo 3. Development occurring around park boundaries poses distinct challenges to managing Saguaro natural resources. Photo from NPS photo archive.

Housing: Housing growth since the year 1970 has largely been characterized by exurban and now suburban growth around the periphery of Tucson. Housing densities are greater around the Tucson Mountain District than they are around the Rincon Mountain District, but both Districts are affected by exurban development within 3 km of their borders. As densities continue to increase under existing zoning, Saguaro will by about the year 2040 be considered a suburban park.

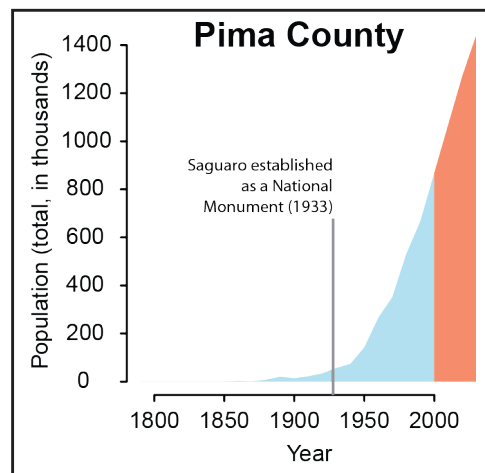


Figure 3. Past and future changes in human population occurring in Pima County (see Results, Section 3.2.1). Blue area reports observed trends according to the US Census (1790-2000); pink area shows statewide population projections through 2030.

Roads: The road transportation network around Saguaro is extensive due to recent growth of Tucson and surrounding communities. Road density occurring within 3 km of Saguaro is approximately 3x higher for the Tucson Mountain District compared to the Rincon Mountain District. The Tucson Mountain District is also especially challenged by Picture Rocks Road, a major commuter road that bisects the Saguaro West Wilderness.

Conservation Context

A landscape-scale plan for conserving Park resources must ultimately be implemented in some broader conservation context. Conservation context takes into account neighboring lands, including the landowners, whether and how neighbors manage their lands for conservation, and other important socioeconomic factors that drive policy and determine conservation opportunity. Below is a summary for Saguaro of important aspects of their broader conservation context that effect landscape-scale conservation:

Protected Areas: The East and West Saguaro Wildernesses, along with the Pusch Ridge (USFS) Wilderness, anchor the larger network of protected areas that help connect Saguaro National Park to surrounding landscapes.

Landowners: Other major landowners around Saguaro include USFS and BLM, as well as Tribal and State lands (Figure 4).



Photo 4. Ponderosa pine forest in the high elevation wilderness area of the Rincon Mountain District, Saguaro National Park. Photo by Don Swann.

These lands vary tremendously in level of protection, but nonetheless represent key potential partners in future landscape-level conservation partnerships.

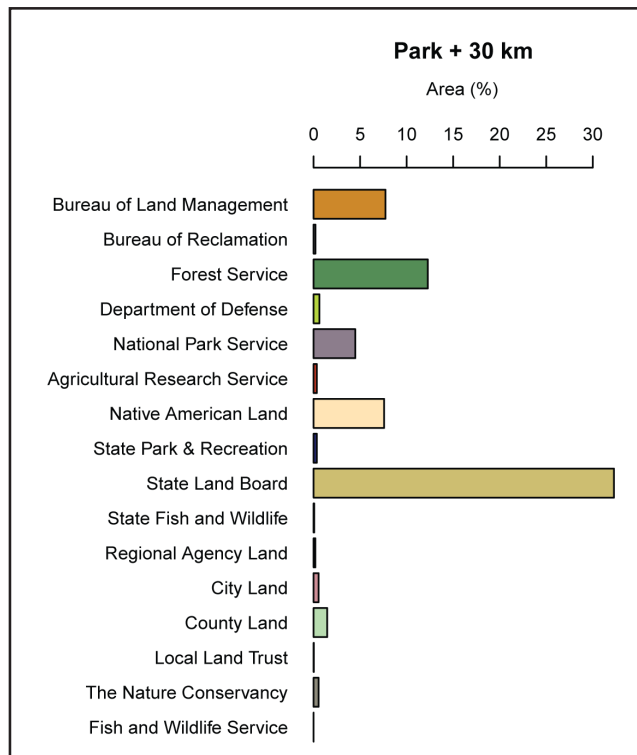
Land Use & Zoning: Much of the recent growth and human habitat conversion around Tucson is easily visualized with land use and zoning data. An added value of these data over other landscape indicators like land cover is that they provide more direct insights into the causes and trajectories of habitat loss, and thus provide the Park with more of an opportunity to proactively engage the different groups that drive landscape-level change.

Socioeconomics: A wide variety of socioeconomic indicators (e.g., race, age, education, employment, poverty, income) are available to Saguaro from the decadal Census. Results suggest clear spatial patterns in the case of many of these indicators, as well as spatial correlations among indicators. Taken in combination, this information may be used by Saguaro to strategize how best to engage local communities in park issues and activities.

Future Directions

This report provides Saguaro National Park with a foundational framework for I&M (Inventory and Monitoring) landscape dynamics monitoring and reporting. The

Figure 4. Major landowners within 30 kilometers of Saguaro National Park (see Results, Section, 3.3.1). Approximately 31% of land in this area is considered private non-conservation.



intent is for this framework to be repeated in the future (e.g., every 5 to 10 years) so that Saguaro can continue to address basic questions related to changes in the natural systems, human drivers, and conservation context occurring around the Park. However, prior to the development of another full-length report, several important smaller projects may be considered and undertaken in the near future:

- Custom models of habitat connectivity could be developed for key species of special interest to the Park. Many of the landscape indicators considered in this report are known to impede wildlife movement via a multitude of mechanisms. Using data detailed in the methods section, custom connectivity models could be built and overlaid with conservation context to visualize how areas that are important for preserving landscape-scale connectivity align with lands that vary in level of protection and ownership. They could also be considered in relation to other landscape data and models provided in HabiMap (<http://www.habimap.org/>), a dynamic online map recently released by the Arizona Game and Fish Department. Such detailed analyses and map overlays would help the Park strategize where and who to engage in conservation partnerships.
- The viewsheds (i.e., areas within view from key observation points) presented under conservation context may be overlaid with multiple human drivers of landscape change (e.g., population, housing, roads, nighttime lights) to visually assess and quantify potential threats to wilderness character. However, for such results to be useful and reliable in a planning context, the viewshed models presented in this report need to be validated by on-the-ground observations. Saguaro could perform this accuracy assessment by recording observations from viewing points using a digital camera and comparing known landmarks in the photos to those in the viewsheds.
- By the summer of 2012 it will be possible to update most of the socioeconomic indicators (e.g., race, age, education, poverty, employment) using results from the 2010 Census. Saguaro will then be able to evaluate trends (1990-2010) in the socioeconomic indicators at the census block group level, which is sufficiently detailed to give the Park insights into specific neighborhoods for engaging local communities.
- By early 2013, the housing density model used in this report should also be updated to include results from the 2010 Census, as well as refined and improved scenarios of future housing growth. This time series (1970-2100), which has already proved to be a useful tool for visualizing and communicating growth in Tucson and surrounding communities, will be suited to more detailed analyses of where and when housing growth is expected to occur in the coming decades.
- Also during 2013 we anticipate two important updates to land cover data. One of these will be for the contiguous US (2011 land cover), which may then be coupled with the corresponding 2001 and 2006 datasets to estimate local patterns of land cover change. The other dataset to be updated includes coverage into Mexico, which will enable the Park to visualize broad scale transboundary patterns of recent land cover change. Both datasets will be increasingly useful for addressing questions related to how Saguaro National Park is connected to surrounding landscapes, and how connectivity varies across taxa with different spatial requirements.

Acknowledgements

This project was made possible thanks to the hard work and contributions of a number of people. We thank Saguaro National Park and Sonoran Desert Network I&M staff who participated in the initial project scoping meeting and provided critical feedback at various times during the production of our report: Darla Sidles, Meg Weesner, Perry Grissom, Natasha Kline, Dana Backer, Becky MacEwen, Bob Love, Sarah Studd, Kristen Beaupre, Colleen Filippone, and Cheryl McIntyre. In addition, we thank NPScape team members for their work in preparing data, methods, maps, and foundational reports that provided important landscape ecological concepts and content for us to build upon: John Gross, Peter Budde, Tom Philippi, Lisa Nelson, Brent Frakes, Mike Story, Shepard McAninch, Leona Svancara, Mara Kali, Sean Worthington, Thom Curdts, Dave Hollema, and Nick Viau. Saguaro viewsheds were contributed thanks to analyses performed by Peter Budde and Kirk Sherrill. The NPS Natural Lightscapes Program

(Chad Moore and Dan Duriscoe) provided important guidance on the availability and use of nighttime light data, and Connie Walker (National Optical Astronomy Observatory) assisted us with GLOBE at Night. We thank Jim Malusa and Cori Dolan for help with procuring and using FireScape data, as well as Jane Conners, John Dickinson, and Steve Whitney from the Pima County Information Technology Department for assistance with obtaining and using county-wide GIS data. Fagan Johnson assisted with the layout of this report. Last but not least, we thank the reviewers who provided feedback that considerably improved earlier versions of this report: Jake DeGayner (NPS Southern Arizona Office), Jerime Kellermann (University of Arizona), Jason Mateljak (Fort Bowie National Historic Site, Chiricahua and Coronado National Monuments), and Sarah Studd (NPS Sonoran Desert I&M Network).

List of Abbreviations

Abbreviations	Description
AML	Arc Macro Language
AOA	Area of analysis
BLM	Bureau of Land Management
BOR	Bureau of Reclamation
CLS	Conservation Lands System
CV	Coefficient of variation
DOI	Department of Interior
ESRI	Environmental Systems Research Institute
GAP	Gap Analysis Program
GIS	Geographic Information System
HDF	Hierarchical Data Format
I&M	Inventory and Monitoring Program, or Inventory and Monitoring Division
IUCN	International Union for the Conservation of Nature
NALC	North American Land Change Monitoring System
NASA	National Aeronautics and Space Administration
NLCD	National Land Cover Dataset, or National Land Cover Database
NOAO	National Optical Astronomy Observatory
NPS	National Park Service
NRSS	Natural Resource Stewardship and Science
OTD	Optical Transient Detector
PAD-US	Protected Areas Database of the US
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RMD	Rincon Mountain District (Saguaro National Park East)
SD	Standard deviation
SERGoM	Spatially Explicit Regional Growth Model
SOP	Standard Operating Procedure
TMD	Tucson Mountain District (Saguaro National Park West)
USFS	US Forest Service
USGS	US Geological Survey
WDPA	World Protected Areas Database

1. Introduction

Over a decade ago, park managers expressed concern that a number of park resources were being damaged by activities outside park boundaries (US General Accounting Office 1994). Despite the best possible resource management practices being implemented inside parks, external anthropogenic landscape stressors originating from such sources as population, housing, and roads have increased around most parks over time (Davis & Hansen 2011), and projections suggest that these stressors will in many instances continue to increase for the foreseeable future (Radeloff et al. 2010). Trends of this sort emphasize the need for parks to have their own detailed data on landscape dynamics, for the ongoing analysis and interpretation of landscape data are central to being able to plan and implement management actions that preserve park resources in the face of landscape-level change. This report provides Saguaro National Park with (i) data and methods for ongoing inventorying and monitoring of landscape dynamics, (ii) a detailed analysis of existing landscape data for areas within and surrounding the park, and (iii) interpretation of the results in the context of key defining park natural resources.

Saguaro National Park, like many parks in the western United States, has experienced rapid urban growth outside of its boundaries. When the park was established in 1933, the nearby city of Tucson had fewer than 40,000 residents, and the city was more than 20 miles distant along poorly developed dirt roads. Today, Tucson contains nearly 1 million residents. The park includes two units (Figure 5): the Rincon Mountain District (RMD), approximately 100 square miles on the east side of Tucson, and the Tucson Mountain District (TMD), approximately 40 square miles west of Tucson. Housing developments flank both districts and a major commuter road cuts through the Tucson Mountain District. These landscape-level changes have profoundly affected the Park's resources, especially wildlife such as



Photo 5. Saguaro National Park and the surrounding city of Tucson. NPS photo archive.

javelina, coyotes (McClure et al. 1996), and desert tortoises (Edwards et al. 2004a,b). An estimated 29,000 animals are killed annually by cars on the 76.6 miles of roads that run through the park or along the park's boundary (Gerow et al. 2010). Park resources are impacted by non-native species, particularly domestic dogs and invasive 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 (Monahan et al. 2012a).

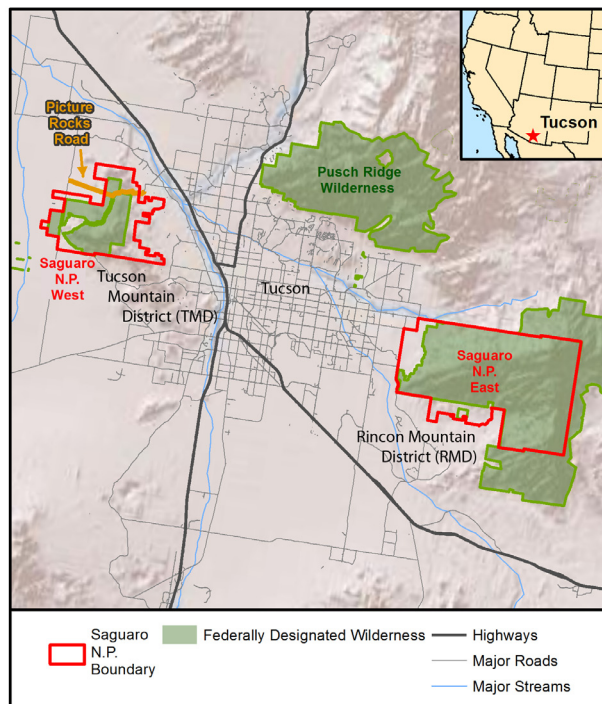


Figure 5. Location of Saguaro National Park, including its western Tucson Mountain District (TMD) and its eastern Rincon Mountain District (RMD). The TMD is heavily impacted by Picture Rocks Road.



Photo 6. Buffelgrass invasion of saguaro habitat. NPS photo archive.

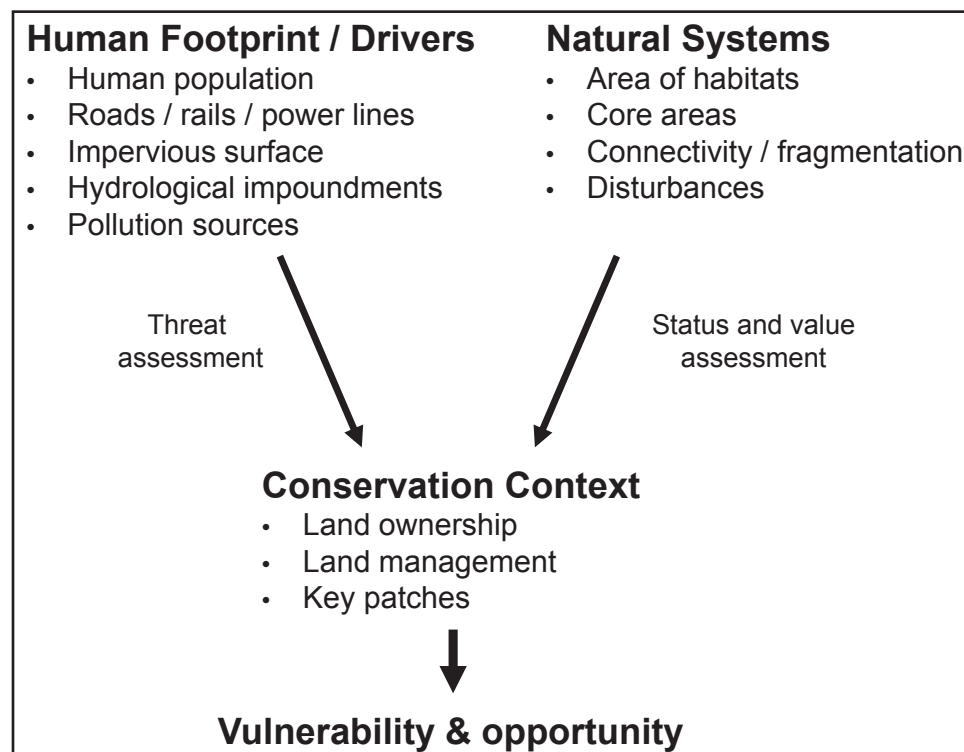
Major landscape-level drivers affecting Saguaro National Park are quantified and interpreted by NPScape (National Park Service 2012), a project run by the NPS Inventory and Monitoring (I&M) Division. The overall goal of NPScape is to support park natural resource management and planning by providing relevant landscape-scale information to all possible NPS units with significant natural resources (National Park Service 1999, National Academy of Public

Administration 2010). Key NPScape objectives are to provide:

- A coherent conceptual and analytical framework for conducting landscape-scale analyses and evaluations that can inform park-level decisions.
- Credible methods that are well documented, founded on strong science, and readily repeatable and extensible with local data.
- Informative and useful data and related products at the broad scales not typically available at the park level.
- Assistance to parks in interpreting results.

NPScape products have been developed using a conceptual framework that links measurable attributes of landscapes to natural resources within parks (Figure 6). The conceptual framework illustrates connections among key attributes of the greater park environment and relates NPScape products to the evaluation of landscape condition and the context of parks. At its core, the NPScape framework is designed to address questions related to resource conservation

Figure 6. Broad categories of measures considered by NPScape, and how they contribute to understanding the landscape context of parks and park resources.



vulnerability and opportunity. These dynamics are shaped most proximately at the landscape scale by three major factors: (i) natural systems, (ii) human drivers, and (iii) conservation context. This framework was 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 & DeFries 2007).



Photo 7. A desert tortoise enjoys fruit from a prickly pear cactus. NPS photo archive.

Consider by way of example a focal resource like the desert tortoise (*Gopherus agassizii*). Within the Park, the tortoise is capable of persisting in part because of the ecological attributes of the larger natural system within which it exists (e.g., overall amount of suitable habitat, integrity and connectedness of the habitat). However, the actual ability of the natural system to maintain viable populations of the tortoise must be further interpreted in the context of human-mediated drivers of landscape change (e.g., population, housing, roads, and other land cover conversion). Tortoise populations within the Park were historically connected to populations outside the Park, but this connectivity is being disrupted by habitat loss due to urban development and barriers that include roads and residential developments (Edwards et al. 2004a,b). Precisely how these drivers interact with the attributes of the natural system to impact conservation vulnerability and opportunity of the tortoise depends further on the stewardship of all management units within the surrounding natural system (e.g., landowner, level of protection, spatial context of other lands suitable for conservation). NPScape

quantifies these critical landscape elements and provides them, along with analysis and interpretation to parks, in an effort to assist management decisions aimed at protecting natural resources like the tortoise.

As evident from the conceptual framework (Figure 6), NPScape excels at providing standardized landscape measures that are of fundamental importance to all or at least most parks. Furthermore, it does so using consistent data and methods that lend themselves to reporting at regional and national scales. NPScape products are thus intended to provide parks with base-level I&M landscape dynamics monitoring support. This model endeavors to promote more specialized landscape-level analyses by enabling I&M networks to redirect resources that would otherwise be spent on foundational landscape dynamics monitoring. In other cases where existing measures and analyses provided by NPScape simply need to be updated using more detailed geospatial data, or perhaps run for other areas of analysis, NPScape methods and tools are made available to again redirect I&M resources that would otherwise be spent replicating analytical techniques already developed at the national level (see Methods, Section 2).

Individual parks like Saguaro benefit from the ability of NPScape to evaluate key landscape measures repeatedly over time using standardized data and methods. Such a consistent approach is noteworthy in that it provides Saguaro with past, present, and future landscape dynamics monitoring data and results that can be factored into park management and planning. These core, I&M landscape indicators that may be monitored consistently over time using standardized methodologies allow Saguaro to address such questions as:

- How do the Rincon and Tucson Mountain Districts of Saguaro experience different types and levels of stress imposed by human drivers of landscape change?
- What are the major forms of land cover change occurring around the park?

- How are forests and grasslands distributed throughout the Sonoran Desert and Madrean Archipelago ecoregions that extend down into Mexico?
- What is the spatial distribution of protected areas around Saguaro and who are the landowners?

While these are important questions for Saguaro that will undoubtedly factor into long-term resource management and planning, they do not necessarily directly address a number of the other more pressing questions that arise in response to current issues confronted by the Park. Fortunately, in addition to NPScape, a considerable amount of local landscape-level data and analysis is also available, specifically through such sources as Pima County (<http://gis.pima.gov/>), FireScape (<http://www.azfirescape.org/>), the Rincon Institute Urban Interface Project (<http://rinconinstitute.org/>), and Arizona Missing Linkages (<http://corridordesign.org/linkages/arizona>). This report seeks to include certain data and results from such local groups in an effort to integrate with standardized NPScape monitoring other Geographic Information System (GIS) data that drive current/ongoing management and planning decisions in the region, and also relate to critical park resources.

At the forefront of important resources for Saguaro that are impacted by decisions made by the greater resource conservation community are preserving wilderness character in the face of a growing city of Tucson and ensuring habitat connectivity for key species of wildlife. Saguaro is poised to play a central role in solutions to both of these challenges. In addition to providing two of the largest tracts of wilderness area in the region, Saguaro also provides critical habitat and connectivity for species of conservation concern. Combining information from NPScape with local GIS data and regional conservation priorities we are able to address in this report a handful of targeted questions that are particularly timely and relevant to Saguaro, including:

- What are the most likely corridors that urban-adaptable species might use to move between the Rincon and Tucson Mountain Districts, and how are these distributed with respect to washes and riparian habitats throughout the basin?
- How are key or vulnerable species distributed in proximity to major human drivers like housing and population density?
- How different are the viewsheds between the Rincon and Tucson Mountain Districts and – considering potential impacts to wilderness character – how are human influences like nighttime lights distributed in each viewshed?
- In strategizing park education and outreach, how are human populations distributed with respect to age and ethnicity around the Rincon and Tucson Mountain Districts?

In summary, this report provides Saguaro National Park with a foundational I&M landscape dynamics monitoring framework used to address basic questions related to the natural systems, conservation context, and human drivers around the Park. It also provides park-specific data and results for issues presently at the forefront of local management and planning decisions under consideration by the greater resource conservation community. Methods are described in sufficient detail to enable replication of the calculations and procedures, particularly as they relate to I&M landscape dynamics monitoring, so that results can be updated for Saguaro over time as new source data become available (typically every 5 to 10 years). Results are intended to provide a snapshot in time with the hope and intent that I&M landscape dynamics updates and new park-specific data and results will be synthesized on an appropriate time scale. Finally, the report concludes with a summary and synthesis of human drivers and advances a series of recommendations for future landscape dynamics monitoring.

2.Methods

2.1 Landscape Indicators

2.1.1 NPScape Indicators for I&M Landscape Dynamics Monitoring

The NPScape landscape indicators summarized in Table 1 were selected after careful consideration of their ecological relevance to Saguaro National Park, as well as more generally the appropriateness of the spatial, temporal, and thematic resolution of the source data available to compute the indicators (see Data Sources, Section 2.3). Importantly, due to these factors it should be recognized that the NPScape indicators analyzed in this report are considered foundational to I&M landscape dynamics monitoring; additional NPScape indicators may be included over time as new data resources become available. This section summarizes the NPScape indicators presently selected and why. Additional background on these choices is provided in Monahan & Gross (2012) and the NPScape Interpretive Guide (Monahan et al. 2012b).

Table 1. Landscape indicators selected by Saguaro National Park and the Sonoran Desert Network to form the basis for foundational I&M landscape dynamics monitoring.

Category	Indicator
Housing	Housing density
Roads	Road density Distance from road
Population	Population (total, density)
Land cover	Land cover area by category
Landscape pattern	Area density pattern by land cover category
Conservation status	Protected area Land ownership

In the case of human drivers, housing density was selected as a focal indicator because – depending on proximity to a protected area like Saguaro National Park – humans and pets associated with this measure can have profound direct and indirect effects on the distribution, abundance, and population viability of native species (McDonnell & Hahs 2008). Road density was similarly selected because the traffic associated with roads is known to negatively impact many native species through roadkill, road-avoidance, and human access (Forman & Alexander 1998).

A disadvantage of roads is that they are inherently difficult to map and monitor consistently over time, but road traffic is often highly correlated with local population size (Monahan et al. 2012b). Total population and population density were thus selected to monitor local human impacts.

Many of the habitats of special conservation concern to Saguaro (e.g., riparian, saguaro-dominated) are too taxonomically detailed or spatially restricted to be reliably mapped consistently over time by the sort of national or even regional land cover mapping efforts that are required by NPScape. However, two important components of the natural system that are ecologically informative and available to NPScape are land cover area by category (Anderson level I and II classifications) and area density pattern by land cover category. While land cover area by category may seem too basic to be informative as a landscape indicator, in Canadian parks it

was precisely this measure as computed for each park and surrounding landscape that had the greatest support over many variables in accounting for park extirpation of mammal species (Wiersma et al. 2004). Additionally, due to the fact that land cover loss results in reduced natural area, creation of edges, and increased isolation of resulting remnant patches (Ewers & Didham 2006, Kupfer 2006), all detrimental to bio-

diversity, change in this indicator over time is also especially important. Area density pattern by land cover category complements the simple area estimates by describing landscape dynamics such as dominance, fragmentation, edge abundance, and patchiness (Riitters 2011).

Lastly, formally designated protected areas (i.e., lands that receive permanent protection from land cover conversion and are mandated to maintain at least a primarily natural state) and land ownership were

chosen as landscape indicators for conservation context. While no single percentage of protected area can be used to ensure protection or maintenance of biodiversity (Lindenmayer & Franklin 2002, Groves 2003, Svancara et al. 2005), the amount and distribution of protected areas provide insights into whether and how species traverse the landscape through a network of formally protected natural habitats. Additionally, as evident by local planning partnerships like FireScape and the Arizona Wildlife Linkages Workgroup, knowledge of surrounding land ownership is critical to coordinated resource conservation (Monahan & Gross 2012).

2.1.2 Landscape Indicators Selected Specially for Saguaro National Park

In addition to the NPScape indicators, other landscape-scale indicators related to attributes of the natural system, human drivers, and conservation context were included to further assist Saguaro in evaluating resource conservation challenges and opportunities (Table 2). Additional abiotic indicators (natural systems) were chosen because they affect the distributions of vulnerable species occurring inside and around the park (e.g., climate, hydrology), relate to renewable energies that are subject to potential development in areas adjoining the park (e.g., wind, solar), and relate to important natural

disturbances such as fire (e.g., lightning). Nighttime light pollution was included as an additional human driver because it links very clearly to park natural resources like wilderness character. An expanded set of indicators related to conservation context was also considered because Saguaro faces distinct resource conservation challenges and opportunities by nature of being a park that is split by a rapidly growing city (Tucson and neighboring suburbs and towns). While anthropogenic landscape-level changes (e.g., increases in housing density) are often assessed for their negative effects on park resources, an important goal at Saguaro is to increase the Park’s relevancy in the surrounding community, particularly among youth. Hence, in order to assist Saguaro with strategizing how best to engage local communities, the report also includes a number of other demographic (e.g., age, education, race) and land use/planning indicators. Although these landscape indicators related to natural systems, human drivers, and conservation context are not analyzed as extensively as the core landscape indicators considered by NPScape, a major advantage of including them here is to facilitate more direct comparisons and interpretations than is otherwise possible when results are spread across disparate reports.

Table 2. Other landscape indicators related to natural systems, human drivers, and conservation context that complement the core I&M indicators listed in Table 1.

Category	Indicator
Climate	Minimum monthly temperature
	Maximum monthly temperature
	Total monthly precipitation
	Minimum temperature of the coldest month
	Maximum temperature of the warmest month
	Annual precipitation
	Temperature seasonality (SD in monthly mean temperature)
	Precipitation seasonality (CV in monthly precipitation)
Hydrography & connectivity	Watersheds, number and area
	Wash network, location
	Drainage basins, number and area
	Wildlife corridors, location
Lightning	Annual flash rate
	Average September – June (low) flash rate
	Average July (mid) flash rate

Table 2. Other landscape indicators related to natural systems, human drivers, and conservation context that complement the core I&M indicators listed in Table 1 (continued).

Category	Indicator
Lighting (continued)	Average August (high) flash rate
Renewable energy	Wind speed
	Concentrating solar power
	Geothermal favorability, index
Vulnerable species	Needle-spined pineapple cactus (<i>Echinomastus erectocentrus</i> var. <i>erectocentrus</i>)
	Pima pineapple cactus (<i>Coryphanta scheeri</i> var. <i>robustispina</i>)
	Gentry indigobush (<i>Dalea tentaculoides</i>)
	Huachuca water umbel (<i>Lilaeopsis schaffneriana</i> var. <i>recurva</i>)
	Tumamoc globeberry (<i>Tumamoca macdougali</i>)
	Desert pupfish (<i>Cyprinodon macularius macularius</i>)
	Gila chub (<i>Gila intermedia</i>)
	Gila topminnow (<i>Poeciliopsis occidentalis occidentalis</i>)
	Longfin dace (<i>Agosia chrysogaster</i>)
	Sonora sucker (<i>Catostomus insignis</i>)
	Desert box turtle (<i>Terrapene ornata luteola</i>)
	Chiricahua leopard frog (<i>Rana chiricahuensis</i>)
	Lowland leopard frog (<i>Rana yavapaiensis</i>)
	Giant spotted whiptail (<i>Chemidophorus burti stictogrammus</i>)
	Ground snake (<i>Sonora semiannulata</i>)
	Mexican garter snake (<i>Thamnophis eques megalops</i>)
	Tucson shovelnose snake (<i>Chionactis occipitalis klauberi</i>)
	Abert's towhee (<i>Pipilo aberti</i>)
	Bell's vireo (<i>Vireo bellii</i>)
	Cactus ferruginous pygmy owl (<i>Glaucidium brasilianum cactorum</i>)
	Rufous-winged sparrow (<i>Aimophila carpalis</i>)
	Swainson's hawk (<i>Buteo swainsoni</i>)
	Southwestern willow flycatcher (<i>Empidonax traillii extimus</i>)
	Western burrowing owl (<i>Athene cunicularia hypugaea</i>)
	Western yellow-billed cuckoo (<i>Coccyzus americanus occidentalis</i>)
	Allen's big-eared bat (<i>Idionycteris phyllotis</i>)
	California leaf-nosed bat (<i>Macrotus californicus</i>)
	Lesser long-nosed bat (<i>Leptonycteris curasoae yerbabuenae</i>)
	Mexican long-tongued bat (<i>Choeronycteris mexicana</i>)
	Pale Townsend's big-eared bat (<i>Plecotus townsendii pallescens</i>)
	Western red bat (<i>Lasiurus blossevillii</i>)
	Western yellow bat (<i>Lasiurus xanthinus</i>)
	Arizona shrew (<i>Sorex arizonae</i>)
Nighttime lights	Nighttime lights, sky-down, visible
	Nighttime lights, sky-down, atmospheric scattering
	Nighttime lights, ground-up, visible
Transportation	Road network, location
	Railroad network, location
	Airports, number & location
	Trail network, location

Table 2. Other landscape indicators related to natural systems, human drivers, and conservation context that complement the core I&M indicators listed in Table 1 (continued).

Category	Indicator
Transportation (continued)	Bike route network, location
	Bus route network, location
	HandiCar zones, area and location
Viewsheds (see AOA, below)	RMD & TMD, from road key observation points
	RMD & TMD, from front-country key observation points
	RMD, from back-country key observation points
Land use & zoning	Land use
	Land use intensity
	New building permits, type
	Number of structures built
	Subdivisions, lot count
	Parcels, area
	Neighborhood associations, area
Socioeconomics	Jurisdictions, identities
	Race – Asian American (number, density)
	Race – Black (number, density)
	Race – Hispanic (number, density)
	Race – Native American (number, density)
	Race – White (number, density)
	Age – median
	Age – under 5 yrs (number, density)
	Age – 5 to 19 yrs (number, density)
	Age – 21 yrs and over (number, density)
	Age – 65 yrs and over (number, density)
	Education – no school (number, density)
	Education – middle and part of high school (number, density)
	Education – high school graduate (number, density)
	Education – Bachelor's degree (number, density)
	Schools – elementary, middle, high (number)
	School districts – elementary, middle, high (number, area)
	School children – grades 1-8 (number)
	School children – grades 9-12 (number)
	Household size – owner occupied (average)
	Household size – renter occupied (average)
	Monthly owner costs as % of income – 35% or more (number, density)
	Gross rent as % of income – 35% or more (number, density)
	Poverty – families below (number, percentage)
	Employment – employed (number, density)
	Employment – unemployed (number, density)
	Income (\$)
	Structure value (\$)
	Popular attractions (identity, location)
	Popular attractions (identity, location)
	Modern cultural attractions (identity, location)

2.2 Ecologically Informative Areas of Analysis

Landscape indicators important to parks and park resources often vary with scale or spatial extent. Areas of analysis (AOAs) represent formal definitions on a map of what is meant by ‘landscape’ (Figure 7). AOAs are critical to any landscape project because they ensure that everyone analyzing and interpreting landscape data and results are doing so under a common spatial framework that is ecologically relevant to the questions being addressed. In this report, we consider multiple AOAs that collectively allow us to consider the major park/boundary, local, and ecoregional scales that drive most landscape dynamics of relevance to Saguaro.

Importantly, multiple AOAs are considered for each indicator because:

- No single AOA is fully suited to answering questions related to a particular landscape indicator.

- Different landscape indicators are typically informative over different AOAs.
- Local planning regions (e.g., FireScope) define AOAs for a specific set of project questions and goals that do not necessarily drive park and I&M priorities and strategy.

Focal AOAs considered in this report are shown in Maps 1 [RMD], 2 [TMD], 3 [Park, both districts], and 4 [ecoregions]. The ecological relevance of each is detailed below and summarized in Table 3.

2.2.1 Park, Boundary, and Upstream Watershed AOAs

The most relevant spatial scale for many resource conservation decisions at Saguaro will consist of the area within park boundaries (Maps 1 [RMD] and 2 [TMD]). Wildlife may move among areas within the park, plants disperse and colonize, and development and visitor use have impacts that extend spatially from their locations within

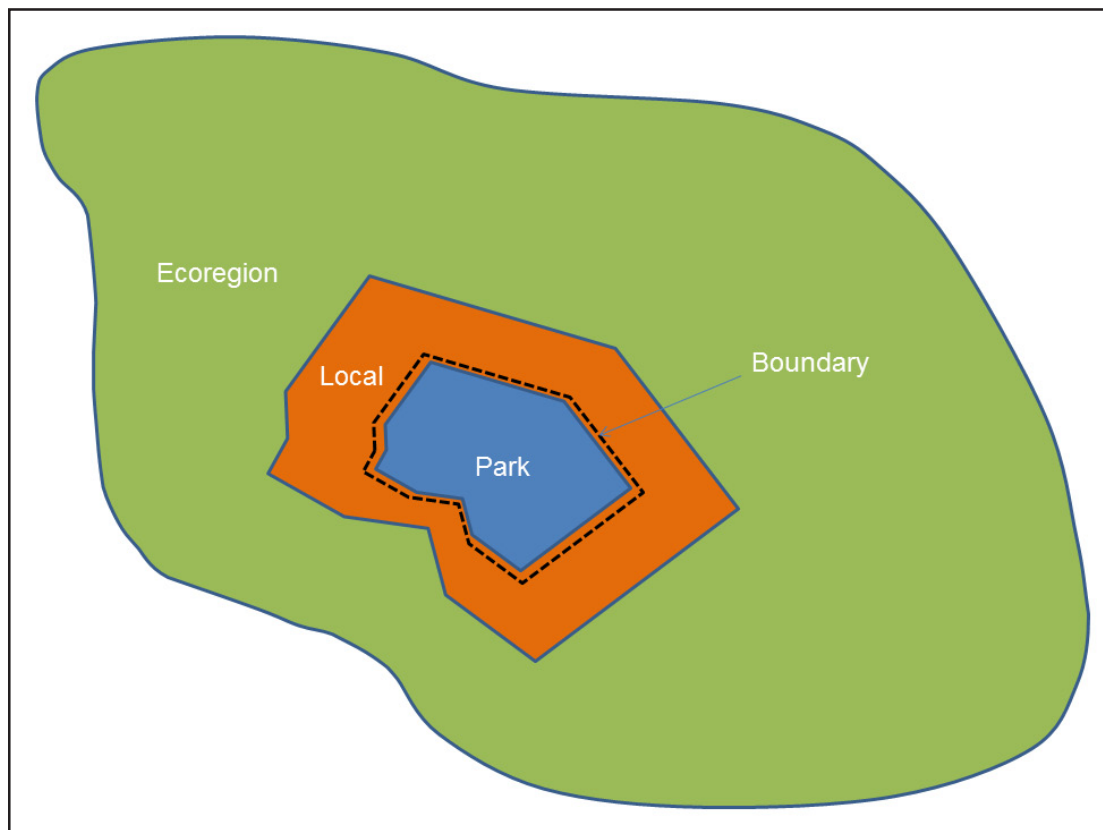


Figure 7. A schematic diagram illustrating a few major types of ecologically informative areas of analysis (AOAs), and why it is important to assess landscape indicators across scales. The park-scale reflects the area within which park managers have maximum control over decisions related to resource conservation. The boundary scale immediately adjacent to the park (e.g., ≤ 3 km from park) captures any human-caused edge effects (e.g., homeowner activities adjacent to the park). The local scale (e.g., ≤ 30 km from park) relates holistically to the landscape context of a park by integrating natural systems, human drivers, and conservation status. Finally, ecoregional scales inform large-scale and long-term environmental changes like climate change.

Table 3. Summary of AOAs considered in this report and why they are ecologically relevant.

AOA	Ecological Relevance
Park	The scale at which Saguaro National Park has maximum management control; the Rincon and Tucson Mountain Districts contain Wilderness areas but are separated by the growing city of Tucson and surrounding communities
Park + 3 km buffer	Captures the effects of human drivers that are most proximate and direct to the Park; allows for these landscape dynamics to be quantified separately for the Rincon and Tucson Mountain Districts
Park upstream watersheds	In the case of Saguaro National Park, largely headwater catchments that relate to watershed services downstream in surrounding communities; also, catchments can influence movements of species inside park boundaries
Park + 30 km buffer	A local park landscape that tends to integrate the combined effects of human drivers, natural systems, and conservation context outlined in Figure 6
FireScope	An entire mountain range encompassing areas where fire is an important part of the ecosystem, as well as areas that require protection from fire; drives local resource conservation management and planning
Viewsheds	Areas that are visible from key observation points inside the Park; informative AOAs for such 'visual' Park resources as visitor experience and wilderness character
Ecoregions	Geographies at scales suitable for management that share major common ecosystems; Saguaro is uniquely positioned on the border of two ecoregions: the Sonoran Desert and Madrean Archipelago

the park. This is also the scale where Saguaro has the greatest control over landscape-level change.

The landscape immediately adjacent to the park (≤ 3 km) has a large effect on permeability or connections between the park and the surrounding landscape (Maps 1 [RMD] and 2 [TMD]), and thus on the importance of landscape attributes in the broader local area (Hansen & DeFries 2007). Roads and highly developed areas can act as barriers to movement of wildlife between the park and surrounding lands, isolating Saguaro resources from important habitats outside the Park. Land cover characteristics at this local scale can have a strong effect on fire management strategies and the probability that wildfires ignited on the surrounding lands will burn into the Park. Activities and processes occurring within the area immediately adjacent to Saguaro are sufficiently close that even small effects can propagate into the Park and affect resources. Housing adjacent to the Park boundary can increase pet-wildlife interactions, exotic plant introductions from yards and gardens, and the ignition frequency of small fires. Roads in and near Saguaro's boundaries provide additional visitor access,

and may increase the potential for poaching within the Park.

Because Saguaro is a headwaters park, park upstream watersheds also delineate a relevant and useful set of AOAs for landscape analysis (Maps 1 [RMD] and 2 [TMD]), largely because of the downhill and downstream transport of materials and energy. For example, landscape processes in the upstream watersheds (Wilderness areas for Saguaro) affect hydrology, water chemistry, and aquatic biota. Saguaro contributes these watershed services to areas and communities in and around the city of Tucson. On the flip side, watersheds also delineate areas within which stressors such as invasive species may move, either up or down slope. Even for headwater parks like Saguaro, park upstream watersheds are informative for evaluating how resource stressors that invade from the Park's boundary might colonize other areas of the Park.

2.2.2 Local 30 km and FireScope AOAs

Although analyses within and immediately adjacent (<3 km) to Saguaro are important, many GIS datasets are unsuited for analysis at such fine scales. Local aerial photogra-

phy and fine-scale vegetation maps, county property records, and county/state road and traffic data are usually better suited to analyses that focus on relatively small areas within a few kilometers of a park. Instead, most NPScape and other GIS data considered in this report are suited to analyses that focus on larger areas and on park resources that are dependent on landscapes that extend well beyond park boundaries. For example, many ecological processes operate at a local scale on the order of 15-40 km (Clark 1985, Wiens 1989). Specific examples include the propagation of wildland fires, dispersal of local pollutants, daily to weekly movements of birds and larger mammals, and yearly to multi-decadal dispersal of amphibians, reptiles, and smaller mammals. There is no unique and uniform distance that defines the local scale, and for reporting purposes we chose 30 km from the Park boundary as an approximate distance for quantifying landscape effects of this type (Map 3).

For Saguaro, FireScape is a local collaboration directed at landscape-scale fire and ecosystem management (<http://www.azfirescape.org/>). FireScape considers the Santa Catalina and Rincon Mountains in Pima, Pinal and Cochise counties. The spatial extent of the FireScape boundary classifies it as a local AOA for the RMD of Saguaro (FireScape does not include the TMD, Map 3). Multiple agencies and institutions contribute to FireScape, including Coronado National Forest, Saguaro National Park, University of Arizona, The Nature Conservancy, and the Southern Arizona Buffelgrass Coordination Center. Hence, FireScape is an important AOA for Saguaro (RMD) because it is an existing planning region that has already galvanized a number of important landscape-level collaborations and activities.

2.2.3 Local viewsheds for RMD and TMD

Viewsheds are important local AOAs for Saguaro because they relate to visitor experience and wilderness character. For example, consider how visitor experience along front country trails is shaped by what is visible both within and perhaps beyond park boundaries. Depending on visitor

preference, one might choose a ridge trail with a view of the city, or a canyon trail secluded from external sights. In addition, consider how the wilderness character of back country trails might be compromised by nighttime light pollution, which could be evaluated quite simply to a first approximation by overlaying viewsheds on top of a map of nighttime lights. In this report we consider viewsheds computed separately for RMD and TMD, from 'key observation points' located along roads and both front and back country trails inside the Park (see Data Sources [Section 2.3], and results presented in Section 3.3.3).

2.2.4 Sonoran Desert and Madrean Archipelago Ecoregional AOAs

Landscape attributes at broader, regional spatial scales often affect park natural resources on time scales of decades to centuries. At this spatiotemporal scale, species are most likely to interact through gene flow and long-term extinction and recolonization processes. This regional perspective is necessary to plan for or respond to issues such as the ability of altered landscapes to support regional biodiversity, and to evaluate impacts from broad-scale drivers like climate change. As the NPS confronts challenges of global changes, including ongoing and future climate change, a regional perspective will be essential for long-term conservation of biodiversity (National Park Service 2010a). Furthermore, in evidence of the importance of ecoregional scale approaches to resource conservation, the Department of Interior recently established Landscape Conservation Cooperatives and regional Climate Science Centers (DOI Secretarial Order 3289), and other DOI bureaus like the BLM are conducting assessments at ecoregional scales. Saguaro is uniquely positioned in that the TMD and RMD span two ecoregions, the Sonoran Desert ecoregion to the west (TMD) and the Madrean Archipelago (Sky Island) ecoregion to east (RMD; Map 4).

2.3 Data Sources

2.3.1 NPScape Data

The compilation and derivation of NPScape data are described in great detail in a se-

ries of methodological reports or Standard Operating Procedures (SOPs). NPScape SOPs used in this report include: population (National Park Service 2010b,c), housing (National Park Service 2010d), roads (National Park Service 2010e), land cover (National Park Service 2010f,g), landscape pattern (National Park Service 2010h), and conservation status (National Park Service 2011a,b). Importantly, NPScape data described in these SOPs are derived from the published and authoritative source data listed in Table 4.

Although described in the aforementioned NPScape SOPs and source data references (Table 4), several important details of NPScape data merit explicit mention in this report:

Housing: Estimates of housing density originate from a data-driven model, the spatially explicit regional growth model

(SERGoM, Table 4), which is what permits future projections to be made for the 21st Century. Housing density classes follow from Theobald (2005), and the non-uniform ranges are designed to capture low-density housing dynamics that are important for ecological studies: private/undeveloped, < 1.5 units/km², 1.5-3 units/km², 4-6 units/km², 7-12 units/km², 13-24 units/km², 25-49 units/km², 50-145 units/km², 146-494 units/km², 495-1,234 units/km², 1,235-2,470 units/km², > 2,470 units/km², commercial/industrial, and urban-regional park. These rather finely divided housing density classes may be further summarized according to rural (private undeveloped and housing densities up through 6 units/km²), exurban (7-145 units/km²), suburban (146-1,234 units/km²), and urban (> 1,235 units/km²).

Roads: Road data originate from ESRI (Environmental Systems Research Institute 2010), but spatial coverage does not include Mexi-

Table 4. Data used to estimate the NPScape indicators considered in this report. Data sources cross reference the indicators in Table 1.

Measure	Source Data	Years	Resolution	Reference
Population	US Census Bureau	1990, 2000, 2010	Census block groups	US Census Bureau 1991, 2001, 2011
	US Census Bureau	1790-2000, by decade	County	Waisanen & Bliss 2002
	State of Arizona	2060-2055, by decade	County	Arizona Commerce Authority 2006
Housing	Spatially Explicit Regional Growth Model (SERGoM)	1970-2100, by decade	100 m cells	Theobald 2005
Roads	Environmental Systems Research Institute (ESRI)	Varies, up to 2005	Varies	Environmental Systems Research Institute 2010
Land cover	National Land Cover Data (NLCD)	2001, 2006	30 m cells	Fry et al. 2011
	North American Land Change Monitoring System (NALC)	2005	250 m cells	Commission for Environmental Cooperation 2010
Pattern	North American Land Change Monitoring System (NALC)	2005	250 m cells	Source data reference for NALC
Conservation status	Protected Areas Database of the US (PAD-US)	Varies	Varies	USGS Gap Analysis Program 2011
	World Protected Areas Database (WDPA)	Varies	Varies	World Commission on Protected Areas 2011

co. Major roads include all highways and interstates. All roads include major roads plus streets. Weighted road density is estimated by multiplying interstate lengths by a factor of 10 and highway lengths by a factor of 3 (streets are effectively unweighted and given a factor of 1); these weights are designed to capture the effects of variable traffic volume by major road type.

Population: While historical data originate from the US Census Bureau, the intermediate source used by NPScape was Waisanen & Bliss (2002). State projections were obtained from the Arizona Department of Commerce, Center for Economic Advancement (Arizona Commerce Authority 2006).

Land cover: Source datasets do not permit thematic classifications at finer taxonomic resolutions than an Anderson Level II classification. Change in land cover area by category could only be computed from a single source dataset (2001 and 2006).

Landscape pattern: Because pattern indicators derive from land cover, they are also limited by the same issues related to thematic/taxonomic resolution described above. Area density pattern was developed here for forest and grassland land cover types because these relate to important habitats found in Saguaro (desert grasslands, pine forests and mixed conifer forest) that are to varying degrees fragmented by shrub (dominant land cover type). In brief, the area density analysis works by sliding a moving window of particular size (e.g., 7 x 7 pixels) across the landscape and – for each center pixel of a particular target cover type (e.g., forest) – computing the percentage of pixels in the window that match the target. These percentages are then classified into one of seven density classes: intact, interior, dominant, transitional, patchy, rare, or none. The following window sizes were selected to encompass a range of scales that are considered to be ecologically relevant and practical for management (pixel size = 250 m): 7 x 7 pixels (3.06 km²), 11 x 11 pixels (7.56 km²), 15 x 15 pixels (14.06 km²), 27 x 27 pixels (45.56 km²), 39 x 39 pixels (95.06 km²). The smallest window was chosen to ensure percentages

could be reliably estimated from a minimum adequate number of pixels (49 pixels). Area density can be computed at either the landscape or sector level (Riitters 2011); the sector level is essentially the landscape level masked by the target cover type. For purposes of this report, we computed area density based on the landscape level. This decision was made because many of the focal species are not strictly tied to forest and grassland habitats, meaning that proximity to these habitats (i.e., as captured by the landscape but not sector level) is also informative.

Protected areas: The “protected area” indicator computed by NPScape is estimated using the Protected Areas Database of the US (PAD-US, USGS Gap Analysis Program 2011) for local AOAs and World Protected Areas Database (WDPA, World Commission on Protected Areas 2011) for ecoregions extending into Mexico. In WDPA, all features are formally defined as protected by IUCN. However, in PAD the picture is more complex. GAP currently uses a scale of 1 to 4 to denote the relative degree of management committed to maintaining biodiversity in each land unit. A status of 1 denotes the highest, most permanent level of protection, and 4 represents the lowest level or unknown status. In assigning conservation status, the gap analysis process follows two guiding principles: first, prescribed management, not land ownership, is the primary determinant in assigning status and second, while data are imperfect, and all land is subject to changes in both ownership and management, the intent of a land steward as evidenced by legal and institutional factors can be used to assign status. The criteria used in assigning a status rank include:

- Permanence of protection from conversion of natural land cover to unnatural (human-induced barren, arrested succession, cultivated exotic-dominated).
- Relative amount of the land unit managed for natural cover, with 5% allowance for intensive human use.
- Inclusiveness of management, i.e., single feature or species versus all biota.

- Type of management (e.g., suppresses or allows natural disturbance) and degree that it is mandated through legal and institutional arrangements.

Using the above criteria, the four biodiversity management status ranks can generally be defined as follows (after Scott et al. 1993, Edwards et al. 1994, Crist et al. 1996):

Status 1: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management.

Status 2: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.

Status 3: An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g., logging) or localized intense type (e.g., mining). It also confers protection to federally listed endangered and threatened species throughout the area.

Status 4: There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of

natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout.

Typically, protected lands are those considered to have permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state (i.e., GAP status 1 and 2) while ‘multiple-use’ lands, such as most areas managed by BLM or USFS, are considered status 3. NPScape “protected area” computed using PAD-US followed this approach and identified all status 1 and 2 lands as ‘protected’.

Land ownership: This indicator was calculated for PAD-US only, not the WDPA, which thematically was too coarse to be useful for Saguaro. The same caveats for protected areas also apply here. Also, specifically in the case of Arizona, under current law State Land Board land is to be sold eventually for development to benefit Arizona schools. These lands are not considered formally protected (above), and with being subject to possible future development are of more limited value to natural resource conservation.

2.3.2 Other Landscape Data

Other data considered in this report originated from a multitude of sources (Table 5). Most were obtained from Pima County (<http://gis.pima.gov/>) and the Pima Association of Governments (<http://www.pagnet.org/tabid/36/default.aspx>).

Table 5. Data used to estimate other landscape indicators that are of special importance to Saguaro National Park. Data sources cross reference the indicators in Table 2.

Measure	Source Data	Years	Resolution	Reference
Climate	PRISM	1970-2000, by month x year	800 m	http://www.prism.oregonstate.edu/
	PRISM	1980-2010, by month x year	4 km	http://www.prism.oregonstate.edu/
Land cover	USGS, Santa Cruz watershed	1979, 1989, 1999, 2009	30 m	http://pubs.usgs.gov/of/2011/1131/

Table 5. Data used to estimate other landscape indicators that are of special importance to Saguaro National Park. Data sources cross reference the indicators in Table 2 (continued).

Measure	Source Data	Years	Resolution	Reference
Land cover (continued)	Hydrologic land cover types (biome)	2008	Varies	Special request from http://gis.pima.gov/
Hydrography & connectivity	Flood control structures	1996	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=fcd_stru
	Springs	1993	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=springs
	Major washes (polygon)	2008	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=wash_maj
	Major washes (linear)	1998	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=washmajl
	All washes	2009	1:100,000	http://gis.pima.gov/data/contents/metadet.cfm?name=washes
	Drainage basins	1991	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=drainbas
	Publically owned basins	2008	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=basinpub
	Privately owned basins	2008	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=basinpvt
	Wildlife corridors	c. 2006	Varies	http://corridordesign.org/linkages/arizona
	Urban-wildlife interface	2003	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=urbnwild
	Wild life lines	c. 2006	270 m	Theobald et al. (2012)
Lightning	Flash rate	1995-2000, by month	0.5 deg	http://thunder.msfc.nasa.gov/data/
Renewable energy	Wind speed	c. 2003	Varies	http://www.nrel.gov/gis/data_wind.html
	Wind speed and direction	1973-2004, by month x day x time	Varies	http://www.wrh.noaa.gov/twc/aviation/windrose_TUS.php
	Concentrating solar power	c. 2009	Varies	http://www.nrel.gov/gis/data_solar.html
	Geothermal favorability	c. 2008	Varies	http://certmapper.cr.usgs.gov/data/geothermal/western_us/spatial/shape/favorabilitysurface.zip
Vulnerable species	Needle-spined pineapple cactus (<i>Echinomastus erectocentrus</i> var. <i>erectocentrus</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Pima pineapple cactus (<i>Coryphanta scheeri</i> var. <i>robustispina</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Gentry indigobush (<i>Dalea tentaculoides</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Huachuca water umbel (<i>Lilaeopsis schaffneriana</i> var. <i>recurva</i>)	2003	Varies	Special request from http://gis.pima.gov/

Table 5. Data used to estimate other landscape indicators that are of special importance to Saguaro National Park. Data sources cross reference the indicators in Table 2 (continued).

Measure	Source Data	Years	Resolution	Reference
Vulnerable Species (continued)	Tumamoc globeberry (<i>Tumamoca macdougalii</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Desert pupfish (<i>Cyprinodon macularius macularius</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Gila chub (<i>Gila intermedia</i>)	2002	Varies	Special request from http://gis.pima.gov/
	Gila topminnow (<i>Poeciliopsis occidentalis occidentalis</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Longfin dace (<i>Agosia chrysogaster</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Sonora sucker (<i>Catostomus insignis</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Desert box turtle (<i>Terrapene ornata luteola</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Chiricahua leopard frog (<i>Rana chiricahuensis</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Lowland leopard frog (<i>Rana yavapaiensis</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Giant spotted whiptail (<i>Chemidophorus burti stictogrammus</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Ground snake (<i>Sonora semiannulata</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Mexican garter snake (<i>Thamnophis eques megalops</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Tucson shovelnose snake (<i>Chionactis occipitalis klauberi</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Abert's towhee (<i>Pipilo aberti</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Bell's vireo (<i>Vireo bellii</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Cactus ferruginous pygmy owl (<i>Glaucidium brasilianum cactorum</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Rufous-winged sparrow (<i>Aimophila carpalis</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Swainson's hawk (<i>Buteo swainsoni</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Southwestern willow flycatcher (<i>Empidonax traillii extimus</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Western burrowing owl (<i>Athene cunicularia hypugaea</i>)	2003	Varies	Special request from http://gis.pima.gov/

Table 5. Data used to estimate other landscape indicators that are of special importance to Saguaro National Park. Data sources cross reference the indicators in Table 2 (continued).

Measure	Source Data	Years	Resolution	Reference
Vulnerable Species (continued)	Western yellow-billed cuckoo (<i>Coccyzus americanus occidentalis</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Allen's big-eared bat (<i>Idionycteris phyllotis</i>)	2003	Varies	Special request from http://gis.pima.gov/
	California leaf-nosed bat (<i>Macrotus californicus</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Lesser long-nosed bat (<i>Leptonycteris curasoae yerbabuenae</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Mexican long-tongued bat (<i>Choeronycteris mexicana</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Pale Townsend's big-eared bat (<i>Plecotus townsendii pallescens</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Western red bat (<i>Lasiurus blossevillii</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Western yellow bat (<i>Lasiurus xanthinus</i>)	2003	Varies	Special request from http://gis.pima.gov/
	Arizona shrew (<i>Sorex arizonae</i>)	2003	Varies	Special request from http://gis.pima.gov/
Population	Total	2005, 2040	Varies	http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx
Housing	Number of units	2005, 2040	Varies	http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx
Nighttime lights	Nighttime lights, sky-down, visible	1997, 2009	~1 km ²	http://ngdc.noaa.gov/dmsp/downloadV4composites.html
	Nighttime lights, sky-down, scattering	c. 2000	Varies	http://www.lightpollution.it/worldatlas/pages/fig1.htm
	Nighttime lights, ground-up, visible	2010	Varies	http://www.globeatnight.org/analyze.html
	Lighting area codes	2011	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=litecode
Transportation	Airport height zones	2009	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=aez_hz
	Railroads	2005	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=railroad
	Trails	2006	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=trails
	Bike routes	2011	1:56,320	http://gis.pima.gov/data/contents/metadet.cfm?name=bike_rte
	Bike routes (planned)	1999	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=bikeplan

Table 5. Data used to estimate other landscape indicators that are of special importance to Saguaro National Park. Data sources cross reference the indicators in Table 2 (continued).

Measure	Source Data	Years	Resolution	Reference
Transportation (continued)	Park and ride locations	2010	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=parkride
	Bus stops	2010	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=busstops
	Bus routes	2010	1:126,720	http://gis.pima.gov/data/contents/metadet.cfm?name=busroute
	HandiCar service areas	2010	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=handibnd
Conservation status	Conservation Lands System	2005	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=clsadopt
	Ownership	2010	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=preserve
	Protected area	2010	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=preserve
	Superfund sites	2001	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=superfnd
	Active mines	1996	1:3,000	http://gis.pima.gov/data/contents/metadet.cfm?name=mine_act
Land use & zoning	Land use	1993	1:3,000	http://gis.pima.gov/data/contents/metadet.cfm?name=lu_cot93
	Land use intensity	2009	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=cpintens
	New building permits	2010-2011	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=perm_mrg
	Number of structures built	1999-2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2kblt
	Subdivision lot count	2011	1:12,000	http://gis.pima.gov/data/contents/metadet.cfm?name=subdiv
	Parcel size	c. 2010	1:200	http://gis.pima.gov/data/contents/metadet.cfm?name=paregion
	Real property inventory	2010	1:3,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cotparc
	Development plans	2011	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=dev_plan
	Historic districts	2006	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=disthist
	Annexation boundaries	2010	1:3,000	http://gis.pima.gov/data/contents/metadet.cfm?name=annex
	Neighborhood associations (Tucson)	2007	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=nha_city
	Area plan (Tucson)	2000	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=areaplan
	Zoning jurisdictions (Tucson)	2007	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=zone_all

Table 5. Data used to estimate other landscape indicators that are of special importance to Saguaro National Park. Data sources cross reference the indicators in Table 2 (continued).

Measure	Source Data	Years	Resolution	Reference
Land use & Zoning (continued)	Age	2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2ksex
	Education	2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2kedu
	Schools	2011	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=schools
	School districts	2007	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=schoolds
	Elementary school attendance zones	2011	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=schelem
	Middle school attendance zones	2011	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=schmid
	High school attendance zones	2011	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=schhigh
	School children	2005, 2040	Varies	http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx
	Household size	2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2kten
	Monthly owner costs	2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2khhi
	Monthly renter costs	2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2krnt
	Poverty (families)	2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2kpov
	Employment	2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2kemp
	Employment	2005, 2040	Varies	http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx
	Income	1999	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2kinc
	Income	2005, 2040	Varies	http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx
	Structure value	2000	1:24,000	http://gis.pima.gov/data/contents/metadet.cfm?name=cen2kval
	Popular attractions	2003	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=popsites
	Modern cultural attractions	2011	Varies	http://gis.pima.gov/data/contents/metadet.cfm?name=modcult

Several details related to data and data processing merit explicit mention:

- Bioclimatic variables were generated from monthly minimum temperature, maximum temperature, and precipitation using an ARC/INFO AML: <http://www.worldclim.org/bioclim-aml>.
- Lightning flash rate data required extensive processing to translate the data from HDF to ArcGIS rasters with a proper spatial reference. Our processed outputs are available upon written request.
- The Cinzano model of nighttime light pollution was also missing a proper spatial reference. Our processed/corrected version is available upon written request.
- The distributions of vulnerable species (in Pima County) derive from expert-driven habitat models. As such they do not necessarily represent species' true distributions, but rather their potential distributions, where "potential" is qualitatively ranked in a relative sense according to 'high', 'medium', and 'low' (attribute field = 'POTENTIAL').
- A few measure categories have NPScape indicators that are estimated using non-NPScape data. These include land cover, ownership and protected area, population, housing, and roads. In these situations, NPScape methods were used to analyze the data and compute the land-

scape indicators: <http://science.nature.nps.gov/im/monitor/npscape/methods.cfm>. The methods (SOPs and ArcGIS toolboxes) are designed to replicate indicator calculations using other source datasets (i.e., beyond those provided by NPScape).

2.3.3 AOA Data

The AOA data sources are summarized in Table 6. All AOAs except FireScape originate, or are at least provided by, NPScape and the Inventory and Monitoring Division.

Although described in the AOA references (Table 6), a few important details of AOA data merit explicit mention in this report:

- AOAs based on buffers of park boundaries (RMD plus 3 km buffer, TMD plus 3 km buffer, TMD and RMD combined with a 30 km buffer) were derived using park boundaries obtained from the Land Resources Division, with updates and modifications described in National Park Service (2011c).
- The FireScape planning region AOA was obtained following written request through the project website (<http://www.azfirescape.org/>; date obtained: September 2010).
- NPScape upstream watersheds are calculated using flowline data mapped at 1:24,000, and flow accumulation and direction rasters at 30 m.

Table 6. Data for AOAs considered in this report. Data sources cross reference the AOAs in Table 3.

AOA	Source Data	Years	Resolution	Reference
Park	NPScape	2011	Varies	National Park Service 2011c
Park + 3 km buffer	NPScape	2011	Varies	National Park Service 2011c
Upstream watersheds	NPScape	2011	1:24,000, 30 m	National Park Service 2011d
Park + 30 km buffer	NPScape	2011	Varies	National Park Service 2011c
FireScape	FireScape	2010	Varies	http://www.azfirescape.org/
Viewsheds	Inventory and Monitoring Division	2011	30 m	See text, below
Ecoregions (Level II)	Commission for Environmental Cooperation and NPScape	2011	Varies	National Park Service 2011e

- Composite viewshed AOAs are new and currently unpublished (Peter Budde and Kirk Sherrill, personal communication) but can be made available upon written request. We summarize the methods here.
 - By way of introduction to understanding viewshed AOAs, traditional viewshed analysis evaluates the visibility of locations in a binary manner (i.e., visible or not visible) across a defined study area of interest from a single defined observation point. A study area of interest is the area for which the viewshed analysis is being performed. A sample point is the location from which the viewshed analysis is being performed, and in this context should be considered as the location of key observation points within each district (TMD and RMD). For purposes of computing viewshed AOAs, Saguaro National Park provided key observation points within each district (Bob Love and Becky MacEwen, personal communication). These were further categorized into three sets that reflect different major types of park use: road observation points for mostly day visitors, front country observation points from along trails used for day hikes, and back country observation points from along trails used for mostly overnight hikes (RMD only).
 - We performed the viewshed analyses using the ArcGIS viewshed tool (Spatial Analyst required). Binary viewsheds were initially produced for each key observation point; these were subsequently combined to create 'composite' viewsheds (described below). Each binary viewshed analysis required the location of the key observation point and a digital elevation model as data inputs. The analyses assumed that observers were at ground level (1 m), visibility did not decay significantly with distance (e.g., due to low air quality), and viewsheds were not significantly impacted by non-topographic features like vegetation structure.
 - A composite viewshed is the visibility of multiple viewsheds combined into one viewshed. A visible value in a composite viewshed implies that – across all the combined viewsheds and corresponding sample points – the area is visible from at least one key observation point. Composite viewsheds are a quick way to synthesize multiple viewsheds into one singular viewshed, thus giving a cursory overview of the potential visual resource effect development across all of the sample points (and corresponding viewsheds) might have. To produce composite viewsheds for each district, we simply summed the binary viewsheds by park use (i.e., based on road points, front country points, and in the case of RMD – back country points).
- All maps in the Map Appendix and new analyses in the Results and Discussion section were based on data in the USA Contiguous Albers Equal Area Conic (USGS version) projection, NAD83 datum.
- Map classes of continuously distributed vector data were established using natural breaks (Jenks).
- Except where noted in map legends, continuously distributed gridded data were symbolized with minimum, maximum, and mean values calculated according to map (not data) extent.



Photo 8. Most precipitation tends to fall in late summer with monsoonal rains. Summer storm over Sabino Canyon, viewed from the Rincons, with Tucson in the distance. Photo by Jim Malusa, courtesy of FireScape.



Photo 9. On rare occasions, snow falls on the desert floor of Saguaro National Park. Photo by Joshua Boles (NPS photo archive).

3. Results and Discussion

3.1 Natural Systems

3.1.1 Climate

Climate is a major driver of the distribution of biodiversity at broad, ecoregional scales. Because Saguaro is located on the boundary between the Sonoran Desert and Madrean Archipelago ecoregions, climate variables tend to exhibit steep transitions or gradients between the two districts. For example, these climate transitions are evident for minimum temperature of the coldest month (Map 5), maximum temperature of the warmest month (Map 6), and annual precipitation (Map 7). Average temperature and precipitation in each unit is shown in Figure 8. Comparing these numbers, it is apparent that TMD is approximately 3°C warmer and 200 mm drier than RMD. Park-level spatial variation is shown for minimum temperature of the coldest month (Map 8), maximum temperature of the warmest month (Map 9), and annual precipitation (Map 10).

At ecoregional scales, Saguaro experiences low temperature (Map 11) and high precipitation (Map 12) seasonality. At the park-level, the two units differ most in terms of temperature seasonality (Maps 13 [temperature seasonality] and 14 [precipitation seasonality]). In TMD and RMD, monthly minimum temperature, maximum temperature, and precipitation are highly correlated (Figure 9). Climatic variation is greater in most months in RMD than in TMD. This is explained in part by differences in size and topographic complexity between the two districts. Compared to TMD, RMD is approximately 60% larger and also encompasses broader elevational gradients. RMD thus encompasses greater among-pixel variation in the measured climate parameters.

Temperature and precipitation variables have also experienced directional change over the 30-year period from 1980 to 2010. For areas in and around Saguaro, minimum temperature of the coldest month has generally decreased (Map 15), while maximum temperature of the warmest month has generally increased (except at high elevations in

RMD; Map 16). However, these patterns of temperature change are considerably more complex when considered over larger ecoregional extents (Maps 15 and 16). Meanwhile, in the case of annual precipitation, both the Sonoran Desert and Madrean Archipelago ecoregions have become drier since the year 1980 (Map 17). Importantly, while these trends are valid estimates based on the climate interpolations, the ecological relevance of the trends remains unknown. Hence, additional research would be required to understand whether and how these recent changes in climate have impacted resources at Saguaro.

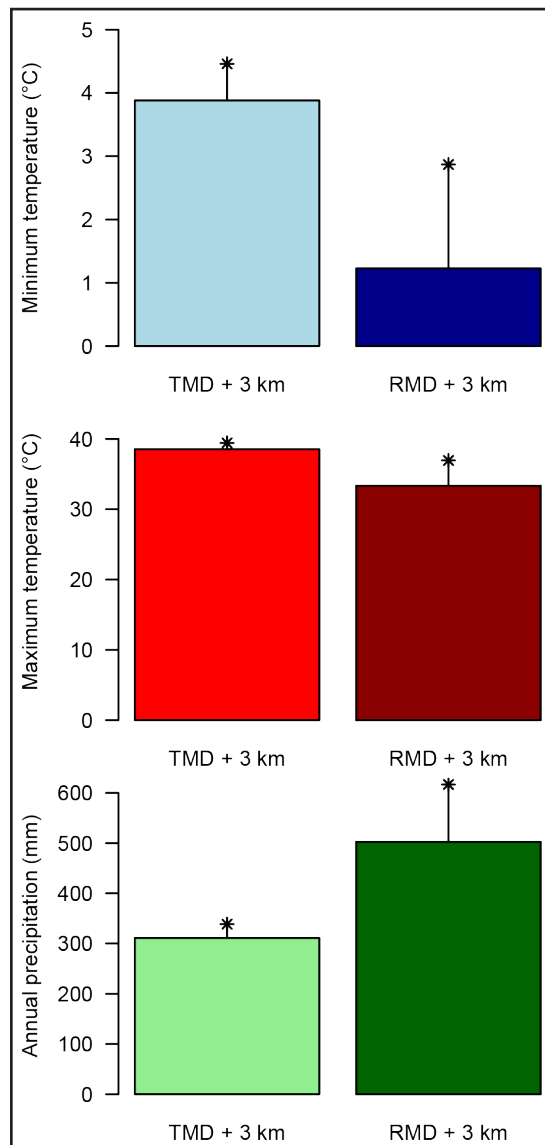
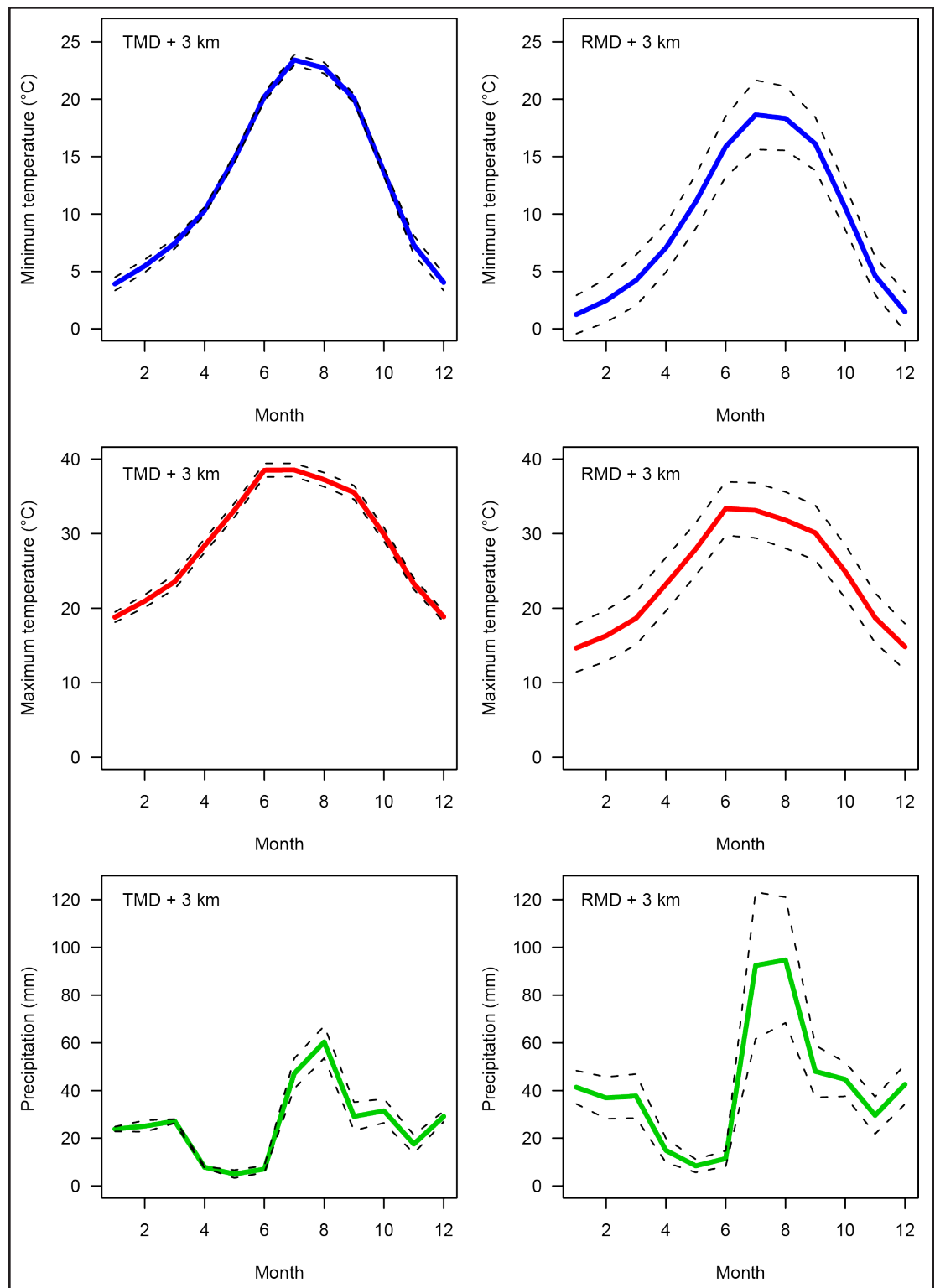


Figure 8. Minimum temperature of the coldest month (top), maximum temperature of the warmest month (middle), and annual precipitation (bottom), reported separately for the two districts of Saguaro National Park with 3 km buffer. Bars denote spatial averages in each district; asterisks denote corresponding standard deviations.

Figure 9. Seasonal trends in minimum monthly temperature (top), maximum monthly temperature (middle), and monthly precipitation (bottom), reported separately for the two districts of Saguaro National Park with 3 km buffer. Solid lines denote spatial averages in each district; dashed lines denote corresponding standard deviations.



3.1.2 Land Cover

The rapid climatic transitions between the Madrean Archipelago and Sonoran Desert ecoregions create important differences in the distribution of certain land cover types. Both ecoregions are dominated in an Anderson level I land cover classification scheme by shrub (comprising >70% of area in each

ecoregion). In terms of the second and third Anderson level I land cover ranks, the Sonoran Desert is defined by barren (5.2%) and agriculture (4.3%), and the Madrean Archipelago is defined by grassland/herbaceous (17.5%) and forest (7.8%) (Figure 10). The high percentage of agriculture in the Sonoran Desert is explained by the fact that

this ecoregion extends west into southern California (Map 4).

In the local area surrounding Saguaro National Park, desert scrub is the dominant land cover type (based on Anderson level II; Map 18). The RMD Saguaro Wilderness contains extensive amounts of forest that are in relatively close geographic proximity to other larger forested areas in the USFS Pusch Ridge Wilderness (Map 18). Between 2001 and 2006, most land cover change resulted in development (variable intensity; Map 19). The expansion of the greater Tucson footprint over this period is evident by the ring of red pixels in Map 19. Note that some of this development was immediately adjacent to TMD (northeast corner). In addition to development, a significant amount of 2001 to 2006 land cover change resulted in shrub in the Pusch Ridge Wilderness. This change was due to the 2003 Aspen Fire. Comparable changes in land cover are visible for the Santa Cruz watershed over the period of



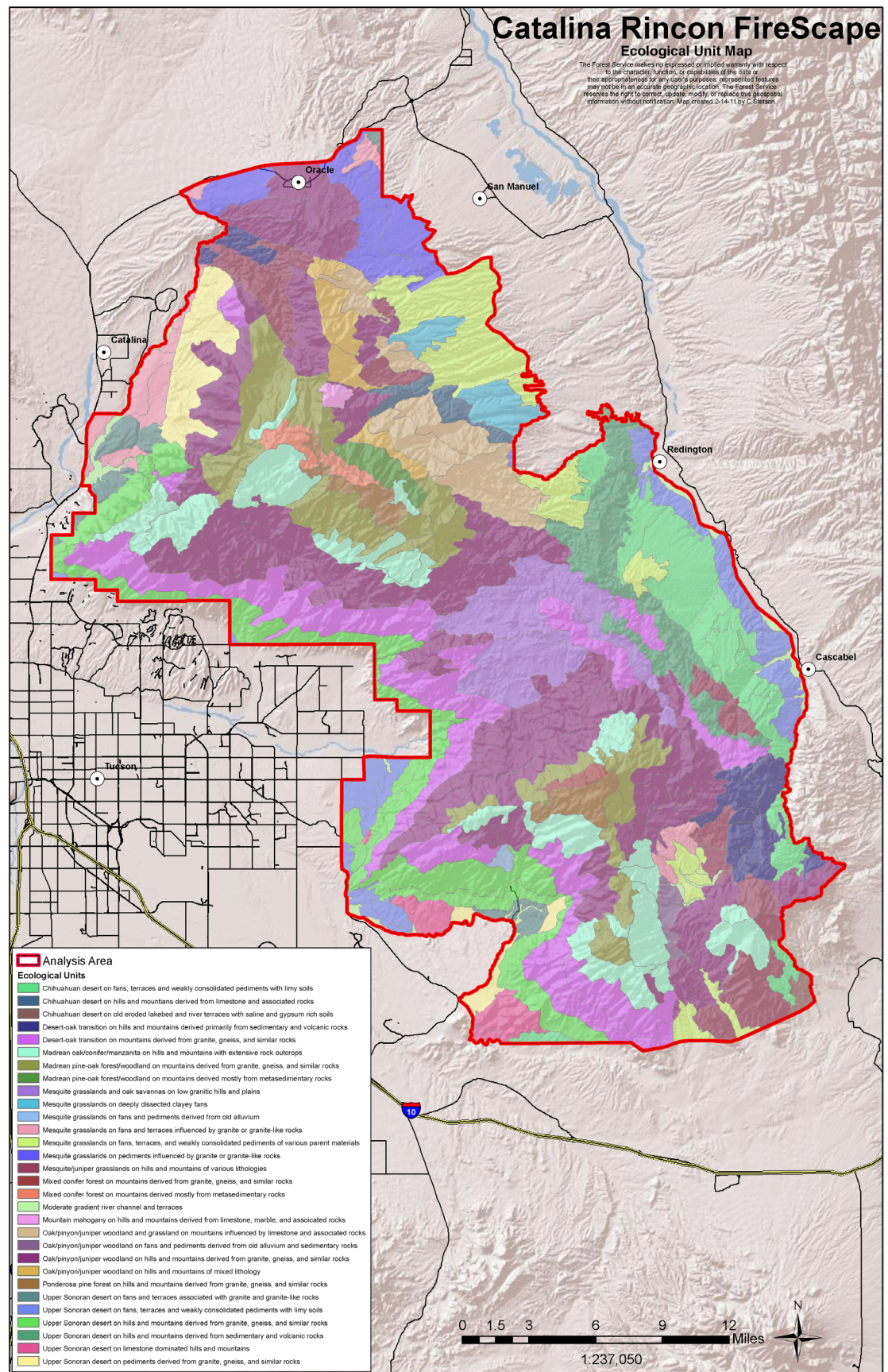
Photo 10. Desert scrub is the dominant land cover type throughout the Sonoran Desert and Madrean Archipelago ecoregions. Photo by Joshua Boles (NPS photo archive).

1979 to 2009 (by decade) in Maps 20 (1979), 21 (1989), 22 (1999), and 23 (2009). This time series is especially useful for visualizing the expansion of the greater Tucson area. An alternative 2008 land cover classification based on hydrologic biomes is provided in Map 24. The FireScape land cover (ecological units) map is shown in Figure 11.



Figure 10. Anderson level I land cover area (%) by ecoregion, excluding the dominant category of shrub, which comprises 87% of the Sonoran Desert and 73% of the Madrean Archipelago.

Figure 11. Ecological units for the Catalina-Rincon FireScape planning region. Map obtained from <http://www.azfirescape.org/content/catalina-rincon-analysis-area-maps>. Northern portions of RMD are located due east of the Tucson label on the map (see Figure 22).



3.1.3 Hydrography & Connectivity

Water is a major driver of natural processes in Saguaro National Park. In addition, wildlife movements are facilitated by surface hydrography, in part because water is a key limiting resource for many species, and also because seasonal surface flows prevent extensive human modification of wash habitats. This connectivity is important at three major scales: within each district (TMD and RMD), between the two districts, and between the Park and surrounding lands.

Within each district, connectivity of habitats may be evaluated based on important ecological characteristics of the wash networks and upstream watersheds (Maps 25 [RMD] and 26 [TMD]). The size and extent of the features, spring regularity and density, and seasonality of surface water flows are all important. For example, a recession of surface flow in a wash network may cause certain species to track water elevationally throughout the year. Springs may also influence the seasonal movements of species, and park upstream watersheds identify topographically distinct areas within which some species preferentially move. In addition to perhaps influencing opportunities for native species to move within each district, wash networks and upstream watersheds may also facilitate the spread of invasives.

Connectivity between TMD and RMD is similarly facilitated by the distribution of wash networks and major drainage basins (Maps 27 [wash networks] and 28 [drainage basins], Figure 12). For certain aquatic species, flood control structures (e.g., impoundments) in intervening areas pose distinct obstacles to movement. Nevertheless, the importance of major wash networks for connecting TMD and RMD is especially apparent when considered in relation to the amount and intensity of developed land cover in the greater Tucson area (Map 29). From this map it is evident how major washes provide corridors that are largely natural, especially when considered in relation to the surrounding suburban and urban areas. While these washes are not universally acceptable to wildlife, they are known to be used by certain urban adaptable species like

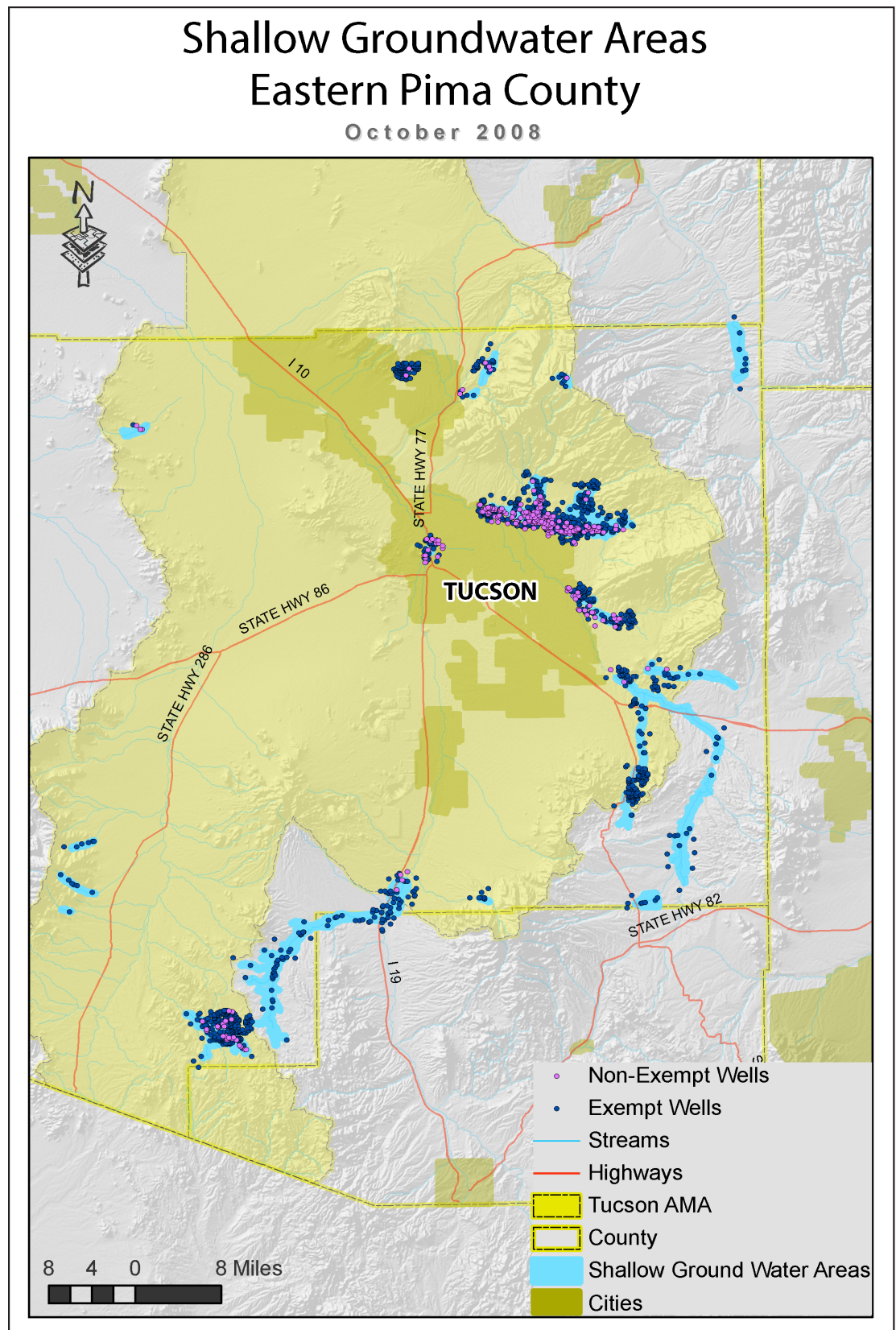


Photo 11. Looking downstream on Big Wash towards the Tangerine Road Bridge, with SR-77 and the Santa Catalina Mountains. Washes provide important corridors for certain species, and in situations like this allow them to pass under roads. Photo from Bier et al. 2006a.

coyote, and even some vulnerable species (see Section 3.1.7, and associated maps). Beyond the washes, connectivity between TMD and RMD is facilitated by a combination of other protected areas, key wildlife corridors, and urban-wild interface (Maps 29 and 30, Figure 13). Combined, these features create a ring of potential habitat encircling Tucson.

Connectivity between the Park and broader landscapes is important for species that tend to move more at ecoregional scales (e.g., birds, ungulates). According to a recently developed measure of structural connectivity for the contiguous US (Theobald et al. 2012, Map 31), RMD contains 3 to 4 areas that are of ‘medium-high’ importance for maintaining national-level connectivity. TMD contains fewer areas that are lower ranked (‘low-medium’ importance), but these areas join in close proximity other areas of considerably higher rank (Map 31). In and around both districts, connectivity is especially oriented on a north-south axis that extends down into Mexico (Map 31). Although the connectivity analysis does not extend south of the US-Mexico border, connectivity for certain species may be evaluated by considering the distributions of major land cover types and other protected areas (Map 32). These analyses would also need to consider the US-Mexico border fence (Flesch et al. 2010).

Figure 12. Map of streams and shallow ground water areas in eastern Pima County, obtained from <http://gis.pima.gov/>.



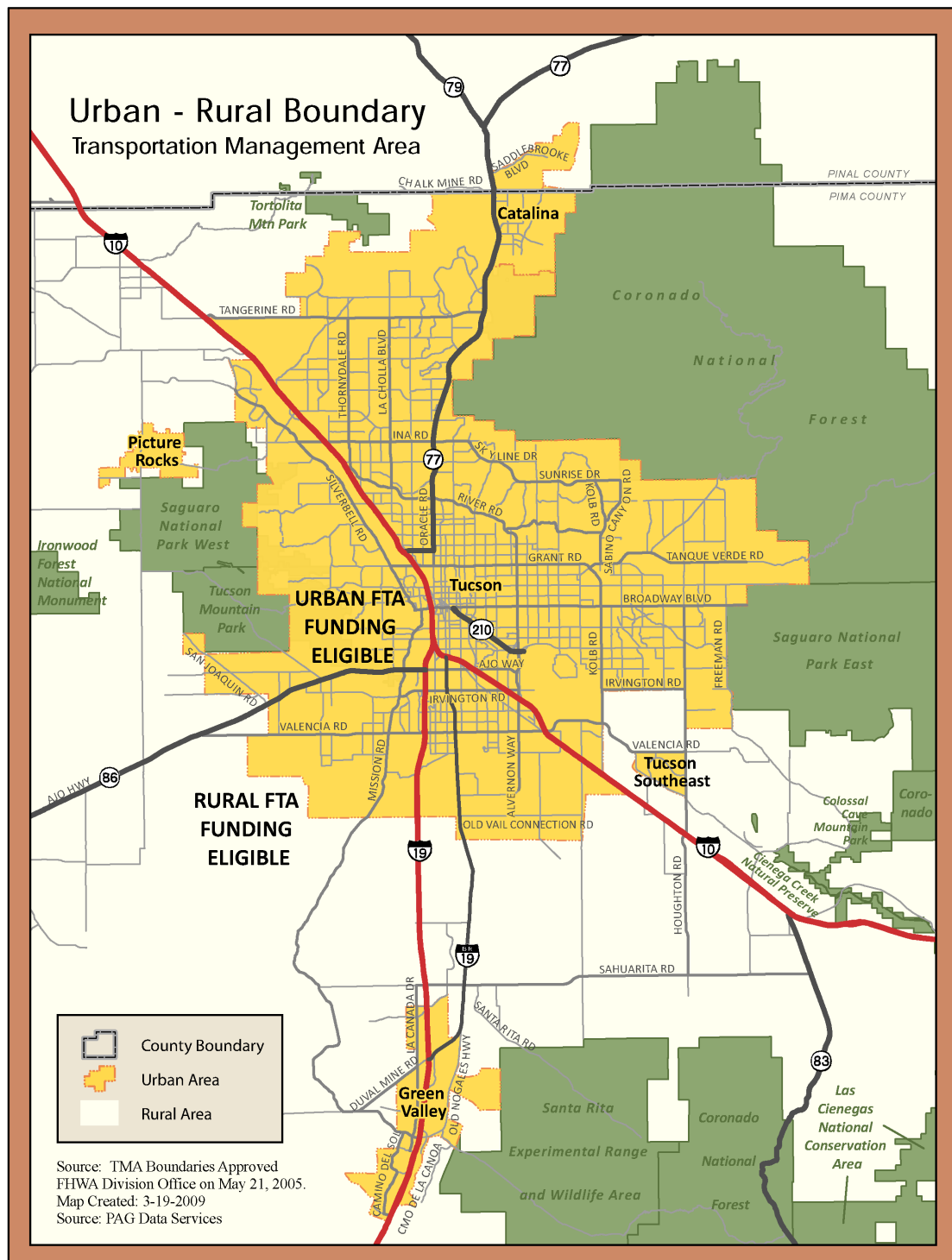


Figure 13. Map of urban-rural-wildlife interface, obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).

3.1.4 Landscape Pattern

Another consideration of connectivity relates to landscape pattern computed using the area density of major land cover types. According to Anderson level I (Figure 10), both forest and grassland habitats are more common in the Madrean Archipelago than they are in the Sonoran Desert. Nevertheless, both cover types provide important habitat

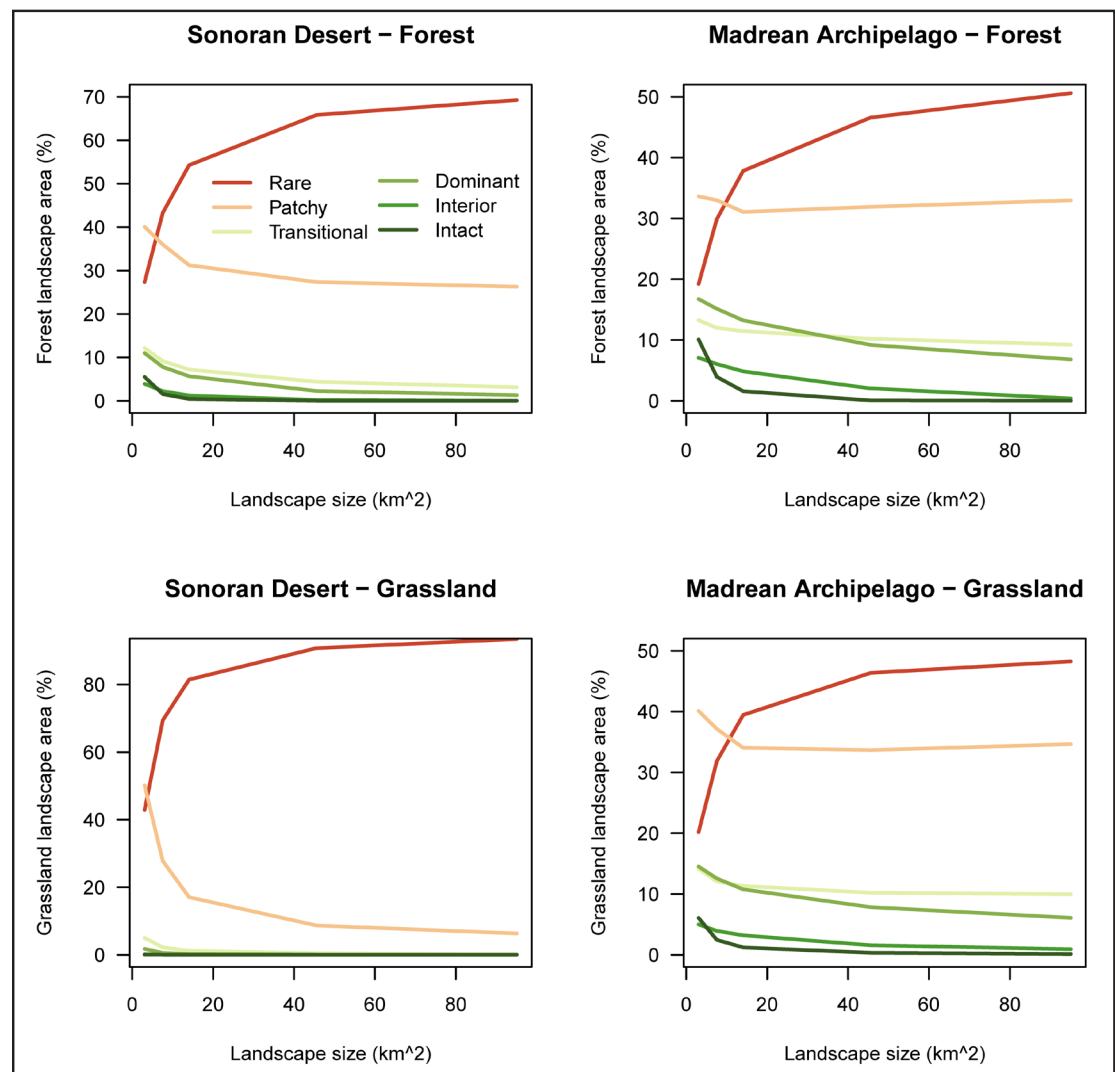
for dependent species where they occur. Related, how intact these habitats are at different spatial scales provides useful insights into the ability of patches to support minimum viable populations. In this context a 'patch' may be envisioned as a spatially contiguous stand of either forest or grassland, measured at a particular spatial resolution.

Summarizing area density for a wide range of landscape sizes (up to c. 95 km²), it is apparent that most forests in the Sonoran Desert are categorized as patchy to rare (Figure 14, top left). These same two categories characterize forests in the Madrean Archipelago, but in this ecoregion a sizeable percentage of forests also rank as transitional and dominant (Figure 14, top right). Very similar patterns are seen with grasslands (Figure 14, bottom row). In both instances, the patterns may also be visualized and interpreted in map form (forest: Maps 33-42 [window size = 3.1 km²], 34 [7.6 km²], 35 [14.1 km²], 36 [45.6 km²], and 37 [95.1 km²]; grassland: 38 [3.1 km²], 39 [7.6 km²], 40 [14.1 km²], 41 [45.6 km²], and 42 [95.1 km²]).

Interpreting these results in the context of wildlife and connectivity requires con-

sideration of the habitat dependencies of particular species (e.g., the degree to which they require either forests or grasslands) and also their dispersal tendencies or home range sizes. For example, in the Madrean Archipelago, forest dependent species with home range sizes that vary from small to large include the Arizona gray squirrel, coati, and black bear. Similarly, in Madrean Archipelago grasslands, focal species might include the antelope jackrabbit, badger, and bobcat. Given knowledge of these approximate home range sizes, plus an understanding of each species' dependency on a given habitat (e.g., intact vs. transitional), from the plots (Figure 14) one can gain a first approximation of the overall amount of suitable habitat for focal species, and from the maps (Maps 33-42) an understanding of where those habitats exist and how are they connected.

Figure 14. Area density of forest (top) and grassland (bottom) land cover types in the Sonoran Desert (left) and Madrean Archipelago (right) ecogenions encompassing Saguaro National Park. Results report the estimated 'patchiness' of each land cover type when evaluated for different landscape sizes.



3.1.5 Fire

Fire is a natural landscape disturbance that can affect the area density of major land cover types like forest and grassland. However, most of the lower elevation habitats in Saguaro are not adapted to fire, but fire in these areas is now increasingly common due to invasion of buffelgrass, a perennial bunchgrass from Africa. Buffelgrass crowds out native plants and increases the frequency and intensity of fire by increasing fuel loads and

providing a continuous fuel source. Humans are a primary source of fire ignition, especially at low elevations. Related, the FireScape FlamMap shows predicted flame length based on existing condition (Figure 15). The land cover maps presented in Section 3.1.2 illustrate both current and historical changes in developed area, or possible sources of ignition, and Map 19 shows the footprints of large fires that occurred between 2001 and 2006. In addition, the population, roads, and

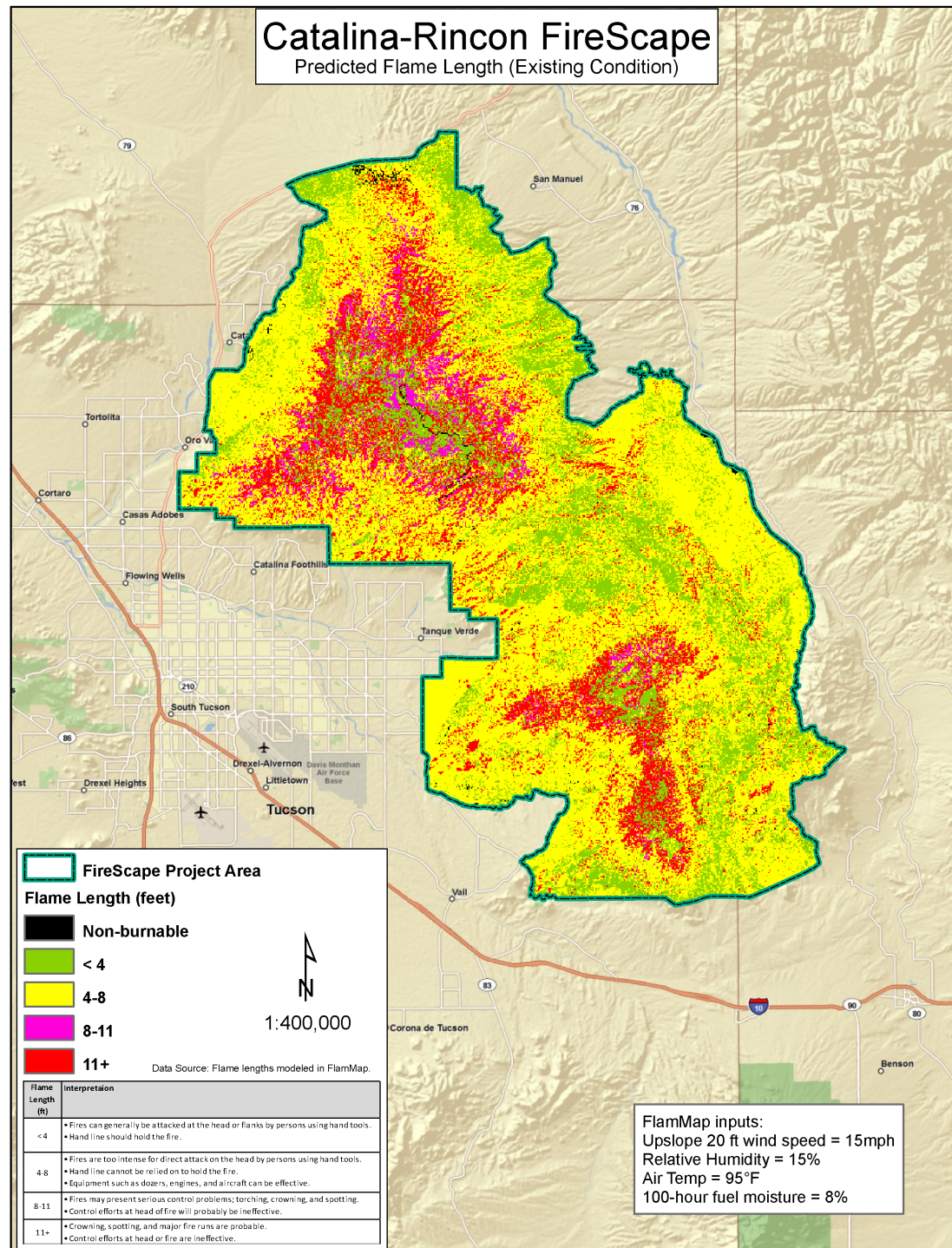


Figure 15. Estimated flame length based on current ecological conditions in the Catalina-Rincon FireScape planning region. Map obtained from <http://www.azfirescape.org/content/catalina-rincon-analysis-area-maps>. RMD is located due east of the Tucson label on the map (see Figure 22).



Photo 12. Forest pattern on Heartbreak Ridge from Rincon Peak Trail. Photo by Laura Bolyard (NPS photo archive).

housing maps presented in Section 3.2 (Human Drivers) are useful for evaluating potential anthropogenic sources of fire ignition.

Lighting is another source of fire ignition. Detailed data on lightning strikes in the local area surrounding Saguaro National Park are available at <https://www.nifc.blm.gov/cgi/Lightning.cgi> (password login required; not obtained for inclusion in this report). Broad landscape differences in annual flash rate are also apparent at ecoregional scales (Map 43). Although these data are spatially coarse (0.5 x 0.5 degrees), they nonetheless show how RMD experiences much higher annual flash rates than TMD. Furthermore, breaking the flash rates out by month, it is readily apparent that monthly flash rates are very low from September through June (Map 44), increasing to modest levels in July (Map 45), and at peak in August (Map 46).

Once ignited, fire spreads via a multitude of mechanisms, but one major mechanism at landscape scales is wind. Wind rose plots calculated from data collected at weather reporting stations are effective for visualizing both diurnal and seasonal variation in wind direction and magnitude. For the Tucson reporting station (located in between TMD and RMD), in the

AM hours most wind arrives from the southeast at 5-12 knots, whereas in the PM hours it arrives more from the northwest at speeds that are often closer to 20 knots (Figure 16). From these plots it is also apparent how seasonal variation is more pronounced in the PM as opposed to the AM hours (Figure 16).

3.1.6 Renewable Energy

Renewable energies are important drivers of ecosystem processes, but in this report they are important landscape indicators insofar as they help Saguaro understand where future changes in land use might occur. Potential sources of renewable energy in the desert southwest are wind (Maps 47 and 48), solar (Map 49), and geothermal (Map 50). While it is beyond the scope of this report to consider plans for renewable energy development, the landscape-level maps and information are intended to help Saguaro understand future energy developments in the context of existing natural systems, conservation context, and other human drivers.

3.1.7 Vulnerable Species

Saguaro National Park provides potential habitat to a number of vulnerable plant, herp, bird, and mammal species in Pima County (Maps 51-83). While the species considered in these maps (Table 2) are by no means exhaustive, collectively they provide a reasonable representation of the basic opportunities and challenges associated with conserving or protecting vulnerable biodiversity at landscape scales. For example, major areas of connectivity highlighted



Photo 13. Bell's Vireo (*Vireo bellii*) utilizes riparian habitats. Photo from http://education.eol.org/field-guide?guidekey=4&eol_id=1051455 (Creative Commons).

in Section 3.1.3 are recapitulated in these maps of potential habitat, including the ring of connectivity to the north and south of Tucson (e.g., ground snake, Map 65) and also the major washes traversing the city (e.g., giant spotted whiptail, Map 64; Mexican garter snake, Map 66; Bell's vireo, Map 69). However, as especially evident in the case of aquatic species (e.g., Huachuca water umbel, Map 54), populations may also be either separated or fragmented by major human drivers of landscape change. Several of these are evident by comparing the vulnerable species maps to the land cover maps (Section 3.1.2), and also to the maps presented in Section 3.2 (Human Drivers).

3.2 Human Drivers

3.2.1 Population

A long term view of population for the four counties near Saguaro National Park (Pima, Pinal, Graham, and Cochise counties) shows the population booms that started in the late 19th and early 20th Centuries (Map 84). Growth was most pronounced in Pima Co., followed by Pinal Co., Cochise Co., and Graham Co. Future population growth is also expected in all four counties, especially in Pinal Co., where – relative to a 2000 baseline – a quadrupling of population is expected by the year 2030 (Map 84). In Pima Co., future growth is expected to be less, but still close to a doubling (relative to 2000) by 2030 (Map 84). At a more local level, evaluated from 2005 to 2040, these future increases are expected to occur in census blocks to the north and south of Tucson, along the I-10, I-19, and Highway 77 corridors (Maps 85 [2005] and 86 [2040]). This general growth pattern is already evident in recent decades based on actual census observations (1990, 2000, and 2010), both in terms of total population (Maps 87 [1990], 88 [2000], and 89 [2010]), and in terms of population density (Maps 90 [1990], 91 [2000], and 92 [2010]).

3.2.2 Housing

Housing has increased dramatically around Saguaro National Park over the past several decades, and projections suggest that it will continue to increase through the 21st Century. A simple comparison of the number



Photo 14. Tucson and surrounding communities have experienced rapid human population growth, and projections suggest that these trends will continue through at least 2030. Photo from <http://www.wanttoteach.com/TucsonUnifiedSchools.html>.

of housing units between the year 2005 and projected to the year 2040 is evidence of this trend (Maps 93 [2005] and 94 [2040]). These maps show that future growth is largely expected around the periphery of Tucson. Historical increases in housing density are also apparent since the year 1970 (Maps 95 [1970], 96 [1980], 97 [1990], and 98 [2000]), and again projections suggest that densities will continue to increase dramatically through the year 2100 (Maps 99 [2010], 100 [2020], 101 [2030], 102 [2040], 103 [2050], 104 [2060], 105 [2070], 106 [2080], 107 [2090], and 108 [2100]). While future increases in housing are largely expected to occur within areas that are already developed (due to zoning, see Section 3.3), these density increases within an existing development footprint can nonetheless have profound ecological consequences for park resources. In particular, the continued development of communities around Saguaro will undoubtedly increase the potential for pet-wildlife interactions, and noise and light pollution from these communities will increasingly threaten the wilderness character of the Park.

In addition to the maps, it is also useful to interpret housing density patterns across multiple AOAs (Figure 17). For example, from the plots it is apparent that – in the year 2100 – areas within 3 km of TMD are expected to be covered by approximately 70% more

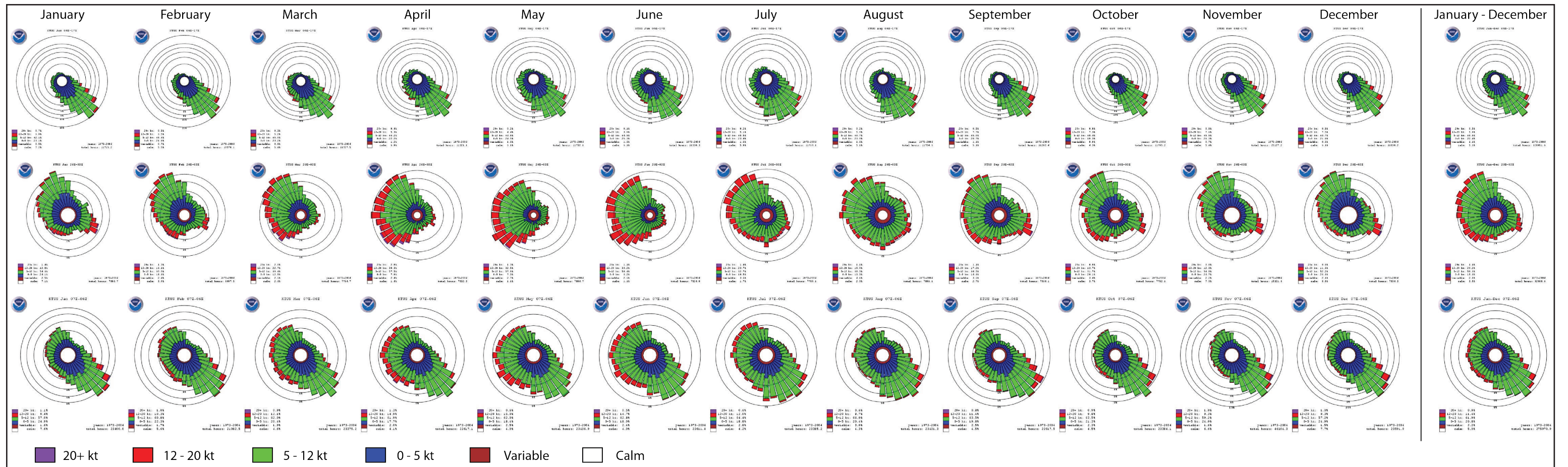


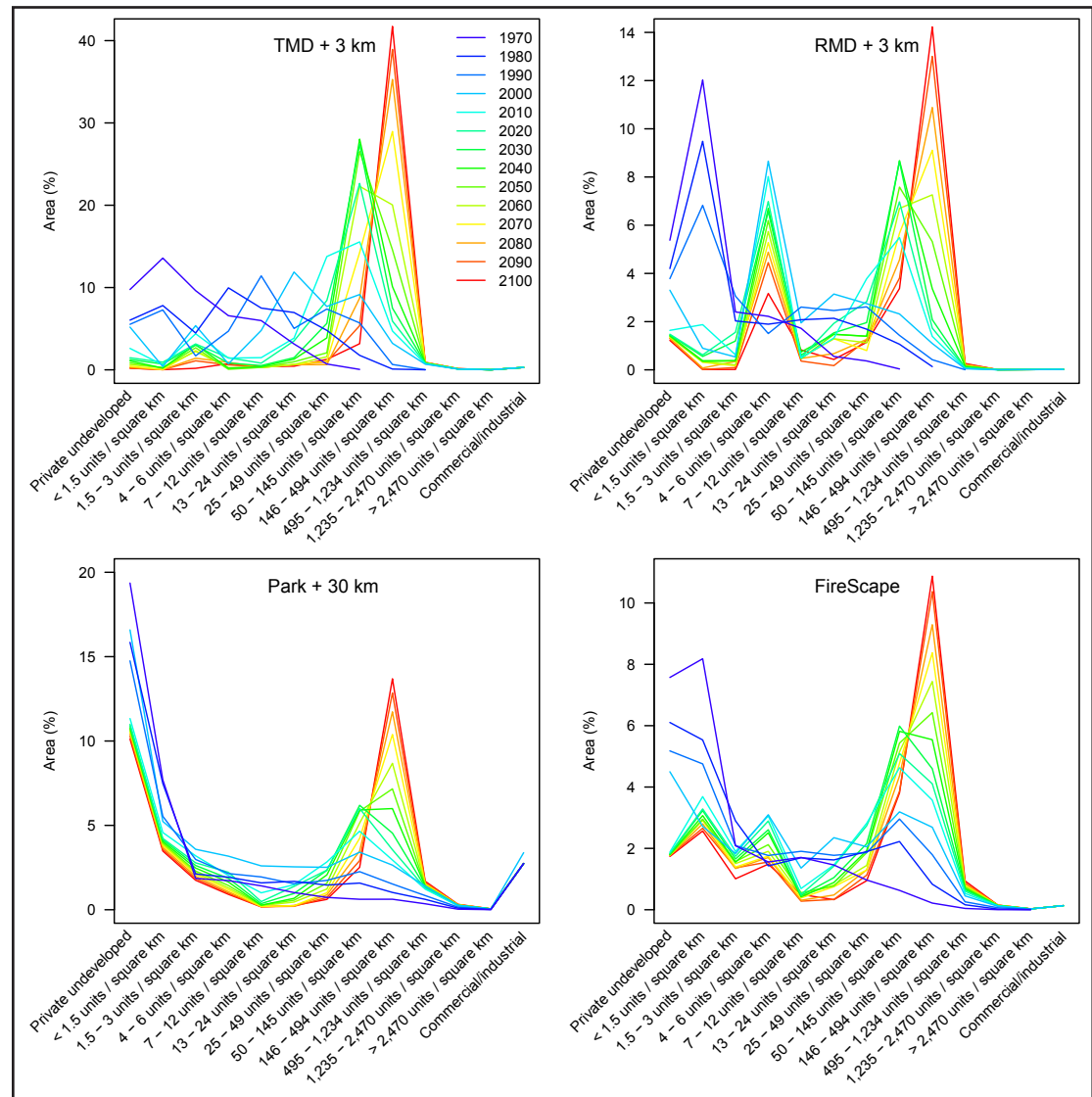
Figure 16. NOAA wind rose statistical summaries (1973-2004) of wind speed vs. wind direction for the Tucson reporting station. Results are shown by month (columns 1-12) and annually (column 13) for AM hours (11 AM – 11 PM; top row), PM hours (1 PM – 8 PM; middle row), and both AM and PM combined (bottom row). Colored bars indicate the speed and direction from which the wind is reaching the station. For example, in the month of January during the AM hours, most wind arrives from the southeast at 5-12 kt (knots; 1 kt = 0.514 m/s or 1.51 mi/hr). Wind rose plots obtained from http://www.wrh.noaa.gov/twc/aviation/windrose_TUS.php.

[Page intentionally left blank]

suburban and urban housing development (>146 units/km²) than areas occurring within 3 km of RMD (Figure 17, top row). Increases in housing density around TMD are also seen to be more transitional, as evident by the density peaks shifting sequentially by decade to higher density classes (Figure 17, top left). Meanwhile, around RMD, growth is much more punctuated, with increases jumping decadally across density classes that broadly capture rural, exurban, suburban, and urban development (Figure 17, top right). At present (year 2010), housing within 3 km of TMD is almost entirely characterized as exurban (50-145 units/km²), whereas within 3 km of RMD it is characterized by a mix of rural (4-6 units/km²) and – to a lesser extent – exurban (Figure 17, top row).

At slightly larger spatial scales (Park plus 30 km buffer and the Firescape AOA), housing density is characterized on average as exurban (Figure 17, bottom row). This characterization for Saguaro National Park has also been reported in other studies (Davis & Hansen 2011), and it reflects the fact that development in the greater Tucson area has expanded dramatically over the past several decades, but the Park is still surrounded on certain sides by undeveloped (protected) areas. As densities continue to increase under existing zoning, Saguaro will soon be considered a suburban park. According to the housing trajectories presented in Figure 17, and as further evident from the maps (Maps 95-108), we can expect this transition from exurban to suburban to occur in under three decades (by the year 2040).

Figure 17. Housing density (number of units per km²) computed for 14 decades (1970-2100) and four AOAs: TMD + 3 km buffer (top left), RMD + 3 km buffer (top right), Park + 30 km buffer (bottom left), and the FireScape planning region (bottom right). Density classes may also be categorized into the following: rural (private undeveloped and housing densities up through 6 units/km²), exurban (7-145 units/km²), suburban (146-1,234 units/km²), and urban ($>1,235$ units/km²).



3.2.3 Roads

The road transportation network around Saguaro is extensive due to recent growth of Tucson and surrounding communities (Map 109). Road density [measured as the total road length (km) per unit of area of landscape (km^2)] is a useful indicator for understanding road effects on terrestrial vertebrates, vegetation, and aquatic resources (Forman & Alexander 1998). In addition to road density, distance to nearest road (measured in meters, Euclidean distance) is another landscape indicator that is useful for understanding the direct (e.g., road kill) vs. indirect (e.g., road avoidance due to noise) effects of roads (Monahan et al. 2012b). While the critical ecological thresholds for these indicators as they relate to Saguaro resources are unknown (determining these thresholds requires further research), insights may be gained by contrasting road density and distance to nearest road for multiple ecologically informative AOAs.

Road density around Saguaro is dominated by the transportation networks connecting Tucson and surrounding communities, but a number of other roads in and around the Park create densities that are informative for understanding wildlife movements and the potential for human-dispersed invasives to establish and spread. For example, TMD contains a number of roads that result in at least some measure of road density throughout most areas of the district (Map 110). Towards the north, TMD is bisected by Picture Rock Road, which due to relatively high traffic volume is also high in terms of weighted road density (approximately $3 \text{ km}/\text{km}^2$). While RMD does not have these same issues with road density within park boundaries, road densities do affect potential connectivity between RMD and the USFS Pusch Ridge Wilderness to the north and west (Map 110).

The map of road density is useful for evaluating possible road effects on park resources at relatively fine spatial scales. However, it is also useful to be able to summarize and contrast road densities among ecologically informative AOAs (Figure 18). For example, from the summary plots it is readily apparent that road density occurring within 3 km of

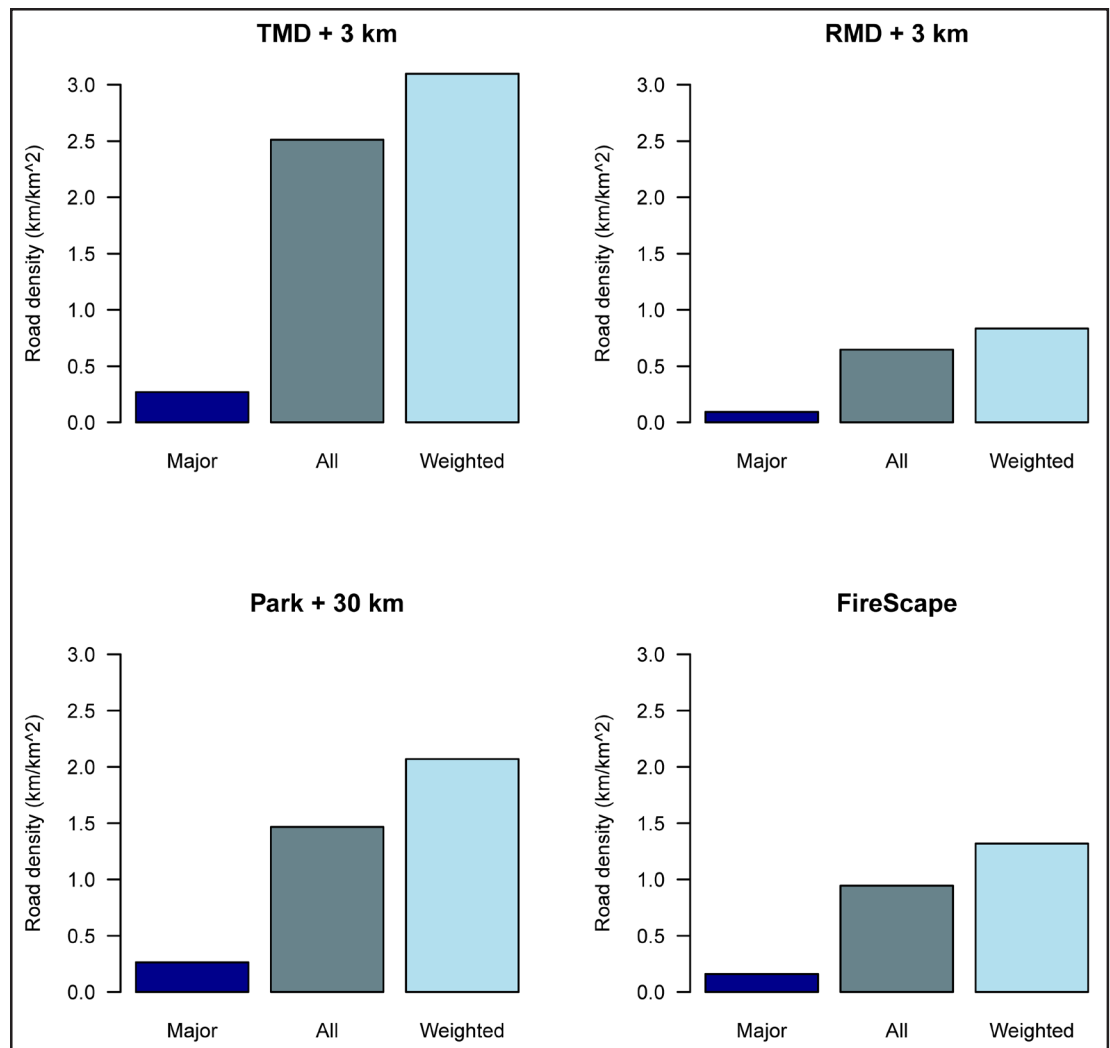


Photo 15. Picture Rocks Road is a major road that bisects Tucson Mountain District. Photo from <http://www.arizonaroadbikerides.com/picture-rocks-bike-ride-tucson-arizona/>.

Saguaro is approximately 3x higher for the TMD compared to the RMD (Figure 18, top row). Within 30 km of the park, road densities are lower due to the proximity of other protected areas (primarily USFS lands), but are still rather high due to the greater Tucson transportation network (Figure 18, bottom left). Importantly, the movements of many species of wildlife tend to be adequately described by this AOA, and in the case of Saguaro it is also the scale that physically connects the two districts of the Park. Hence, road densities within the 30 km AOA are especially informative for understanding the overall impediment posed by roads to TMD-RMD connectivity. Finally, road density within the FireScape planning region is very comparable to that for RMD (Figure 18, bottom right), but it is slightly elevated due to high road density areas occurring between RMD and the USFS Pusch Ridge Wilderness along the southwestern boundary of the FireScape AOA.

The effects of roads on Saguaro resources may also be interpreted in the context of distance to or from nearest road (Map 111). Distance to nearest road is an especially relevant metric for considerations of wilderness character because it may be used to identify large patches of roadless areas whose interiors are far removed from road effects. Many of these road effects are caused by traffic volume, which has increased dramatically

Figure 18. Road density (length of road in km divided by the size of the AOA in km²) computed for three density classes (major roads, all roads, and all roads weighted) and four AOAs: TMD + 3 km buffer (top left), RMD + 3 km buffer (top right), Park + 30 km buffer (bottom left), and the FireScape planning region (bottom right). Major roads include interstates and highways. All roads include interstates, highways, and all streets. Weighted roads is computed from all roads by multiplying interstates by a factor of 10 and highways by a factor of 3.



between 1970 (Figure 19) and 2010 (Figure 20). Note: Other road and transportation Maps 112-115 are presented in Section 3.3.2 (Conservation Context).

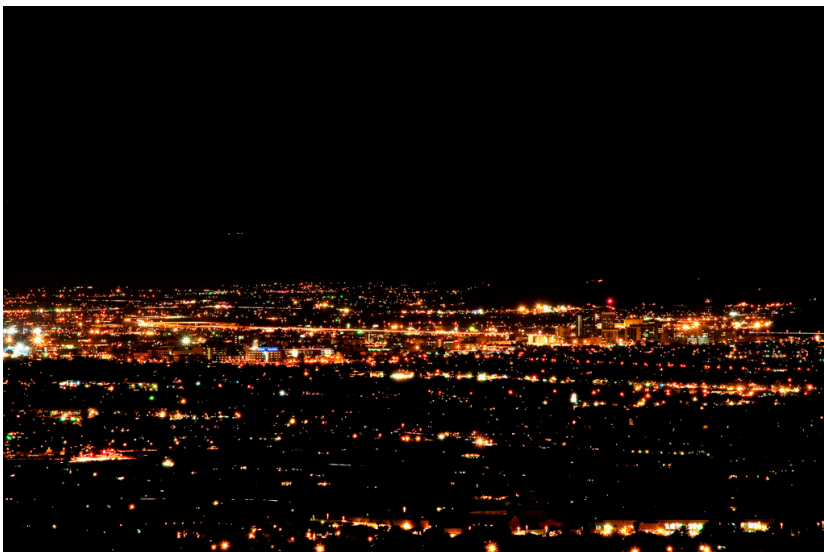


Photo 16. Tucson at night. Photo from <http://www.flickr.com/photos/jaydavisconsulting/4428766364/> (Creative Commons).

3.2.4 Nighttime Lights

Night is an important part of the diurnal cycle for all species, irrespective of when in the day they are active. For example, under the same cover of night, nocturnal species hunt while diurnal species rest, and in both instances their ability to maintain a primarily 'natural' state is dependent in part on the degree to which anthropogenic activities like light pollution impair dark night skies. In addition, around Saguaro National Park, dark night skies are needed for astronomy (e.g., visible spectrum) and preserving wilderness character in the Saguaro and Pusch Ridge Wilderness areas. Nighttime light pollution is an important human driver for Saguaro insofar as it helps the Park understand the potential effects of humans and development on resources that are critically dependent on night.

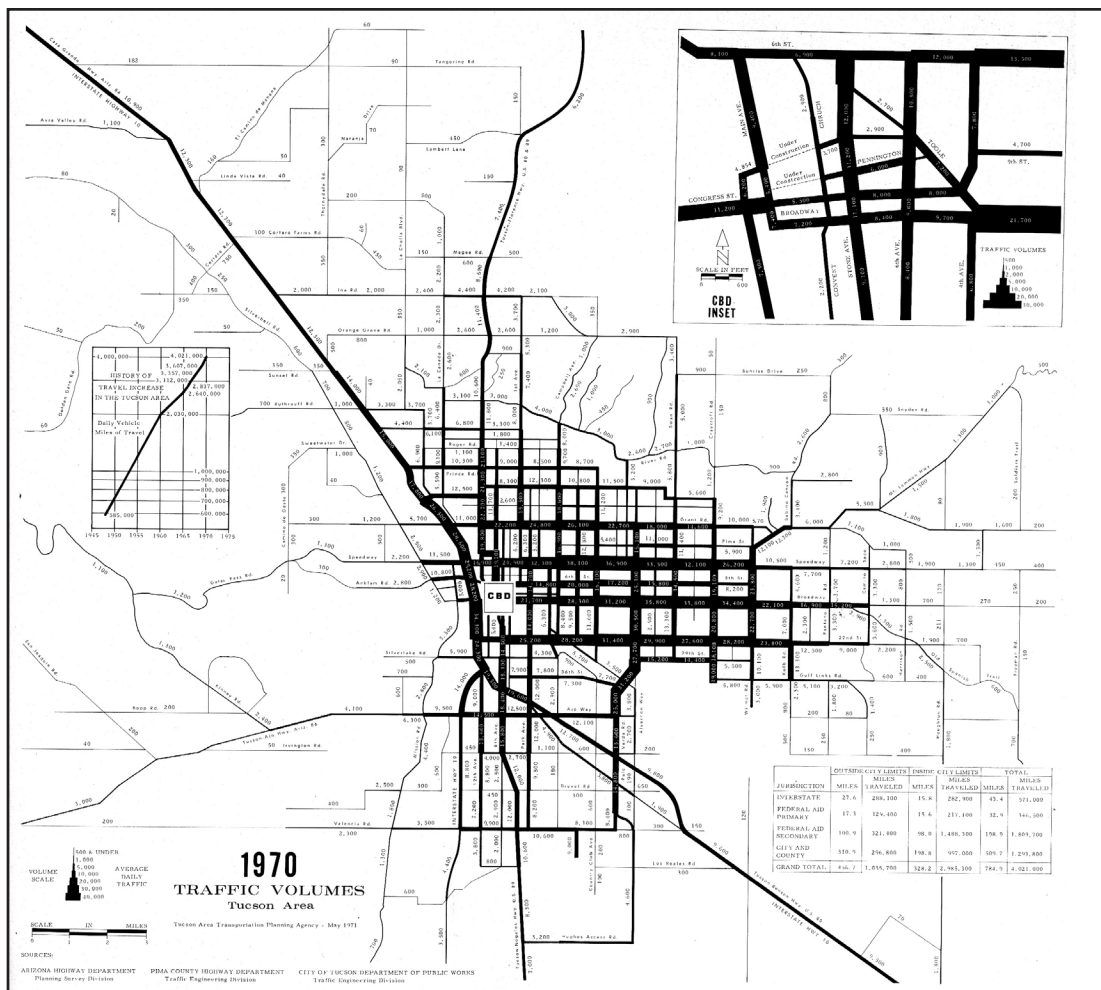


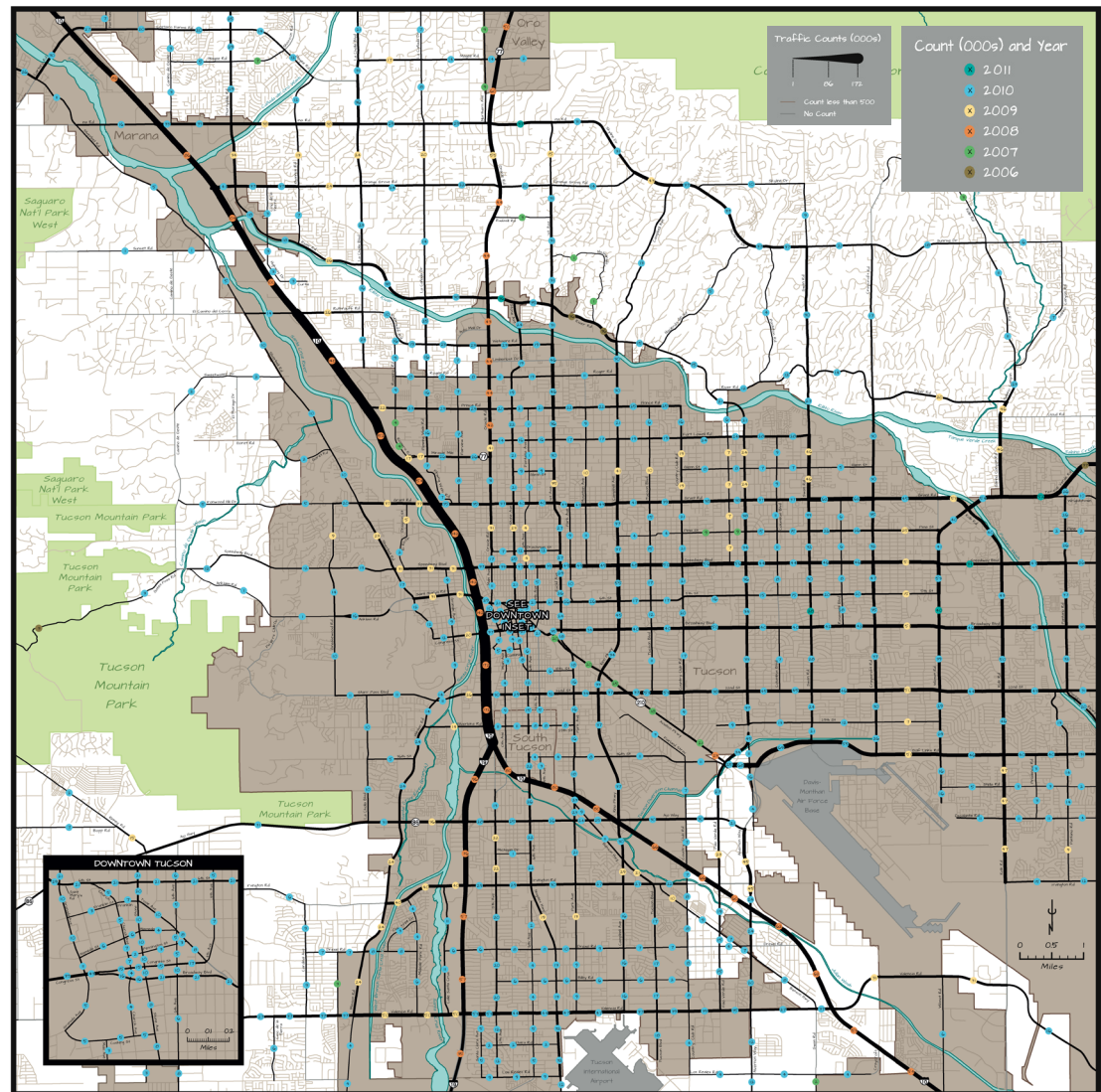
Figure 19. Traffic volume in and around Tucson in the year 1970. Significant traffic counts are symbolized by the black lines, where in the main map thinnest = 1,000 two-way weekday traffic count, mid = 20,000 two-way weekday traffic count, and thickest = 40,000 two-way weekday traffic count. Map obtained from the Pima Associations of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).

Two primary ways of measuring night skies and nighttime light pollution are through direct observation and through models. In addition, night skies may be measured from either the ground-up or sky-down. The different methods of measurement are generally designed to answer different questions that are considerably more technical than the broad, landscape-level questions considered here. Nevertheless, because a distinct advantage of this report is that it presents a wide variety of landscape indicators and maps in a standardized (and thus comparable) framework, we include examples of each night sky metric so that they may be evaluated relative to other maps and indicators.

Sky-down measurements based on direct observation are available for multiple years, encompassing the range reported here for 1997 (Map 116) and 2009 (Map 117). From these maps it is apparent that 2009 had more area associated with high visibility of nighttime lights. While some of this change is

undoubtedly attributable to the increase in human development that occurred over the same time period, note that the observations are not strictly comparable because different sensors were used to record the two datasets. Maps 116 and 117 provide useful direct observations of nighttime lights, but they do not take into account atmospheric scattering, or light pollution propagation. This is shown in an empirical sky-down model (Map 118), which when compared to direct observations (Maps 116 and 117) illustrates the potentially important effects of atmospheric scattering on dark night skies. Lastly, Map 119 shows ground-up observations of night skies in relation to Pima County lighting area codes. Limiting magnitude, as reported in Map 119, is a term used to describe the brightness of an object, where 1 is most bright and 7 is most dark. A general pattern evident in Map 119 is that limiting magnitudes tend to be smaller in more developed areas (e.g., areas with high nighttime light visibility in Maps 116 and 117). Of

Figure 20. Traffic volume in and around Tucson in the year 2010. Significant traffic counts are symbolized by the black lines, where in the main map thinnest = 1,000 two-way weekday traffic count, mid = 86,000 two-way weekday traffic count, and thickest = 172,000 two-way weekday traffic count. Map obtained from the Pima Associations of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



course, these areas also have more observations, meaning that the spatial distribution of limiting magnitudes may be no different than random expectations (i.e., once sampling differences are accounted for). However, the Saguaro BioBlitz – conducted October 21-22, 2011 – recently collected new measurements of limiting magnitude in a standardized fashion (Figure 21). Figure 21 confirms that night skies are consistently darker throughout the Park (achieving a maximum limiting magnitude of 7 at Happy Valley Saddle in the RMD – thousands of stars visible), compared to downtown Tucson (limiting magnitude of 2 – fewer than 50 stars visible).

3.3 Conservation Context

3.3.1 Conservation Status

The conservation status of lands in the local area surrounding Saguaro National Park may be generally assessed in terms of use, ownership, and level of protection. In terms of broad use categories, the Conservation Lands System provides basic insights into the how the lands in Pima County are grouped according to the Sonoran Desert Conservation Plan (Map 120). Major owners of conservation lands in the local Park area include USFS, BOR, and BLM (Map 121), and in the FireScape planning region major owners include USFS, State lands, and Saguaro (NPS) (Figure 22). Ownership is also summarized in Figure 23. These lands receive varying levels of protection, with the TMD, RMD, and

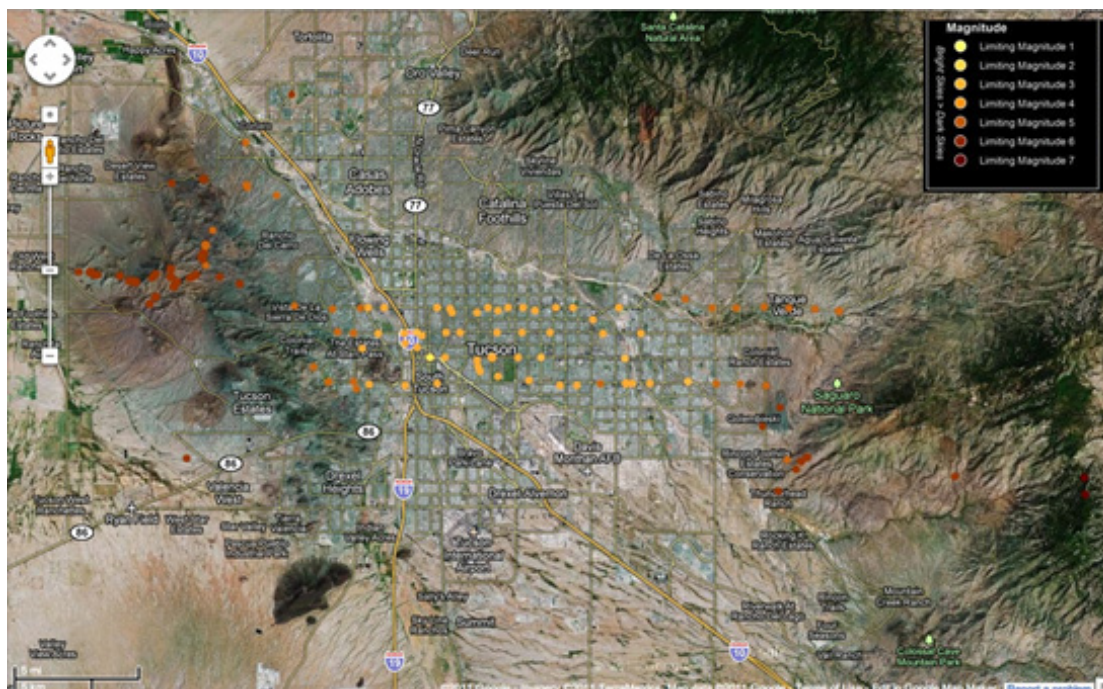


Figure 21. Map of a night sky inventory recorded during the recent Saguaro BioBlitz. Map provided by Constance Walker, courtesy of Mark Newhouse and Dave Bell (National Optical Astronomy Observatory, NOAO). Colored points symbolize limiting magnitudes, where yellow = 1 (most bright) and dark red = 7 (most dark).

other Wildernesses (e.g., USFS Pusch Ridge) providing important anchors to the broader network of protected areas encircling Tucson (Map 122). As discussed in Section 3.1.3, this protected area network is important to habitat connectivity, especially between TMD and RMD, and also between the Park and surrounding landscape. Protected areas, as defined in this report by lands having a GAP status code of 1 or 2 (see Section 2.3.1 for definitions), are further summarized in Figure 24.

3.3.2 Transportation

Roads were considered in Section 3.2.3 as a human driver of landscape change. While roads in and around Saguaro National Park do pose distinct challenges to natural resource conservation, they also facilitate park visitation and are important in a conservation context, especially when considered as part of a larger transportation network (Map 112). The two districts of Saguaro are also well connected to one another and the greater Tucson area by a series of Pima County trails and bike routes (Map 113, Figures 25 and 26). The existing bus network and park & ride locations reach within a few miles of TMD and RMD (Map 114), but from many of those end-points visitors may still reach the Park through county trails and bike routes. Handicap visitors may also reach

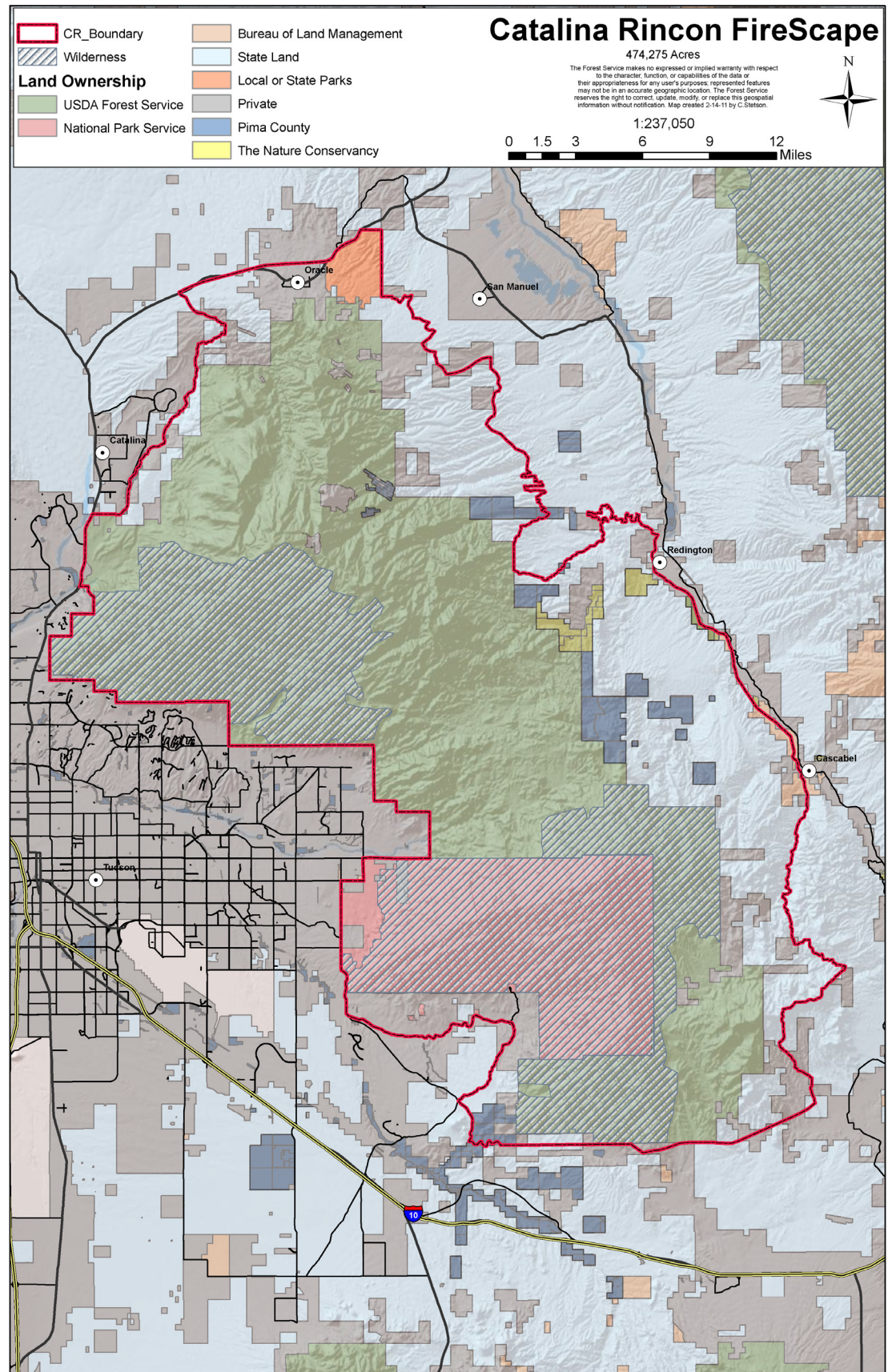
both districts through an unincorporated RTA expanded HandiCar service (Map 115). Accessibility as measured by motor vehicle travel time is also shown with respect to the University of Arizona (Figure 27).

3.3.3 Viewsheds

Both districts of Saguaro National Park serve as headwaters for surrounding areas (see hydrography maps in Section 3.1.3). Hence, from many observation points throughout the Park, the viewsheds are extensive and encompass much of the greater Tucson area. Viewsheds are important landscape indicators for Saguaro because they inform our understanding of the conservation context of certain visual park resources like wilderness character.

A total of 17 key observation points were identified in the TMD, and another 19 in the RMD. These were further categorized according to major types of park access: roads, front country (day hikes), and back country (overnight hikes). The TMD included 7 road points and 10 front country points; RMD included 4 road points, 7 front country points, and 8 back country points. The composite viewsheds associated with these different sets of key observation points are shown in Maps 123-127.

Figure 22 Land ownership (both conservation and non-conservation lands) in the the Catalina-Rincon FireScape planning region. Map obtained from <http://www.azfirescape.org/content/catalina-rincon-analysis-area-maps>.



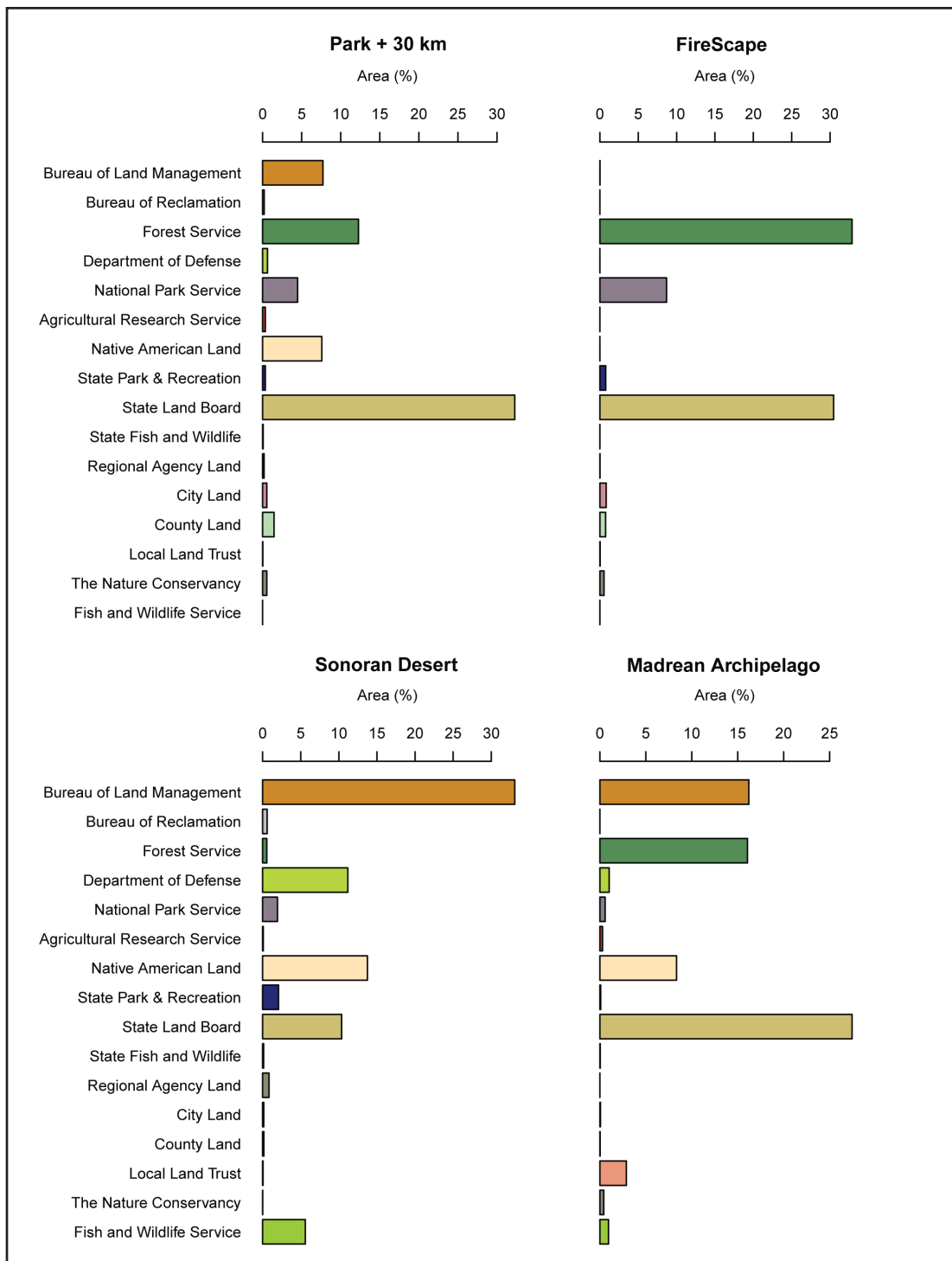


Figure 23. Area managed by major landowners, expressed as a percentage of each AOA: Park + 30 km buffer (top left), FireScape (top right), Sonoran Desert (bottom left), and Madrean Archipelago (bottom right). Ownership data provided by NPScape, obtained originally from PAD-US.

Figure 24. Protected areas by AOA: Park + 30 km buffer, FireScope, Sonoran Desert, and Madrean Archipelago. Percentage of protected area (left) and mean size of protected area (right). Protected areas summarized in the figure are defined by GAP status codes 1 and 2 (see Section 2.3.1). Data provided by NPScape, obtained originally from PAD-US.

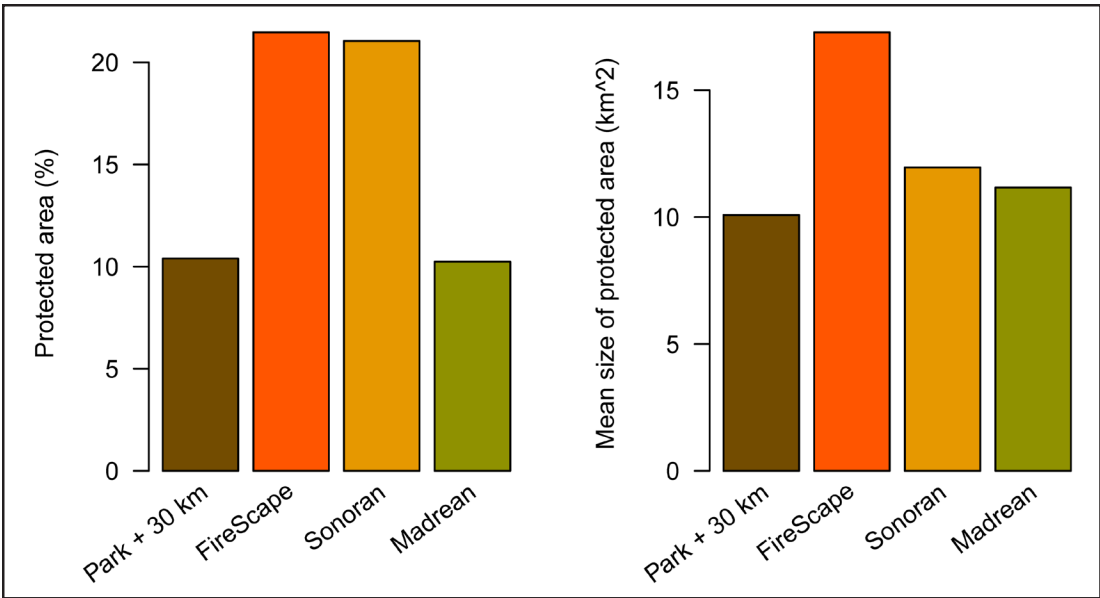
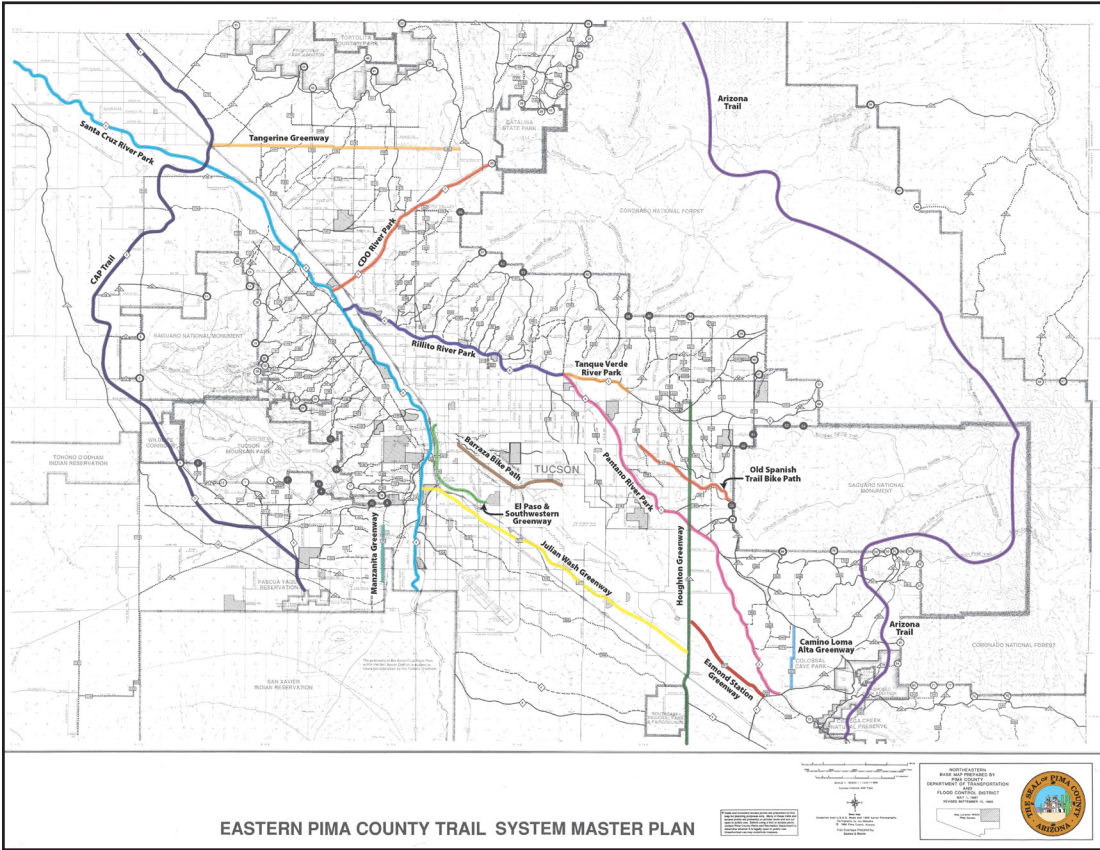


Figure 25. Northern portions of the eastern Pima County trail system master plan. Trails are indicated by the colored/labeled polylines. Map obtained from <http://www.pima.gov/nrpr/geninfo/masterplan.htm>.



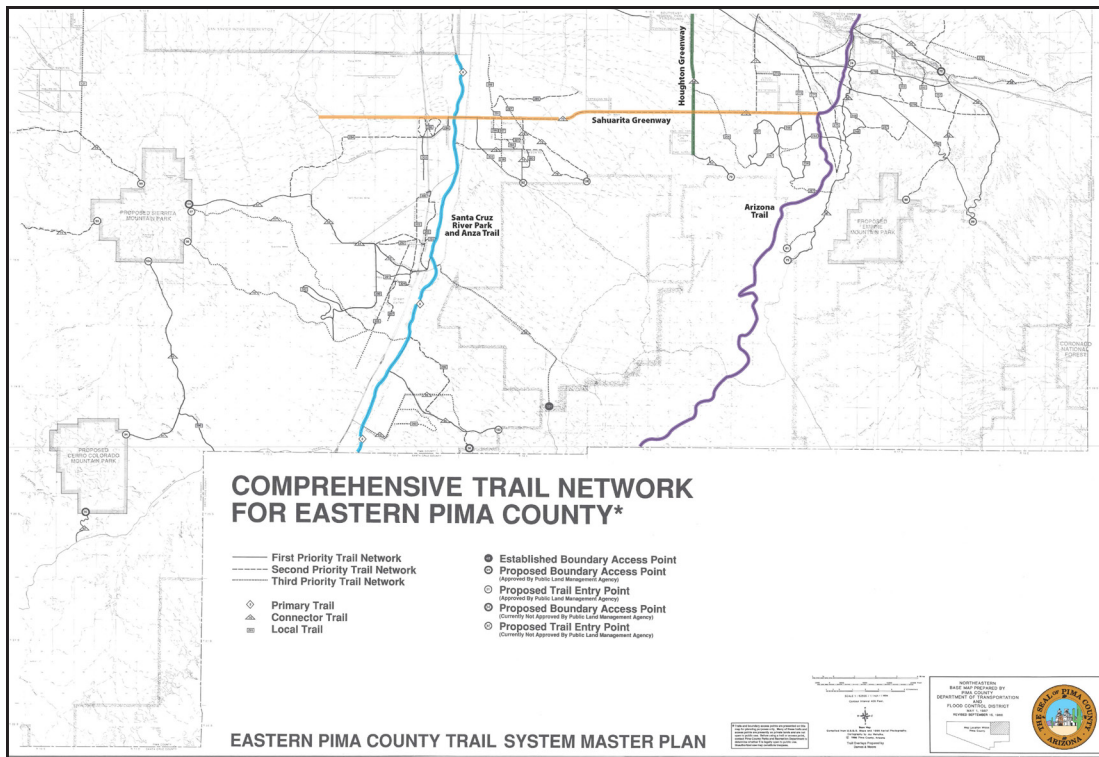


Figure 26. Southern portions of the eastern Pima County trail system master plan. Trails are indicated by the colored/ labeled polylines. Map obtained from <http://www.pima.gov/nrpr/geninfo/masterplan.htm>.

In TMD, more areas surrounding the district are visible from front country points than they are from points along roads (Maps 123 [roads] and 124 [front country]). In addition, more areas of Tucson are visible from front country points, and RMD is only visible from points along roads. Meanwhile, in RMD, the viewsheds become larger as one moves between road, front country, and back country points (Maps 125 [roads], 126 [front country], and 127 [back country]). This pattern is largely explained by the observation that the three sets of points are distributed along an elevational gradient. Viewsheds from RMD roads and front country points are most similar, and only from back country points are areas to the north and east visible. Practically the entire greater Tucson area is visible from at least one road, front country, and back country point in the RMD, and in all three classes observers are only able to see the eastern slopes of the TMD.

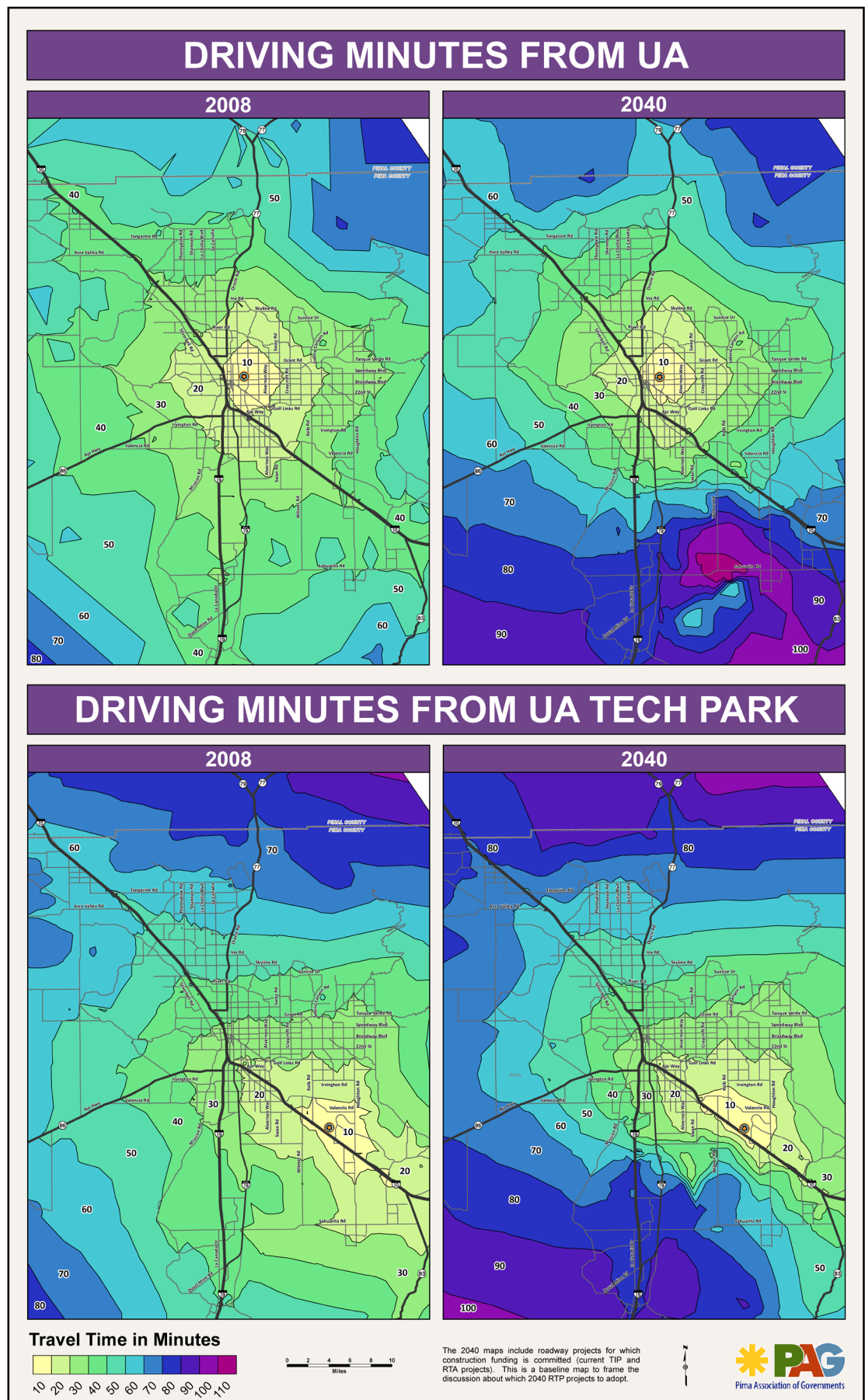
These inferences about TMD and RMD viewsheds are based on models that make a number of assumptions about the accuracy of the input data, topography, and observer characteristics. As such they provide hypoth-

eses that may be tested in the field, and a useful extension of this viewshed work would be to validate or ground-truth the maps using observer photographs taken from each key observation point.

3.3.4 Land Use & Zoning

Current land use and zoning in Tucson and surrounding communities can have major lasting effects on the opportunities and challenges associated with managing park natural resources. Even a simple comparison of land use between 1993 (Map 128) and 2009 (Figure 28) shows how patterns have changed around the periphery of Tucson, including areas adjacent to the TMD and RMD. Areas immediately adjacent to both districts are presently defined by the comprehensive plan as having land use intensities characterized by resource transition, low intensity urban, and both low and medium intensity rural (Map 129). The peripheral growth or expansion of Tucson outwards from the city center and towards TMD, RMD, and the Coronado National Forest is shown by the number of new building permits issued (Map 130) and the number of new structures built (Map 131). The proliferation of subdivisions in the foothills north of Tucson is visible in Map

Figure 27. Estimated travel times from the main University of Arizona campus, near the city center of Tucson (top row), and the University of Arizona Tech Park, located to the southwest of Tucson (bottom). Travel times are shown for the years 2008 (left column) and 2040 (right column). Map obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



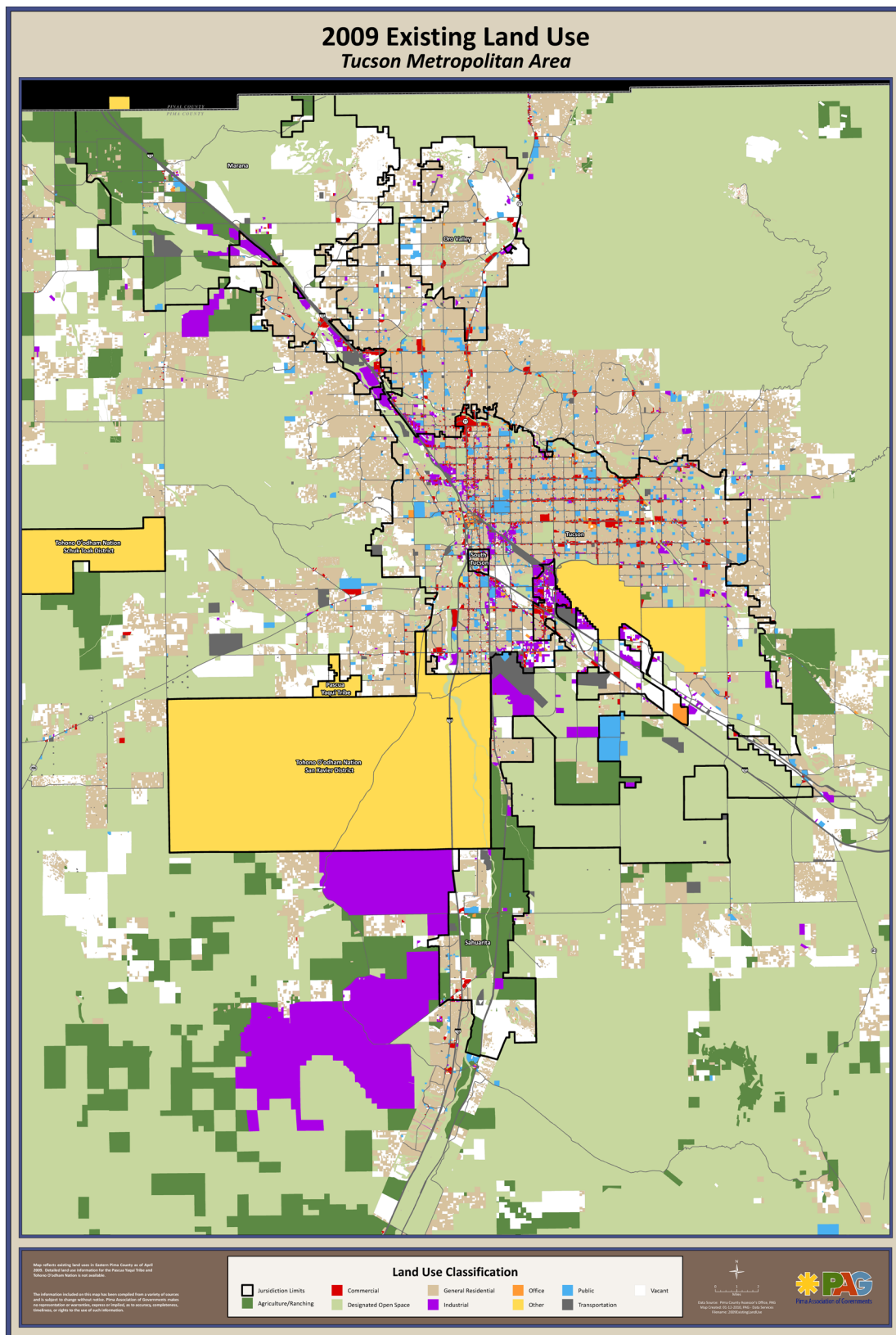


Figure 28. Existing land use (year 2009) in the Tucson metropolitan area. Map obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).

132. These areas are characterized by smaller lot sizes (Map 133) and patches of new development (Map 134). As further reference, maps are provided for Tucson neighborhood associations (Map 135), the Tucson area plan (Map 136), and Pima County zoning (Map 137).

3.3.5 Socioeconomics

Saguaro faces a number of questions concerning how best to engage local communities in Tucson and surrounding areas. These questions are non-trivial due in large part to spatial variation in socioeconomics. The US Census collects and compiles relevant socioeconomic data every decade. NPScape and the NRSS Social Science Division analyze and interpret these data as they are made available. Unfortunately, due to time lags associated with processing the latest Census we were unable to incorporate the 2010 data into this report, but such an update will be possible as early as 2013. The results presented in this section are mostly based on results of the 2000 census, and where possible both totals and densities are given by census block.

Race or ethnicity is one important socioeconomic indicator for the Park that may be used to help strategize education and outreach. Races considered here include Asian American, Black, Hispanic, Native American, and White. Maps of population totals show how numbers are greatest for Hispanics and Whites, and also that totals

are quite variable by census block (Maps 138 [Asian American], 139 [Black], 140 [Hispanic], 141 [Native American], and 142 [White]). The corresponding density maps show how Asian American and Whites tend to be concentrated in areas to the north of Tucson, while Blacks, Hispanics, and Native Americans tend to be concentrated in areas to the south (Maps 143 [Asian American], 144 [Black], 145 [Hispanic], 146 [Native American], and 147 [White]).

Age also shows characteristic patterns that are important for Saguaro in understanding how best to engage local communities. City center and areas south of Tucson tend to be dominated by younger generations (age 21-30), whereas areas to the north are characterized more by people over 40 (Map 148 [median age]). These basic patterns are also visible in maps where age is broken out by age group (Maps 149 [under 5 years], 150 [5-19 years], 151 [over 20 years], and 152 [over 65 years]). Corresponding densities by age group show that most people under 20 years in age are distributed through central and south Tucson (Maps 153 [under 5 years] and 154 [5-19 years]). As reference, densities of people 21 and over and 65 and over are shown in Maps 155 and 156.

Education is another important socioeconomic indicator, both in terms of the level of education reached by adults and the education opportunities afforded by schools. There is a pretty clear pattern of people with no school tending to live in south Tucson, those with Bachelor's degrees being in the north, and an educational gradient in between (Maps 157 [no school], 158 [middle and part of high school], 159 [high school graduate], and 160 [Bachelor's degree]). These patterns are also especially apparent in the corresponding maps of density by education class (Maps 161 [no school], 162 [middle and part of high school], 163 [high school graduate], and 164 [Bachelor's degree]). Education opportunities – both in a general sense and for Saguaro in strategizing where and how to engage school groups – are shown by the distributions of schools and school districts (Maps 165 [grade schools], 166 [middle schools], and 167 [high



Photo 17. Senita Valley Elementary School, located at 10750 E Bilby Road in Tucson, is about 5 miles (estimated 12 minute drive time) from the entrance to RMD.

schools]). According to forecasts provided by the Pima Association of Governments, we expect the number of school children grades 1 through 8 to increase dramatically to the northwest and south of Tucson by the year 2040 (Maps 168 [2005] and 169 [2040]). This same basic growth pattern is expected for school children grades 9 through 12 (Maps 170 [2005] and 171 [2040]).

Finally, we consider a number of socioeconomic indicators related to households, poverty/income, and employment. Household sizes tend to be largest in south Tucson, as well as communities further south, both in terms of owner (Map 172) and renter (Map 173) occupied units. Monthly owner costs as a percentage of income are quite variable compared to monthly renter costs, which tend to impact more people near the city center (Maps 174 [owner] and 175 [renter]). Comparable patterns are evident in terms of density (Maps 176 [owner] and 177 [renter]). The number of families by census block below poverty is quite variable (Map 178), but the percentage of families below poverty tends to be highest in central-south Tucson and areas further south (Map 179). Employment patterns are also oriented on a north-south axis, with most people employed being in central-north and those

unemployed in central-south; these patterns are evident both in terms of totals (Maps 180 [employed] and 181 [unemployed]) and densities (Maps 182 [employed] and 183 [unemployed]). Forecasts provided by the Pima Association of Governments suggest that Tucson and surrounding areas will see large increases in the number of people employed by the year 2040 (Maps 184 [2005] and 185 [2040]), but in interpreting these maps it is important to note that populations are also projected to increase dramatically over this same time period (see corresponding population Maps 85 [2005] and 86 [2040]). Per capita income is generally greatest around RMD, TMD, and areas north of Tucson (Map 186). Incomes are expected to increase in most areas between 2005 (Map 187) and 2040 (Map 188). Median structure value (Map 189) follows a similar pattern to per capita income (Map 186). Proximity to popular attractions likely drives some of these values (Map 190). In addition, Map 190 identifies major destinations that may be visited by people also visiting Saguaro National Park.

4. Synthesis

The purpose of this report is to provide Saguaro National Park with (i) data and methods for ongoing inventorying and monitoring of landscape dynamics, (ii) a detailed analysis of existing landscape data for areas within and surrounding the Park, and (iii) interpretation of the results in the context of key defining park natural resources. The data and methods are detailed in Section 2, and analysis and interpretation are provided in Section 3. This Synthesis is intended to provide additional interpretation, specifically on the status and trend of human drivers around Saguaro that have and will likely continue to affect park resources, and also on guidance for future work.

4.1 Status and Trend of Human Drivers

Of the three major landscape elements considered in the conceptual model of Figure 6 (human drivers, natural systems, and conservation context), there is special interest from a park I&M perspective in summarizing the status and trend of human drivers. Human drivers of landscape change are important because they represent external factors that can transcend park boundaries and negatively impact park resources. In reviewing the results presented in Section 3.2 it is apparent that many of the human drivers are correlated. For example, sky-down observations of nighttime lights (Maps 116 and 117) are clearly (and expectedly) positively correlated with developed areas (Map 18), total population (Map 89), housing density (Map 99), and road density (Map 110), yet negatively correlated with distance to nearest road (Map 111). With this in mind, landscape status and trend may be summarized using a handful of carefully chosen indicators.

Two important criteria for choosing these indicators are (i) ease of interpretation, and (ii) spatiotemporal resolution of source data. NPScape indicators were selected with these two criteria in mind (Table 1), and because they have been computed consistently across

parks they also provide a useful comparative framework for evaluating and interpreting Saguaro indicators. This comparative framework is important because critical ecological thresholds associated with many landscape indicators are often not known, at least for a particular geography (Monahan et al. 2012b). In the absence of such detailed knowledge, status and trend can at least be evaluated in a relative sense using among-park comparisons.

A summary of the status and trend of human drivers for Saguaro National Park and surrounding 30 km is provided in Table 7. Several important insights emerge from this synthesis:

- Relative condition is conserved across the three indicators (weighted road density, population density, and housing density), reaffirming the correlations mentioned in the previous paragraph, and further suggesting that these correlations also hold across other parks (both nationally and in shrub dominated ecosystems).
- Relative conditions for Saguaro are consistently greater than the medians of each indicator, indicating that the Park is considerably more challenged than most other NPS units by human drivers of landscape change.
- These challenges are especially pronounced when Saguaro is compared to other parks in shrub dominated ecosystems, where across all three indicators it is in the top 90th percentile for relative condition (shrub).
- Housing density has increased dramatically since the year 1970, and projections not reported in the table suggest that it will increase by another 43% (reaching 2,558 units/km²) by the year 2050.

Table 7. Status and trend of human drivers according to the Park + 30 km AOA. Relative condition is the 'current' percentile for Saguaro National Park, calculated on two statistical distributions: all natural resource NPS units in the contiguous US with their respective 30 km buffers (National, $n = 260$), and all natural resource NPS units in shrub dominated ecosystems (like Saguaro) with their respective 30 km buffers (Shrub, $n = 61$). Relative change is calculated as recent change divided by past condition, expressed as a percentage.

Indicator	Current Condition	Recent Change	Relative Condition (National)	Relative Condition (Shrub)	Relative Change
Road density – weighted Year: 2005 Units: km / km ²	2.07	NA	62.3%	95.1%	NA
Population density Years: 1990, 2010 [current] Units: people / km ²	116.7	+37.1	73.5%	93.4%	+46.6%
Housing density Years: 1970, 2010 [current] Units: # housing units / km ²	1,785	+1,374	69.5%	95.0%	+334%

- It appears that housing densities have increased more rapidly than population densities, although the two estimates of relative change reflect different baselines (1970 [housing] vs. 1990 [population]). The relative change in housing density between 1990 and 2010 is about 61%, which is comparable to the relative change in population over the same time period.

4.2 Future Directions

This report provides Saguaro National Park with a foundational framework for I&M landscape dynamics monitoring and reporting. The intent is for this framework to be repeated in the future so that Saguaro can continue to address basic questions related to the natural systems, human drivers, and conservation context influencing Park resources. Most landscape-level data are refreshed or updated every 1 to 5 years. Hence, results can be updated for Saguaro over time as new source data become available (e.g., every 5 to 10 years).

Our initial report benefitted especially from landscape-level data provided by NPScape, the Pima County Information Technology Department, and the Pima Association of Governments. These three major data sources will presumably continue to

remain available, meaning that they can be used to calculate landscape indicators in subsequent reports. An important question will be whether there are other sources of landscape-level data that become available, which may provide more accurate estimates of the landscape indicators considered here, or possibly even allow researchers to estimate new landscape indicators (i.e., beyond those considered in this report). As considered carefully here with selecting GIS data to inform landscape dynamics reporting, it will be important to critically evaluate with new datasets whether the source data represent an inventory (which may never be updated again) or are derived from fully standardized methods that are repeated over time and thus suited for monitoring. This distinction has big implications for whether Saguaro will be able to evaluate landscape trend, or be limited to an estimate of status.

In the next year or two we will see important updates to a handful of the NPScape source datasets considered here. In particular, Summary Files 1 and 3 of the US Census will be released and processed, which means most of the socioeconomic indicators can be re-estimated according to the 2010 Census. Additionally, NPScape and the NRSS Social Science Division have retrospectively added these same socioeconomic attribute fields to

the 1990 and 2000 Census datasets. Hence, beyond the 2000 socioeconomic inventories considered in this report, it will be possible by c. 2013 to also consider how these socioeconomic indicators have changed over the past three decades (at the level of a census block group). Given the importance of socioeconomic indicators for Saguaro in strategizing how to engage local communities, an analysis and summary of these data will make for a useful standalone addition to this report.

NPScape housing projections, which are based on the Spatially Explicit Regional Growth Model (SERGoM, Theobald 2005) will also be updated to include the 2010 Census, as well as other modifications, including refined and improved scenarios of future housing growth. It is anticipated that these new estimates of NPScape housing density will be available in 2013 (Dave Theobald, personal communication).

The National Land Cover Dataset of 2011 is anticipated to be released in 2013 (Collin Homer, personal communication). The methods used in the processing of these data will make them comparable to both the 2001 and 2006 datasets. Hence, with the release of the 2011 land cover data it will be possible to further investigate land cover trends in and around Saguaro. To put this in context, the data and analyses will essentially provide a broader extent (same spatial resolution, 30 m) and more recent snapshot (2011 vs. 2009) of the land cover change product provided by Villarreal et al. (2011). In addition, the North American Land Change Monitoring System has indicated that they plan on releasing updated land cover maps and change detection products at regular intervals. These data are at a coarser spatial resolution (250 m) but have the distinct advantage of providing seamless coverage into Mexico.

Finally, we offer a few ideas for how the analyses presented here may be profitably extended to further benefit Saguaro National Park. Ensuring habitat connectivity for wildlife and preserving wilderness character in the face of a growing city of Tucson are two of the most pressing landscape-level

resource challenges being confronted by the Park. In addition to other efforts underway with modeling and analyzing connectivity in and around Saguaro (e.g., Arizona Wildlife Linkages Workgroup, Arizona Missing Linkages, HabiMap), the datasets analyzed in more of a univariate sense in this report could be further analyzed using multivariate techniques to address targeted, park-centric and specific questions related to functional connectivity. For example, many of the human drivers presented in Section 3.2 are known to impede wildlife movement via a multitude of mechanisms, and indeed several of these datasets were used as inputs to the new model of structural connectivity developed by Theobald et al. (2012; Map 31). Depending on the Park's choice of focal species, several of these human drivers could be integrated to create 'resistance' or 'cost' surfaces that summarize areas where the movement of each species is either impeded or prevented. Combining such surfaces with knowledge of the biology of the organism, including its habitat requirements, methods like Circuitscape (McRae 2006, McRae & Beier 2007, McRae et al. 2008) can be used to build custom models of functional connectivity for key species in Saguaro. The results of these models could then be overlaid with conservation context to visualize how areas that are important for preserving landscape-level connectivity align with lands that vary in level of protection and ownership. Knowledge of these factors would help the Park strategize where and who to engage in conservation partnerships.

Preserving wilderness character requires an in depth assessment of where and how factors beyond park boundaries might negatively impact the quality of wilderness values and experiences inside the Park. The local areas of analysis (AOAs) considered in this report are relevant to such an assessment, including especially the viewsheds (Maps 123-127). It would be advantageous to quantify the human drivers of each viewshed, which in turn inform our understanding of wilderness character at key observation points in the Saguaro Wilderness in TMD and RMD. The reason that these summaries were not included in the present report is that the

viewsheds are effectively GIS models that require validation or ground truthing before they can be reliably used in such a fashion. Hence, owing to the special importance of Park viewsheds for assessing opportunities and challenges associated with preserving wilderness character, another useful project that builds on results presented in this report would be to use photos from the key observation points to evaluate the extent to which our viewsheds correspond to what people see on-the-ground. Then, depending on the degree of correspondence, the

viewsheds could be reparamaterized and recomputed, and subsequently summarized for human drivers. Such results would provide Saguaro with a quantitative ranking of their key observation points inside park boundaries. They could also be used to train a spatially explicit model of viewsheds and corresponding human drivers from any point within the Park, which could then be used to help shape current decisions related to Wilderness planning.

References

- Arizona Commerce Authority. (2006) Arizona Department of Commerce – Center for Economic Advancement. <http://www.azcommerce.com/>.
- Clark, W.C. (1985) Scales of climate impacts. *Climatic Change*, 7, 5-27.
- Commission for Environmental Cooperation. (2010) 2005 Land Cover of North America at 250 meters. <http://www.cec.org/naatlas/>.
- Crist, P., Thompson, B. & Prior-Magee, J. (1996) Land management status categorization for Gap Analysis: A potential enhancement. Gap Analysis Bulletin #5. National Biological Service, Moscow, ID.
- Davis, C.R. & Hansen, A.J. (2011) Trajectories in land use change around U.S. national parks and their challenges and opportunities for management. *Ecological Applications*, 21, 3299-3316.
- Edwards Jr, T.C., Homer, C. & Bassett, S. (1994) Land management categorization: a users' guide. A Handbook for Gap Analysis, Version 1, Gap Analysis Program.
- Edwards, T., Schwalbe, C.R., Swann, D.E. & Goldberg, C.S. (2004a) Implications of anthropogenic landscape change on inter-population movements of the desert tortoise (*Gopherus agassizii*). *Conservation Genetics*, 5, 485-499.
- Edwards, T., Stitt, E.W., Schwalbe, C.R. & Swann, D.E. (2004b) Desert Tortoise (*Gopherus agassizii*): Movement. *Herpetological Review*, 35, 381-382.
- Environmental Systems Research Institute (ESRI). (2010) U.S. and Canada Detailed Streets. Compiled by Tele Atlas North America (2005), Inc., distributed by ESRI. Redlands, CA. DVD.
- Ewers, R.M. & Didham, R.K. (2007) Habitat fragmentation: panchreston or paradigm? *Trends in Ecology & Evolution*, 22, 511.
- Flesch, A.D., Epps, C.W., Cain, J.W., Clark, M., Krausman, P.R. & Morgart, J.R. (2010) Potential effects of the United States-Mexico border fence on wildlife. *Conservation Biology*, 24, 171-181.
- Forman, R.T.T. & Alexander, L.E. (1998) Roads and their major ecological effects. *Annual Review of Ecology and Systematics*, 29, 207-231.
- Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N. & Wickham, J. (2011). Completion of the 2006 National Land Cover Database for the conterminous United States. *Photogrammetric Engineering & Remote Sensing*, 77, 858-864.
- Gerow, K., Kline, N.C., Swann, D.E. & Pokorny, M. (2010) Roadkill surveys in Saguaro National Park: Quantifying a major source of wildlife mortality. *Human-Wildlife Interactions*, 4, 283-292.
- Groves, C.G. (2003) Drafting a conservation blueprint. Island Press, Washington, DC.
- Hansen, A.J. & DeFries, R. (2007) Ecological mechanisms linking protected areas to surrounding lands. *Ecological Applications*, 17, 974-988.

References (continued)

- Kupfer, J.A. (2006) National assessments of forest fragmentation in the US. *Global Environmental Change*, 16, 73-82.
- Lindenmayer, D.B. & Franklin, J.F. (2002) *Conserving forest biodiversity: a comprehensive multi-scaled approach*. Island Press, Washington, DC.
- McClure, M.F., Smith, N.S. & Shaw, W.W. (1996) Densities of coyotes at the interface of Saguaro National Monument and Tucson, Arizona. *Southwestern Naturalist*, 41, 83-87.
- McDonnell, M.J. & Hahs, A.K. (2008) The use of gradient analysis studies in advancing our understanding of the ecology of urbanizing landscapes: current status and future directions. *Landscape Ecology*, 23, 1143-1155.
- McRae, B.H. (2006) Isolation by resistance. *Evolution*, 60, 1551-1561.
- McRae, B.H. & Beier, P. (2007) Circuit theory predicts Gene flow in plant and animal populations. *Proceedings of the National Academy of Sciences of the USA*, 104, 19885-19890.
- McRae, B.H., Dickson, B.G., Keitt, T.H. & Shah, V.B. (2008) Using circuit theory to model connectivity in ecology and conservation. *Ecology*, 10, 2712-2724.
- Monahan, W.B. & Gross, J.E. (2012) Upstream landscape dynamics of US National parks with implications water quality and watershed management. *Sustainable Natural Resources Management*. (ed A. Kaswamila), In Tech. ISBN 978-953-307-670-6.
- Monahan, W.B., Gross, J.E., Svancara, L.K. & Philippi, T. (2012b) A Guide to Interpreting NPScape Data and Analyses. Natural Resource Report NPS/NRSS/NRTR—2012/578. National Park Service, Fort Collins, CO.
- Monahan, W.B., Swann, D.E., Hubbard, J.A. & Gross, J.E. (2012a) Monitoring park landscape dynamics through NPScape: Saguaro National Park. *ParkScience* 29(1):69-78.
- National Academy of Public Administration. (2010) An Independent Review of the National Park Service's Natural Resource Stewardship and Science Directorate. National Academy of Public Administration. Available at www.napawash.org.
- National Park Service. (1999) *Natural resource Challenge: The National Park Service's action plan for preserving natural resources*.
- National Park Service. (2010a) *National Park Service Climate Change Response Strategy*. National Park Service Climate Change Response Program, Fort Collins, Colorado.
- National Park Service. (2010b) NPScape population measure – Phase 1 data processing SOP: Acquiring and processing 2000 census data at the block group level – detailed instructions for Access 2007. Natural Resource Report NPS/NRPC/IMD/NRR—2010/249. National Park Service, Fort Collins, CO.
- National Park Service. (2010c) NPScape population measure – Phase 1 metrics processing SOP: Current population total and density, historic population density, and projected population density. Natural Resource Report NPS/NRPC/IMD/NRR—2010/254. National Park Service, Fort Collins, CO.

References (continued)

- National Park Service. (2010d) NPScape housing measure – Phase 1 metrics processing SOP: Current housing density, historic housing density, and projected housing density metrics. Natural Resource Report NPS/NRPC/IMD/NRR—2010/251. National Park Service, Fort Collins, CO.
- National Park Service. (2010e) NPScape roads measure – Phase 2 road metrics processing SOP: Road density and distance from roads. National Park Service, Natural Resource Program Center, Fort Collins, CO.
- National Park Service. (2010f) NPScape landcover measure – Phase 1 metrics processing SOP: Landcover area per category, natural vs. converted landcover, landcover change, and impervious surface metrics. Natural Resource Report NPS/NRPC/IMD/NRR—2010/252. National Park Service, Fort Collins, CO.
- National Park Service. (2010g) NPScape landcover measure – Phase 2 North American Land Cover metrics processing SOP: Landcover area per category and natural vs. converted landcover metrics. National Park Service, Natural Resource Program Center, Fort Collins, CO.
- National Park Service. (2010h) NPScape pattern measure – Phase 2 North American Land Cover pattern metrics processing SOP: Forest and grassland density. National Park Service, Natural Resource Program Center, Fort Collins, CO.
- National Park Service. (2011a) NPScape conservation status measure – Phase 2 Protected Areas Database of the United States metrics processing SOP: Protected area and ownership category metrics. National Park Service, Natural Resource Program Center, Fort Collins, CO.
- National Park Service. (2011b) NPScape conservation status measure – Phase 2 World Database of Protected Areas metrics processing SOP: Protected area and governance/ownership metrics. National Park Service, Natural Resource Program Center, Fort Collins, CO.
- National Park Service. (2011c) NPScape NPS boundary-derived areas of analysis SOP: Park, 3km, and 30km areas of analysis. National Park Service, Natural Resource Program Center, Fort Collins, CO.
- National Park Service. (2011d) NPScape Upstream Watershed – Phase 2 Upstream Watershed Delineation Processing SOP. Upstream Watershed Analysis for the National Park Service. National Park Service, Natural Resource Program Center, Fort Collins, CO.
- National Park Service. (2011e) NPScape Ecoregion-Derived Areas of Analysis SOP: Commission for Environmental Cooperation Terrestrial and Marine Ecoregions and FWS Landscape Conservation Cooperative Areas of Analysis. National Park Service, Natural Resource Program Center, Fort Collins, CO.
- National Park Service. 2012. NPScape: monitoring landscape dynamics of US National Parks. <http://science.nature.nps.gov/im/monitor/npscape/>.
- Radeloff, V.C., Stewart, S.I., Hawbaker, T.J., Gimmi, U., Pidgeon, A.M., Flather, C.H., Hammer, R.B. & Helmers, D.P. (2010) Housing growth in and near United States protected areas limits their conservation value. *Proceedings of the National Academy of Sciences of the United States of America*, 107, 940-945.

References (continued)

- Riitters, K.H. (2011) Spatial patterns of land cover in the United States: a technical document supporting the Forest Service 2010 RPA Assessment. Gen. Tech. Rep. SRS-136.
- Scott, J.M., Davis, F., Csuti, B., Noss, R.F., Butterfield, B., Groves, C., Anderson, H., Caicco, S., D'Erchia, F. & Edwards Jr, T.C. (1993) Gap analysis: a geographic approach to protection of biological diversity. *Wildlife Monographs*, 123, 3–41.
- Svancara, L.K., Brannon, R., Scott, J.M., Groves, C.R., Noss, R.F. & Pressey, R.L. (2005) Policy-driven versus evidence-based conservation: a review of political targets and biological needs. *BioScience*, 55, 989–995.
- Theobald, D.M. (2005) Landscape patterns of exurban growth in the USA from 1980 to 2020. *Ecology and Society*, 10, 32.
- Theobald, D.M., Reed, S., Fields, K. & Soule, M. 2012. Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the United States. *Conservation Letters*, 5, 123–133.
- US Census Bureau. (1991) Census 1990 Summary Tape File 1 United States. Prepared by the U.S. Census Bureau, 1991. <http://factfinder.census.gov/metadoc/1990stf1td.pdf>.
- US Census Bureau. (2001) Census 2000 Summary File 1 United States. Prepared by the U.S. Census Bureau, 2001. <http://www.census.gov/prod/cen2000/doc/sf1.pdf>.
- US Census Bureau. (2011) Census 2010 Summary File 1 United States. Prepared by the U.S. Census Bureau, 2011. <http://www.census.gov/prod/cen2010/doc/sf1.pdf>.
- US General Accounting Office. (1994) Activities outside park borders have caused damage to resources and will likely cause more. US Government Printing Office, GAO/RCED-94-59.
- USGS Gap Analysis Program. (2011) Protected Areas Database of the United States (PADUS) version 1.2 Geospatial Metadata. <http://gap.uidaho.edu/padus/protectedareas.html>. Last accessed February 28, 2011.
- Villarreal, M.L., Norman, L.M., Wallace, C.S.A. & van Riper, Charles, III. (2011) A multitemporal (1979-2009) land-use/land-cover dataset of the binational Santa Cruz Watershed. U.S. Geological Survey Open-File Report 2011-1131, 26 p. and database.
- Waisanen, P.J. & Bliss, N.B. (2002) Changes in population and agricultural land in conterminous United States counties, 1790-1997. *Global Biogeochemical Cycles*, 16, 137-1156.
- Wiens, J.A. (1989) Spatial scaling in ecology. *Functional Ecology*, 3, 385-397.
- Wiersma, Y.F., Nudds, T.D. & Rivard, D.H. (2004) Models to distinguish effects of landscape patterns and human population pressures associated with species loss in Canadian national parks. *Landscape Ecology*, 19, 773-786.
- World Commission on Protected Areas. (2011) World Database on Protected Areas (WDPA). <http://www.wdpa.org/Default.aspx>. Last accessed April 12, 2011.

Map Appendix

	Page
Areas of Analysis (AOAs)	
Map 1. Areas of analysis (AOAs) at the scale of Rincon Mountain District (RMD) – Saguaro National Park East.	A-5
Map 2. Areas of analysis (AOAs) at the scale of Tucson Mountain District (TMD) – Saguaro National Park West.	A-6
Map 3. Areas of analysis (AOAs) at the scale of Saguaro National Park – Rincon and Tucson Mountain Districts combined.	A-7
Map 4. Areas of analysis (AOAs) at the scale of the Madrean Archipelago and Sonoran Desert ecoregions	A-8
Climate	
Map 5. Minimum temperature of the coldest month (1970-2000 normals) for Saguaro National Park and ecoregional vicinity.	A-11
Map 6. Maximum temperature of the warmest month (1970-2000 normals) for Saguaro National Park and ecoregional vicinity.	A-12
Map 7. Total annual precipitation (1970-2000 normals) for Saguaro National Park and ecoregional vicinity.	A-13
Map 8. Minimum temperature of the coldest month (1970-2000 normals) in the local area surrounding Saguaro National Park.	A-14
Map 9. Maximum temperature of the warmest month (1970-2000 normals) in the local area surrounding Saguaro National Park.	A-15
Map 10. Total annual precipitation (1970-2000 normals) in the local area surround- ing Saguaro National Park.	A-16
Map 11. Temperature seasonality (standard deviation in monthly mean tempera- tures, based on 1970-2000 normals) for Saguaro National Park and ecoregional vicinity.	A-17
Map 12. Precipitation seasonality (coefficient of variation in monthly precipitation, based on 1970-2000 normals) for Saguaro National Park and ecoregional vicinity.	A-18
Map 13. Temperature seasonality (standard deviation in monthly mean tem- peratures, based on 1970-2000 normals) in the local area surrounding Saguaro National Park.	A-19
Map 14. Precipitation seasonality (coefficient of variation in monthly precipitation, based on 1970-2000 normals) in the local area surrounding Saguaro National Park.	A-20
Map 15. Change in minimum temperature of the coldest month per year (1980- 2010) for Saguaro National Park and ecoregional vicinity.	A-21

Map Appendix (continued)

Page

Climate (continued)

Map 16. Change in maximum temperature of the warmest month per year (1980-2010) for Saguaro National Park and ecoregional vicinity A-22

Map 17. Change in total annual precipitation per year (1980-2010) for Saguaro National Park and ecoregional vicinity. A-23

Land Cover

Map 18. Land cover (Anderson level II, National Land Cover Dataset 2006) in the local area surrounding Saguaro National Park. A-27

Map 19. Land cover change (Anderson level II, National Land Cover Dataset, 2001 to 2006), shown in relation to the 2006 “changed to” land cover class, in the local area surrounding Saguaro National Park. A-28

Map 20. Land cover (Anderson level II, year 1979) in the local area surrounding Saguaro National Park. A-29

Map 21. Land cover (Anderson level II, year 1989) in the local area surrounding Saguaro National Park. A-30

Map 22. Land cover (Anderson level II, year 1999) in the local area surrounding Saguaro National Park. A-31

Map 23. Land cover (Anderson level II, year 2009) in the local area surrounding Saguaro National Park. A-32

Map 24. Hydrologic land cover types (biome classification) in the local area surrounding Saguaro National Park. A-33

Hydrography & Connectivity

Map 25. Pima County wash network, springs, and flood control structures (source data obtained from the Pima County Information Technology Department, <http://gis.pima.gov/>) in the local area surrounding Rincon Mountain District. Park upstream watersheds provided by NPScape. A-37

Map 26. Pima County wash network, springs, and flood control structures (source data obtained from the Pima County Information Technology Department, <http://gis.pima.gov/>) in the local area surrounding Tucson Mountain District. Park upstream watersheds provided by NPScape. A-38

Map 27. Pima County wash network, springs, and flood control structures in the local area surrounding Saguaro National Park A-39

Map Appendix (continued)

Page

Hydrography & Connectivity (continued)

Map 28. Pima County drainage basins and public vs. private detention and retention basins (source data obtained from the Pima County Information Technology Department, <http://gis.pima.gov/>) in the local area surrounding Saguaro National Park. Park upstream watersheds provided by NPScape A-40

Map 29. Key landscape features enabling potential wildlife movements between Saguaro National Park and surrounding protected areas. Source data: Wildlife linkage designs (Arizona Wildlife Linkages Assessment; <http://corridordesign.org/linkages/arizona>); land cover (NPScape land cover from the National Land Cover Dataset); Washes, riparian habitat, wilderness and other protected areas (Pima County Information Technology Department, <http://gis.pima.gov/>). A-41

Map 30. Pima County urban-wildland interface in the local area surrounding Saguaro National Park. A-42

Map 31. Structural connectivity, based on the degree of naturalness, by Theobald et al. (in press). The relative ranks reflect the importance of areas for connectivity at a national-scale; thicker/darker lines are more important for maintaining national-level connectivity. Note that the lines are not corridors per se, but rather simplifications of how important general areas are for connectivity. A-43

Map 32. Broad-scale features enabling potential wildlife movements between Saguaro National Park and surrounding protected areas. Source data: NPScape protected areas from the World Protected Areas Database and NPScape land cover from the North American Land Change Monitoring System A-44

Forest & Grassland Area Density

Map 33. Forest density computed by NPScape using a moving window of 3.1 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on forest. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System. A-47

Map 34. Forest density computed by NPScape using a moving window of 7.6 km². A-48

Map 35. Forest density computed by NPScape using a moving window of 14.1 km². A-49

Map 36. Forest density computed by NPScape using a moving window of 45.6 km². A-50

Map 37. Forest density computed by NPScape using a moving window of 95.1 km². A-51

Map Appendix (continued)

Page

Forest & Grassland Area Density (continued)

Map 38. Grassland density computed by NPScape using a moving window of 3.1 km ² . Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on grassland. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.	A-52
Map 39. Grassland density computed by NPScape using a moving window of 7.6 km ²	A-53
Map 40. Grassland density computed by NPScape using a moving window of 14.1 km ²	A-54
Map 41. Grassland density computed by NPScape using a moving window of 45.6 km ²	A-55
Map 42. Grassland density computed by NPScape using a moving window of 95.1 km ²	A-56

Lightning

Map 43. Annual flash rate (number of flashes per km ² per year) for Saguaro National Park and ecoregional vicinity.	A-59
Map 44. Monthly flash rate (number of flashes per km ² per month; September through June when there is little to no flash activity) for Saguaro National Park and ecoregional vicinity.	A-60
Map 45. Monthly flash rate (number of flashes per km ² per month; July, when flash activity is modest) for Saguaro National Park and ecoregional vicinity.	A-61
Map 46. Monthly flash rate (number of flashes per km ² per month; August, when flash activity is at a peak) for Saguaro National Park and ecoregional vicinity.	A-62

Renewable Energy

Map 47. Wind speeds at 50 m above ground for Saguaro National Park and ecoregional vicinity.	A-65
Map 48. Wind speeds at 50 m above ground in the local area surrounding Saguaro National Park.	A-66
Map 49. Average annual direct normal solar resource in the local area surrounding Saguaro National Park	A-67
Map 50. Geothermal favorability, ranked qualitatively based on 12 USGS logistic regression models that correlate different geological and geophysical factors to the known presence of moderate (90 - 150° C) to high (> 150° C) temperature geothermal resources in the western United States (http://pubs.usgs.gov/fs/2008/3082/), in the local area surrounding Saguaro National Park	A-68

Map Appendix (continued)

	Page
Vulnerable Species	
Map 51. Habitat suitability model for the needle-spined pineapple cactus, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential	A-71
Map 52. Habitat suitability model for the Pima pineapple cactus, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-72
Map 53. Habitat suitability model for the Gentry indigobush, a vulnerable plant species in Pima County, ranked according to high, medium, and low habitat potential.	A-73
Map 54. Habitat suitability model for the Huachuca water umbel, a vulnerable aquatic plant species in Pima County, ranked according to high, medium, and low habitat potential.	A-74
Map 55. Habitat suitability model for the Tumamoc globeberry, a vulnerable plant species in Pima County, ranked according to high, medium, and low habitat potential	A-75
Map 56. Habitat suitability model for the desert pupfish, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-76
Map 57. Habitat suitability model for the Gila chub, a vulnerable fish species in Pima County, ranked according to high, medium, and low habitat potential.	A-77
Map 58. Habitat suitability model for the Gila topminnow, a vulnerable fish species in Pima County, ranked according to high, medium, and low habitat potential.	A-78
Map 59. Habitat suitability model for the longfin dace, a vulnerable fish species in Pima County, ranked according to high, medium, and low habitat potential.	A-79
Map 60. Habitat suitability model for the Sonora sucker, a vulnerable fish species in Pima County, ranked according to high, medium, and low habitat potential.	A-80
Map 61. Habitat suitability model for the desert box turtle, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-81
Map 62. Habitat suitability model for the Chiricahua leopard frog, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-82
Map 63. Habitat suitability model for the lowland leopard frog, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-83
Map 64. Habitat suitability model for the giant spotted whiptail, a vulnerable lizard species in Pima County, ranked according to high, medium, and low habitat potential.	A-84
Map 65. Habitat suitability model for the ground snake, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-85

Map Appendix (continued)

Page

Vulnerable Species (continued)

Map 66. Habitat suitability model for the Mexican garter snake, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-86
Map 67. Habitat suitability model for the Tucson shovelnose snake, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential	A-87
Map 68. Habitat suitability model for Abert's towhee, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential.	A-88
Map 69. Habitat suitability model for Bell's vireo, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential.	A-89
Map 70. Habitat suitability model for cactus ferruginous pygmy owl, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential.	A-90
Map 71. Habitat suitability model for the rufous-winged sparrow , a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential	A-91
Map 72. Habitat suitability model Swainson's hawk, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential.	A-92
Map 73. Habitat suitability model for the southwestern willow flycatcher, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential.	A-93
Map 74. Habitat suitability model for the western burrowing owl, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential	A-94
Map 75. Habitat suitability model for the yellow-billed cuckoo, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential	A-95
Map 76. Habitat suitability model for Allen's big-eared bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-96
Map 77. Habitat suitability model for the California leaf-nose bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential	A-97
Map 78. Habitat suitability model for the lesser long-nosed bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential	A-98
Map 79. Habitat suitability model for the Mexican long-tongued bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential	A-99
Map 80. Habitat suitability model for Pale Townsend' big-eared bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential	A-100

Map Appendix (continued)

	Page
Vulnerable Species (continued)	
Map 81. Habitat suitability model for the western red bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential	A-101
Map 82. Habitat suitability model for the western yellow bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-102
Map 83. Habitat suitability model for the Arizona shrew, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential.	A-103
Human Population	
Map 84. Historic and projected future trends in total population in the local area surrounding Saguaro National Park.	A-107
Map 85. Current (2005) estimates of total population in the local area surrounding Saguaro National Park	A-108
Map 86. Projected future (2040) estimates of total population in the local area surrounding Saguaro National Park.	A-109
Map 87. Number of people according to the US Census Bureau (1990) in the local area surrounding Saguaro National Park.	A-110
Map 88. Number of people according to the US Census Bureau (2000) in the local area surrounding Saguaro National Park.	A-111
Map 89. Number of people according to the US Census Bureau (2010) in the local area surrounding Saguaro National Park.	A-112
Map 90. Population density according to the US Census Bureau (1990) in the local area surrounding Saguaro National Park.	A-113
Map 91. Population density according to the US Census Bureau (2000) in the local area surrounding Saguaro National Park.	A-114
Map 92. Population density according to the US Census Bureau (2010) in the local area surrounding Saguaro National Park.	A-115
Housing	
Map 93. Number of housing units (year 2005) in the local area surrounding Saguaro National Park.	A-119
Map 94. Number of housing units (projected to the year 2040) in the local area surrounding Saguaro National Park.	A-120

Map Appendix (continued)

Page

Housing (continued)

Map 95. Housing density according to the Spatially Explicit Regional Growth Model (1970) in the local area surrounding Saguaro National Park.	A-121
Map 96. Housing density according to the Spatially Explicit Regional Growth Model (1980) in the local area surrounding Saguaro National Park.	A-122
Map 97. Housing density according to the Spatially Explicit Regional Growth Model (1990) in the local area surrounding Saguaro National Park.	A-123
Map 98. Housing density according to the Spatially Explicit Regional Growth Model (2000) in the local area surrounding Saguaro National Park.	A-124
Map 99. Housing density according to the Spatially Explicit Regional Growth Model (2010) in the local area surrounding Saguaro National Park.	A-125
Map 100. Housing density according to the Spatially Explicit Regional Growth Model (2020) in the local area surrounding Saguaro National Park.	A-126
Map 101. Housing density according to the Spatially Explicit Regional Growth Model (2030) in the local area surrounding Saguaro National Park.	A-127
Map 102. Housing density according to the Spatially Explicit Regional Growth Model (2040) in the local area surrounding Saguaro National Park.	A-128
Map 103. Housing density according to the Spatially Explicit Regional Growth Model (2050) in the local area surrounding Saguaro National Park.	A-129
Map 104. Housing density according to the Spatially Explicit Regional Growth Model (2060) in the local area surrounding Saguaro National Park.	A-130
Map 105. Housing density according to the Spatially Explicit Regional Growth Model (2070) in the local area surrounding Saguaro National Park.	A-131
Map 106. Housing density according to the Spatially Explicit Regional Growth Model (2080) in the local area surrounding Saguaro National Park	A-132
Map 107. Housing density according to the Spatially Explicit Regional Growth Model (2090) in the local area surrounding Saguaro National Park	A-133
Map 108. Housing density according to the Spatially Explicit Regional Growth Model (2100) in the local area surrounding Saguaro National Park	A-134

Roads & Transportation

Map 109. Road network in the local area surrounding Saguaro National Park	A-137
---	-------

Map Appendix (continued)

	Page
Roads & Transportation (continued)	
Map 110. Weighted road density in the local area surrounding Saguaro National Park	A-138
Map 111. Distance to the nearest road in the local area surrounding Saguaro National Park.	A-139
Map 112. Major air, road, and railroad transportation networks (public, private, and military) in the local area surrounding Saguaro National Park.	A-140
Map 113. Pima County trails and bike routes (existing, planned) in the local area surrounding Saguaro National Park.	A-141
Map 114. Pima County park and ride locations, bus lines, and bus stops in the local area surrounding Saguaro National Park	A-142
Map 115. Pima County HandiCar service areas (continued, expanded; http://dot.pima.gov/transsys/specialneeds/) in the local area surrounding Saguaro National Park.	A-143
Nighttime Lights	
Map 116. Direct observations of average visible stable nighttime lights (Defense Meteorological Satellite Program Operational Linescan System 1997) for Saguaro National Park and ecoregional vicinity.	A-147
Map 117. Direct observations of average visible stable nighttime lights (Defense Meteorological Satellite Program Operational Linescan System 2009) for Saguaro National Park and ecoregional vicinity. The 2009 sensor is different from the one used in 1997, meaning that some differences between the two maps may reflect methodological artifacts.	A-148
Map 118. The Cinzano model of nighttime lights that considers atmospheric scattering, or light pollution propagation.	A-149
Map 119. Nighttime 'ground-up' sky observations (dated 2010) and Pima County outdoor lighting area codes (dated 2011) in the local area surrounding Saguaro National Park.	A-150
Conservation Status	
Map 120. Pima County Conservation Lands System (CLS) classification in the local area surrounding Saguaro National Park.	A-153
Map 121. Major landowners and land managing agencies in the local area surrounding Saguaro National Park.	A-154

Map Appendix (continued)

Page

Conservation Status (continued)

Map 122. Multiple levels of protected areas (denoted by GAP status code, see Methods – Section 2.3.1) considered in relation to potential stressors or disturbances originating from superfund sites and active mines in the local area surrounding Saguaro National Park.	A-155
--	-------

Viewsheds

Map 123. Viewsheds from key observation points along roads in TMD.	A-159
Map 124. Viewsheds from key observation points in the front country of TMD.	A-160
Map 125. Viewsheds from key observation points along roads in RMD.	A-161
Map 126. Viewsheds from key observation points in the front country of RMD.	A-162
Map 127. Viewsheds from key observation points in the back country of RMD.	A-163

Land Use & Zoning

Map 128. City of Tucson land use (dated 1993) in the local area surrounding Saguaro National Park.	A-167
Map 129. Pima County comprehensive plan for land use intensity of unincorporated areas in the local area surrounding Saguaro National Park.	A-168
Map 130. Pima County new building permits (2010-2011) in the local area surrounding Saguaro National Park.	A-169
Map 131. Number of structures built between 1999 and March 2000 (US Census Bureau) in the local area surrounding Saguaro National Park.	A-170
Map 132. Pima County subdivisions by lot count (dated April 2011) in the local area surrounding Saguaro National Park.	A-171
Map 133. Pima County parcels by size in the local area surrounding Saguaro National Park	A-172
Map 134. Pima County real property inventory, areas with development plans, historic districts, and annexation boundaries in the local area surrounding Saguaro National Park	A-173
Map 135. City of Tucson neighborhood associations (dated 2007) in the local area surrounding Saguaro National Park	A-174
Map 136. City of Tucson area plan (dated 2000) in the local area surrounding Saguaro National Park	A-175

Map Appendix (continued)

	Page
Land Use & Zoning (continued)	
Map 137. Pima County incorporated and unincorporated zoning jurisdictions (dated 2007) in the local area surrounding Saguaro National Park	A-176
Socioeconomics	
Map 138. Number of Asian Americans (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-179
Map 139. Number of Blacks (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-180
Map 140. Number of Hispanics (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-181
Map 141. Number of Native Americans (US Census Bureau 2000) in the local area surrounding Saguaro National Park	A-182
Map 142. Number of Whites (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-183
Map 143. Density of Asian Americans (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-184
Map 144. Density of Blacks (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-185
Map 145. Density of Hispanics (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-186
Map 146. Density of Native Americans (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-187
Map 147. Density of Whites (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-188
Map 148. Median age (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-189
Map 149. Number of 4 year olds and under (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-190
Map 150. Number of 5 to 19 year olds (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-191
Map 151. Number of 21 year olds and older (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-192

Map Appendix (continued)

Page

Socioeconomics (continued)

Map 152. Number of 65 year olds and older (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-193
Map 153. Density of 4 year olds and under (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-194
Map 154. Density of 5 to 19 year olds (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-195
Map 155. Density of 21 year olds and older (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-196
Map 156. Density of 65 year olds and older (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-197
Map 157. Number of people who have received no schooling (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-198
Map 158. Number of people who completed middle and part of high school (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-199
Map 159. Number of high school graduates (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-200
Map 160. Number of people with a Bachelor's education (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-201
Map 161. Density of people who have received no schooling (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-202
Map 162. Density of people who completed middle and part of high school (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-203
Map 163. Density of high school graduates (US Census Bureau 2000) in the local area surrounding Saguaro National Park	A-204
Map 164. Density of people with a Bachelor's education (US Census Bureau 2000) in the local area surrounding Saguaro National Park	A-205
Map 165. Pima County elementary schools, elementary school districts, and school district blocks in the local area surrounding Saguaro National Park	A-206
Map 166. Pima County middle schools, middle school districts, and school district blocks in the local area surrounding Saguaro National Park	A-207
Map 167. Pima County high schools, high school districts, and school district blocks in the local area surrounding Saguaro National Park	A-208

Map Appendix (continued)

Page

Socioeconomics (continued)

Map 168. Number of school children, grades 1 through 8 (year 2005) in the local area surrounding Saguaro National Park	A-209
Map 169. Number of school children, grades 1 through 8 (projected to the year 2040) in the local area surrounding Saguaro National Park.	A-210
Map 170. Number of school children, grades 9 through 12 (year 2005) in the local area surrounding Saguaro National Park.	A-211
Map 171. Number of school children, grades 9 through 12 (projected to the year 2040) in the local area surrounding Saguaro National Park.	A-212
Map 172. Average household size of owner-occupied units (US Census Bureau 2000) in the local area surrounding Saguaro National Park	A-213
Map 173. Average household size of renter-occupied units (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-214
Map 174. Number of homeowners whose monthly costs as a percentage of household income is 35% or more (US Census Bureau 2000).	A-215
Map 175. Number of tenants whose gross rent as a percentage of household income is 35% or more (US Census Bureau 2000).	A-216
Map 176. Density of homeowners whose monthly costs as a percentage of household income is 35% or more (US Census Bureau 2000).	A-217
Map 177. Density of tenants whose gross rent as a percentage of household income is 35% or more (US Census Bureau 2000).	A-218
Map 178. Number of families below poverty (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-219
Map 179. Percentage of families below poverty (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-220
Map 180. Number of people employed (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-221
Map 181. Number of people unemployed (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-222
Map 182. Density of people employed (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-223
Map 183. Density of people unemployed (US Census Bureau 2000) in the local area surrounding Saguaro National Park.	A-224

Map Appendix (continued)

Page

Socioeconomics (continued)

Map 184. Number of people employed (year 2005) in the local area surrounding Saguaro National Park. A-225

Map 185. Number of people employed (projected to the year 2040) in the local area surrounding Saguaro National Park. A-226

Map 186. Per capita income in the year 1999 (US Census Bureau 2000) in the local area surrounding Saguaro National Park. A-227

Map 187. Mean income (year 2005) in the local area surrounding Saguaro National Park. A-228

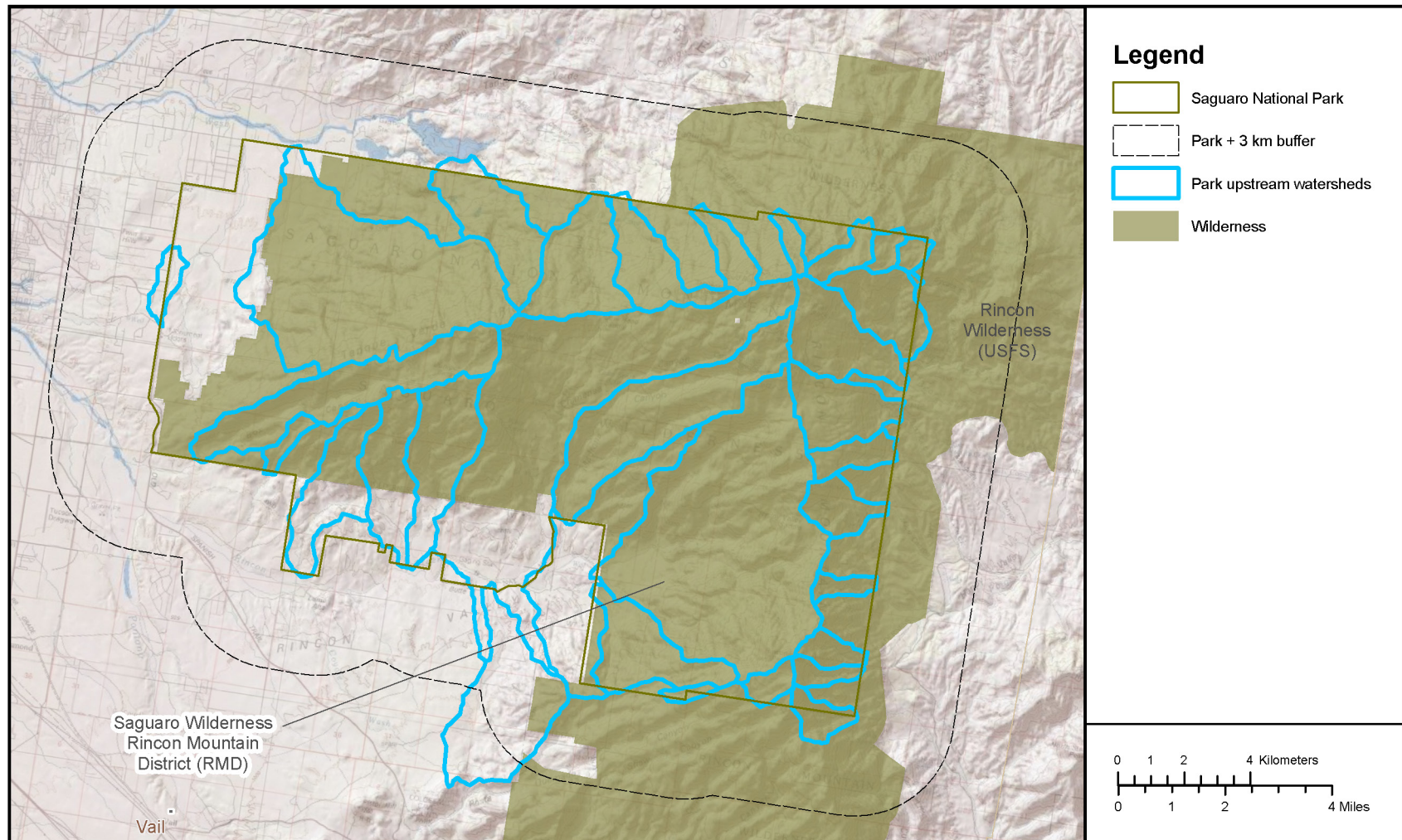
Map 188. Mean income (projected to the year 2040) in the local area surrounding Saguaro National Park. A-229

Map 189. Median structure value (US Census Bureau 2000) in the local area surrounding Saguaro National Park. A-230

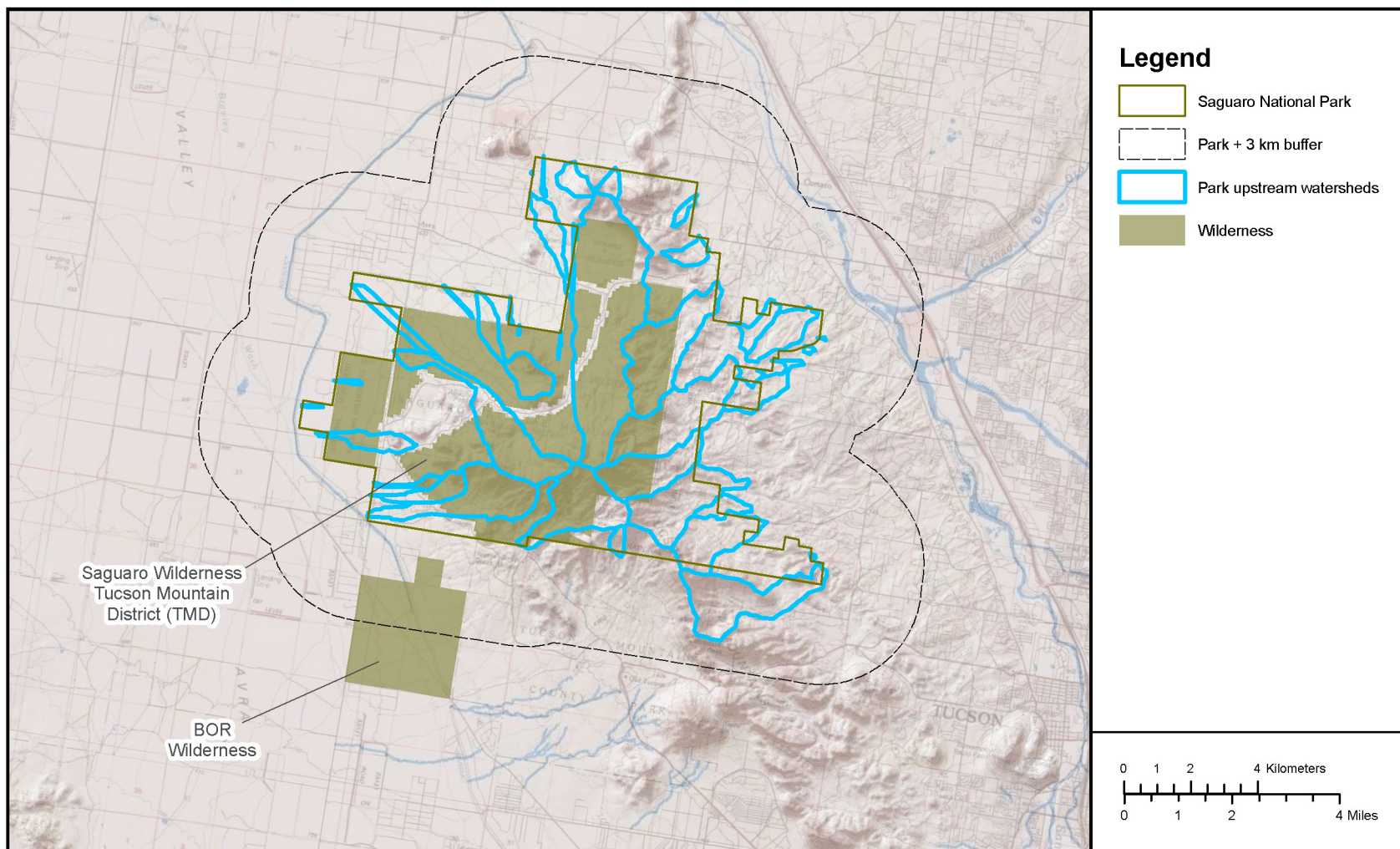
Map 190. Popular and modern cultural attractions in the Tucson area. A-231

Map Appendix

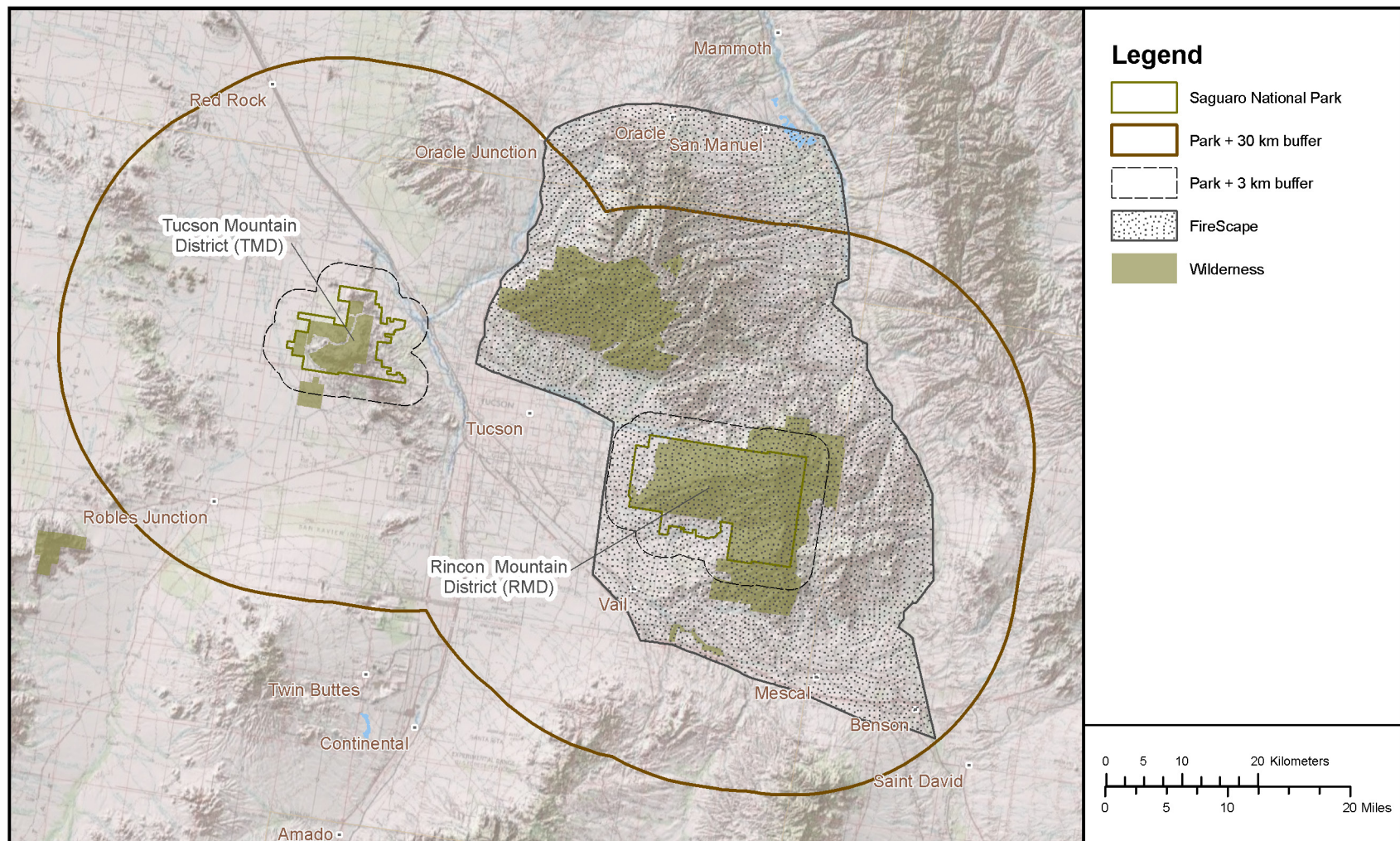
Areas of Analysis (AOAs)



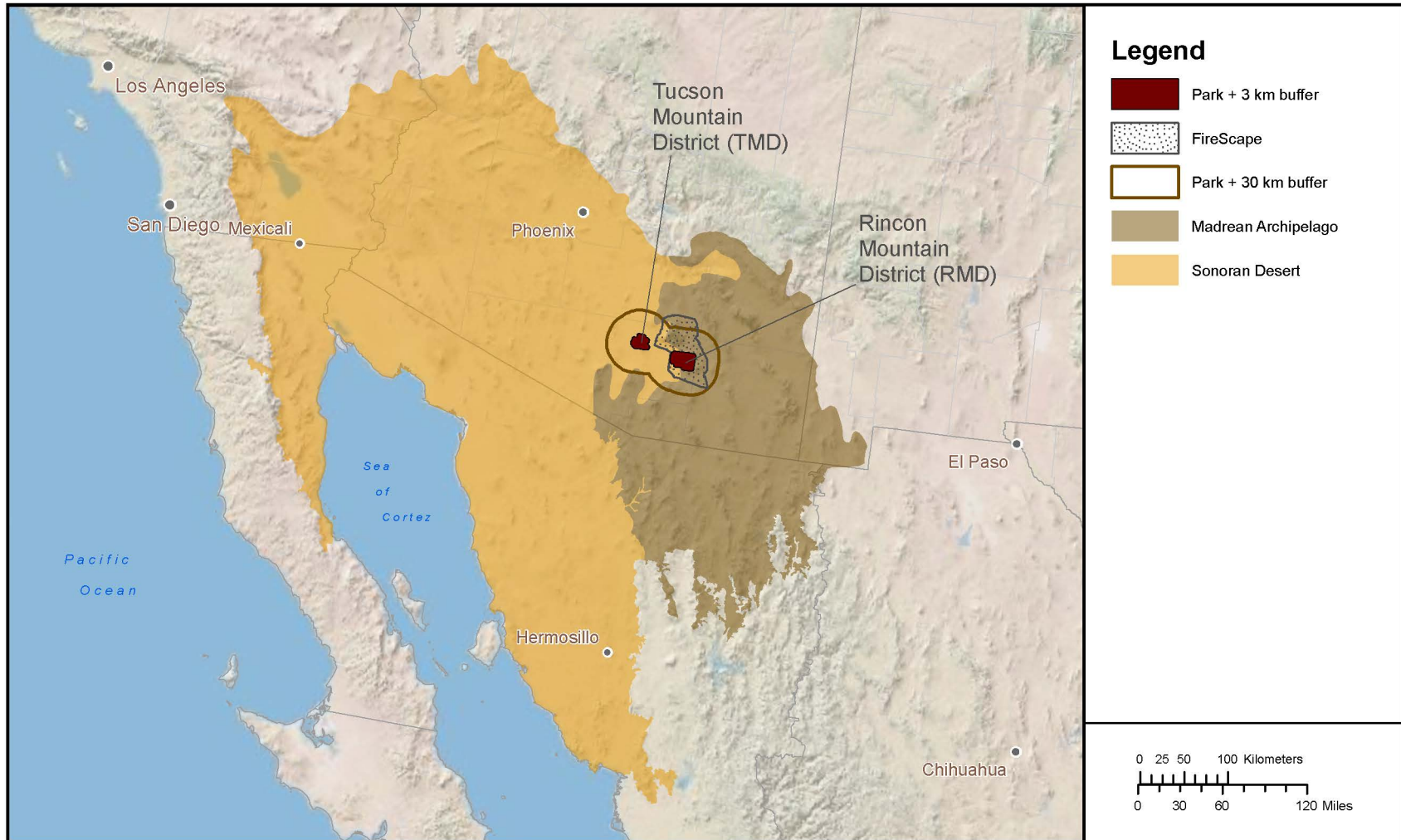
Map 1. Areas of analysis (AOAs) at the scale of Rincon Mountain District (RMD) – Saguaro National Park East. As reference, the area of RMD + 3 km buffer is 526 km².



Map 2. Areas of analysis (AOAs) at the scale of Tucson Mountain District (TMD) – Saguaro National Park West. As reference, the area of TMD + 3 km buffer is 306 km².

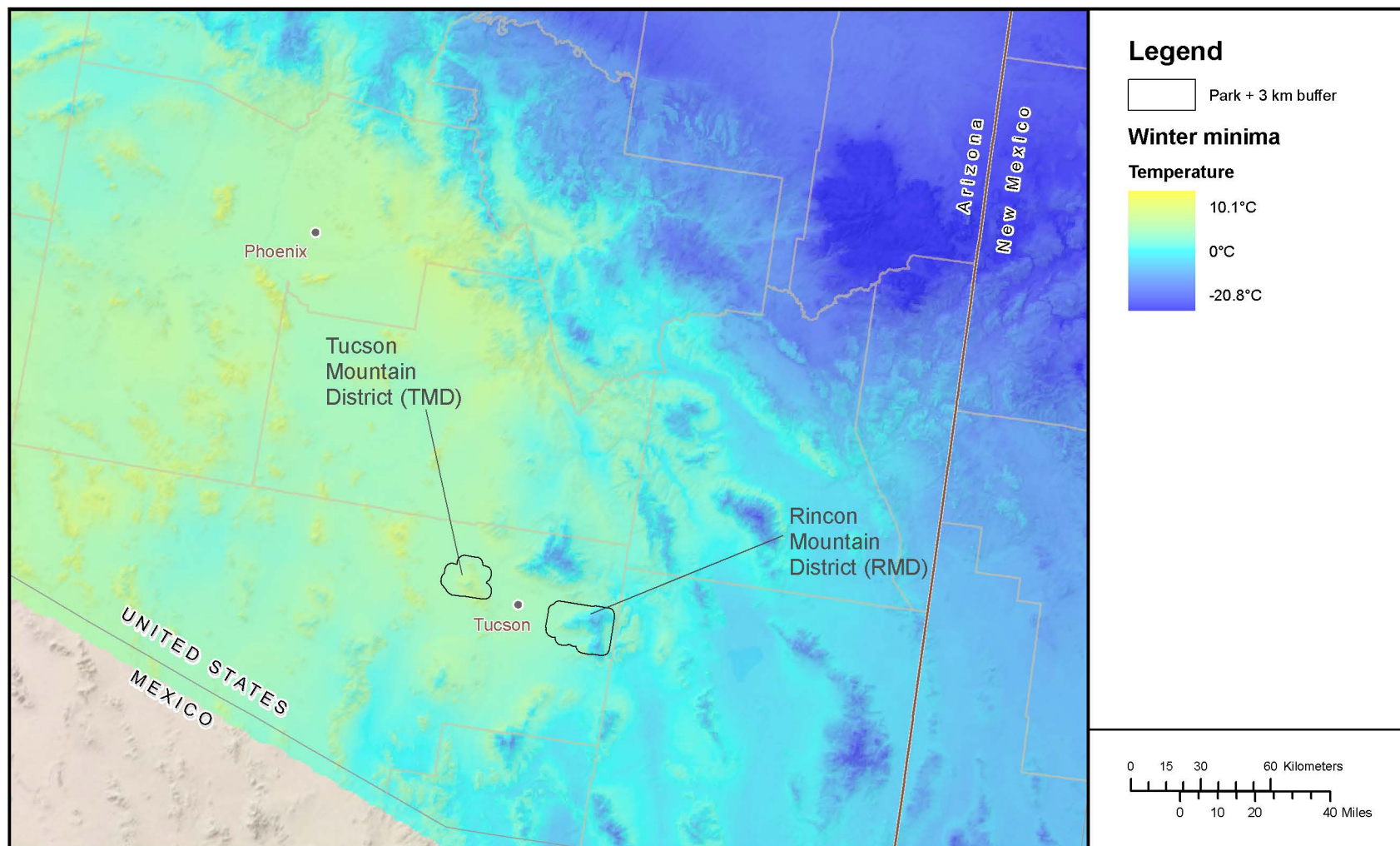


Map 3. Areas of analysis (AOAs) at the scale of Saguaro National Park – Rincon and Tucson Mountain Districts combined. As reference, the area of the Park + 30 km buffer is 8,437 km²; the area of FireScape is 3,136 km².

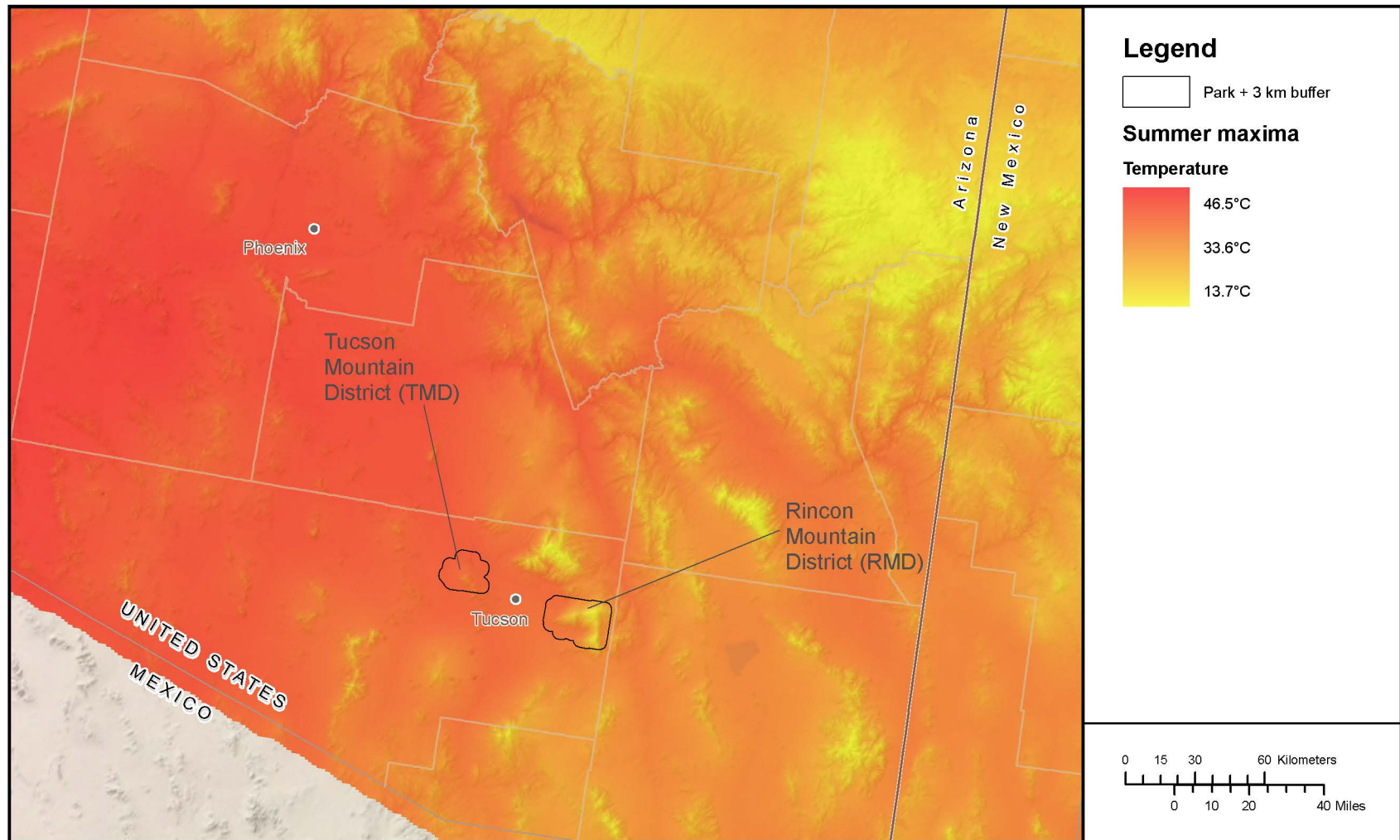


Map 4. Areas of analysis (AOAs) at the scale of the Madrean Archipelago and Sonoran Desert ecoregions. As reference, the area of the Sonoran Desert ecoregion is 217,929 km²; the area of the Madrea Archipelago ecoregion is 74,689 km².

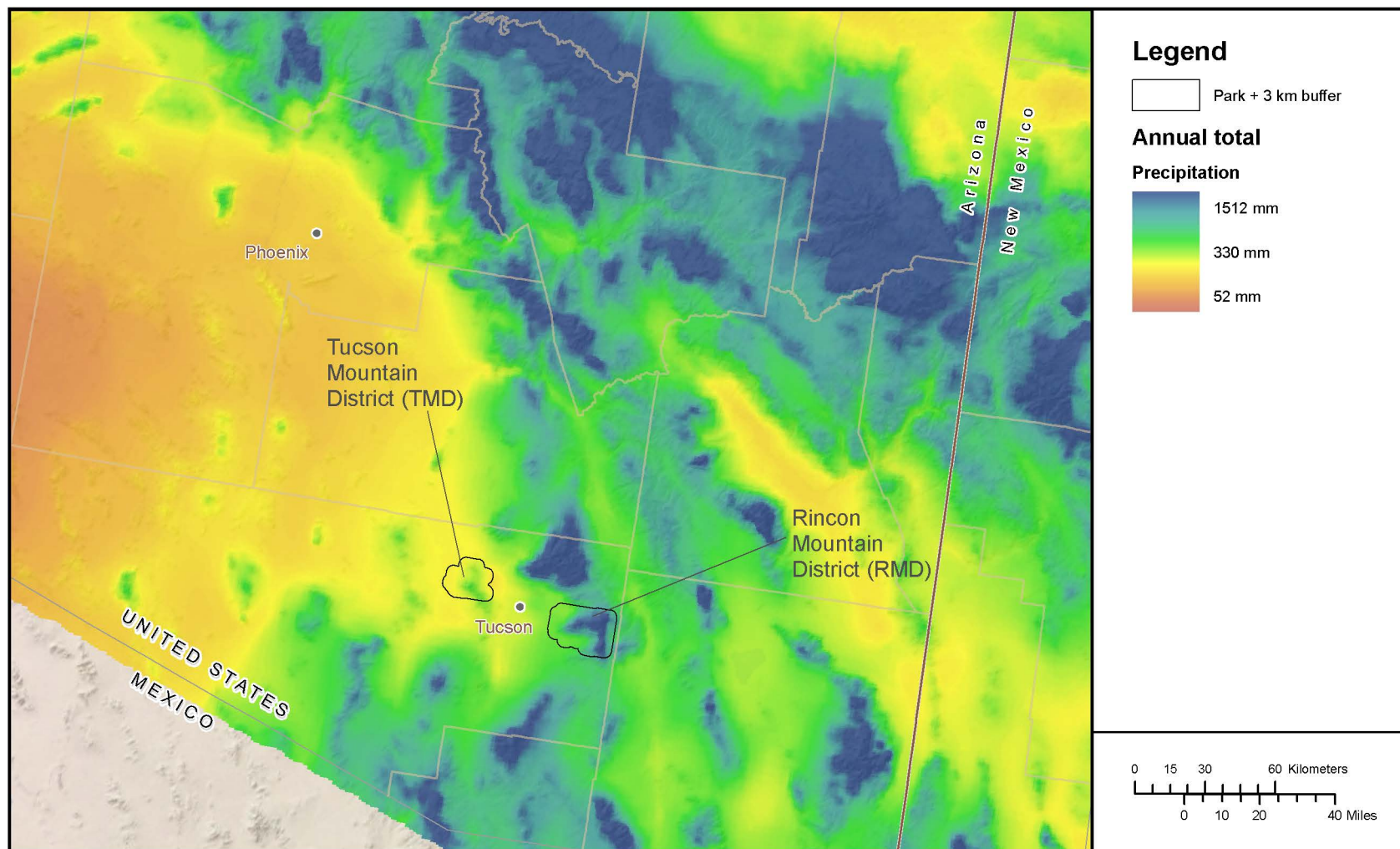
Climate



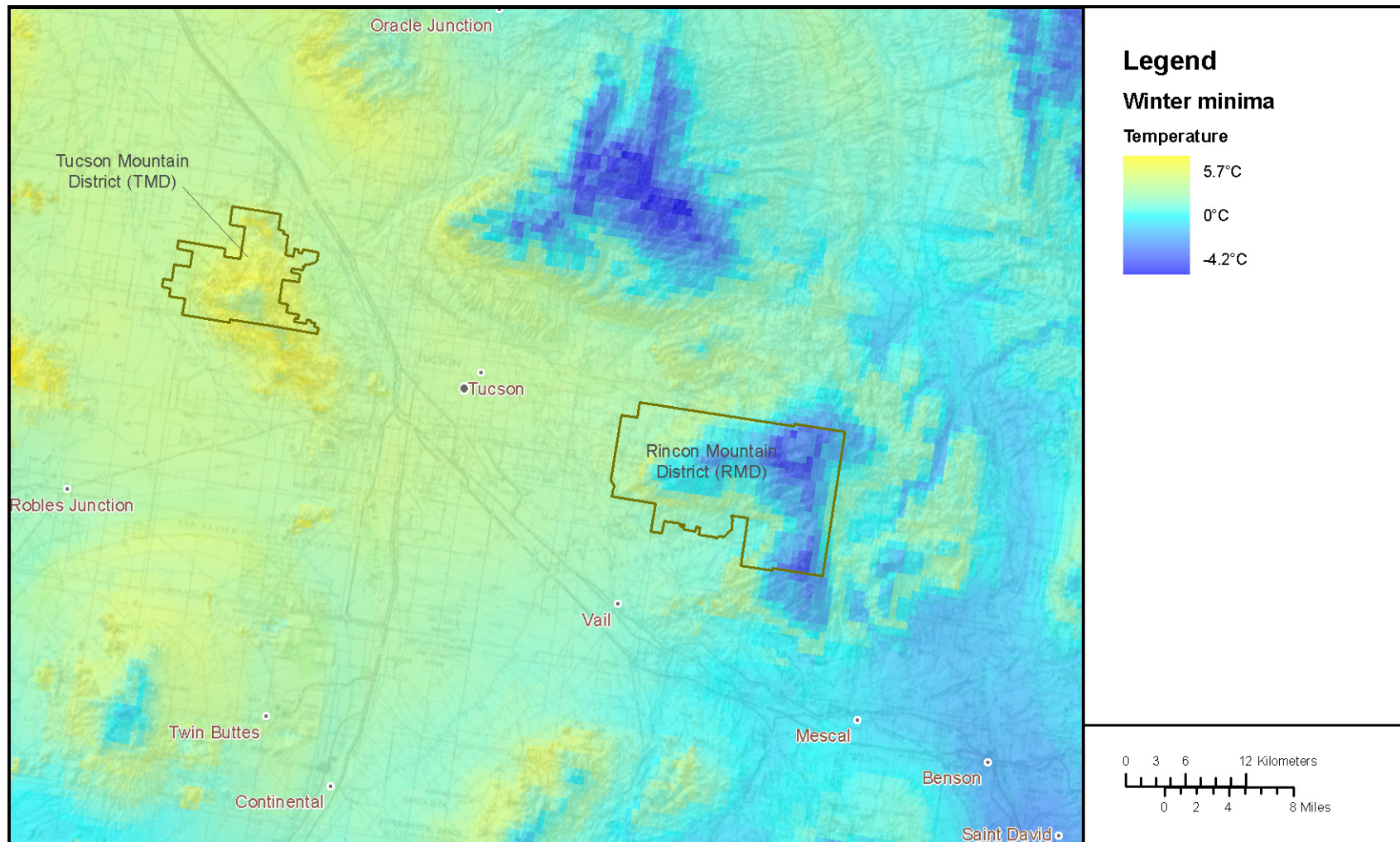
Map 5. Minimum temperature of the coldest month (1970-2000 normals) for Saguaro National Park and ecoregional vicinity. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = -20.8°C and maximum = 10.1°C.



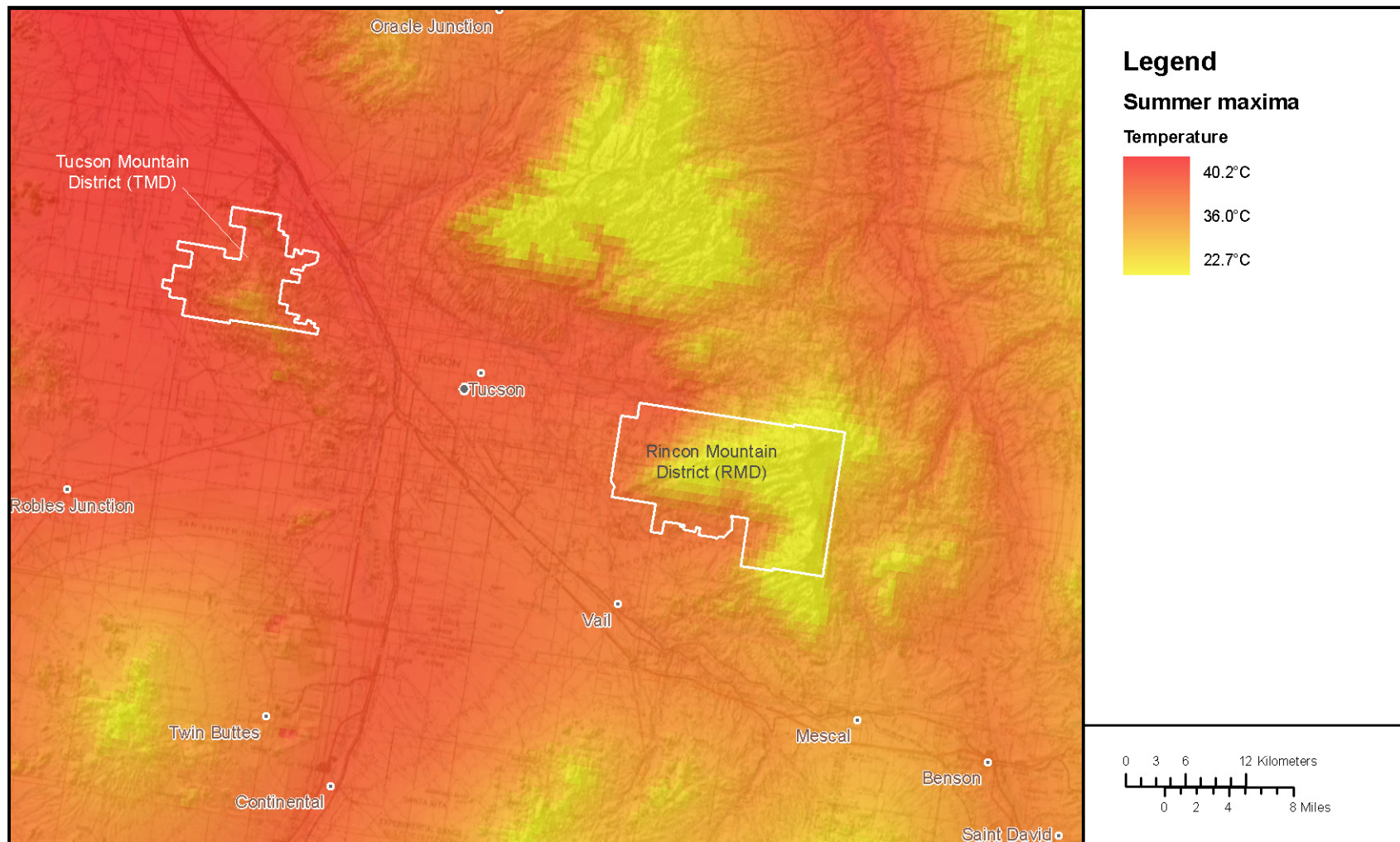
Map 6. Maximum temperature of the warmest month (1970-2000 normals) for Saguaro National Park and ecoregional vicinity. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = 13.7°C and maximum = 46.5°C.



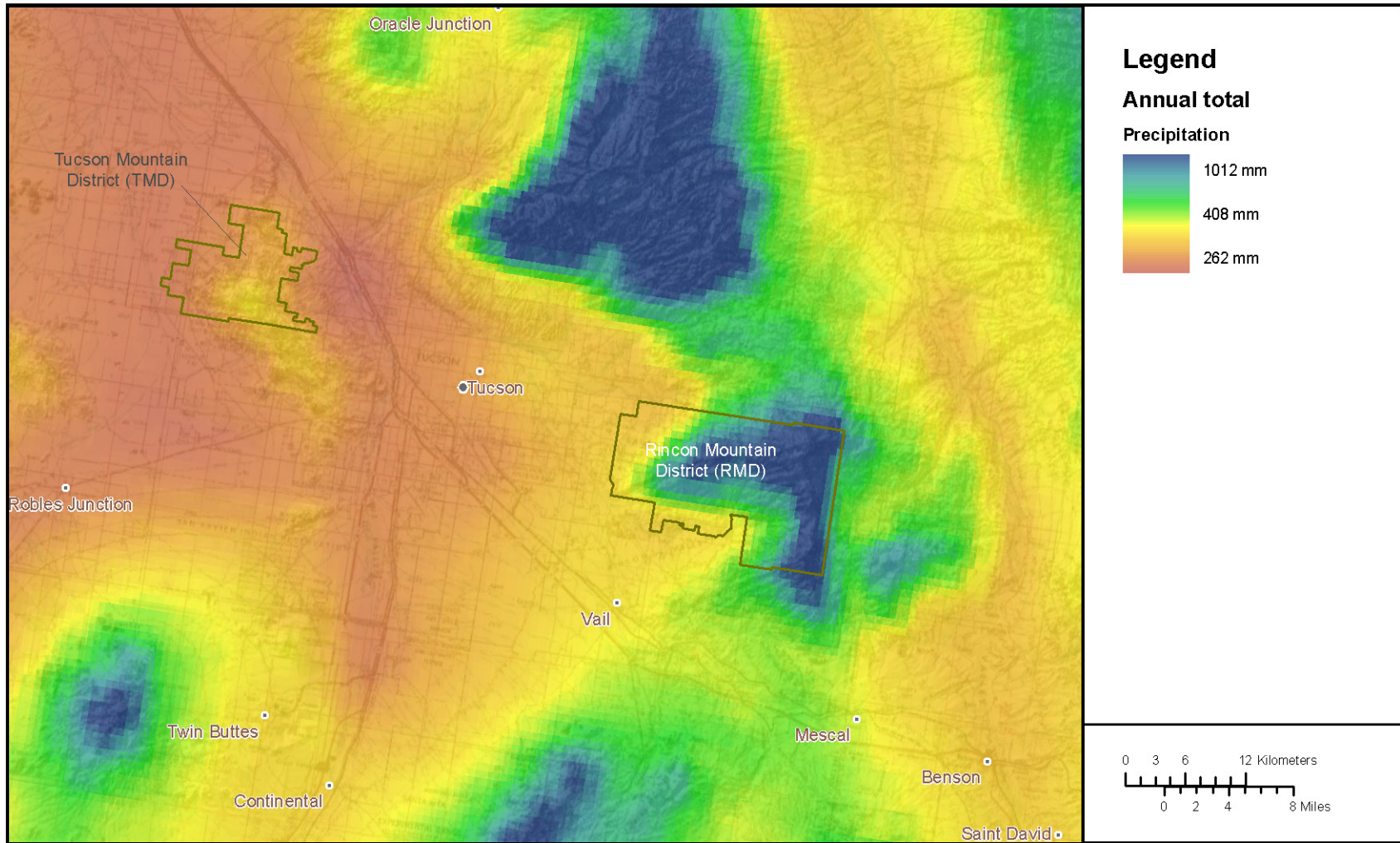
Map 7. Total annual precipitation (1970-2000 normals) for Saguaro National Park and ecoregional vicinity. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = 52 mm and maximum = 1512 mm.



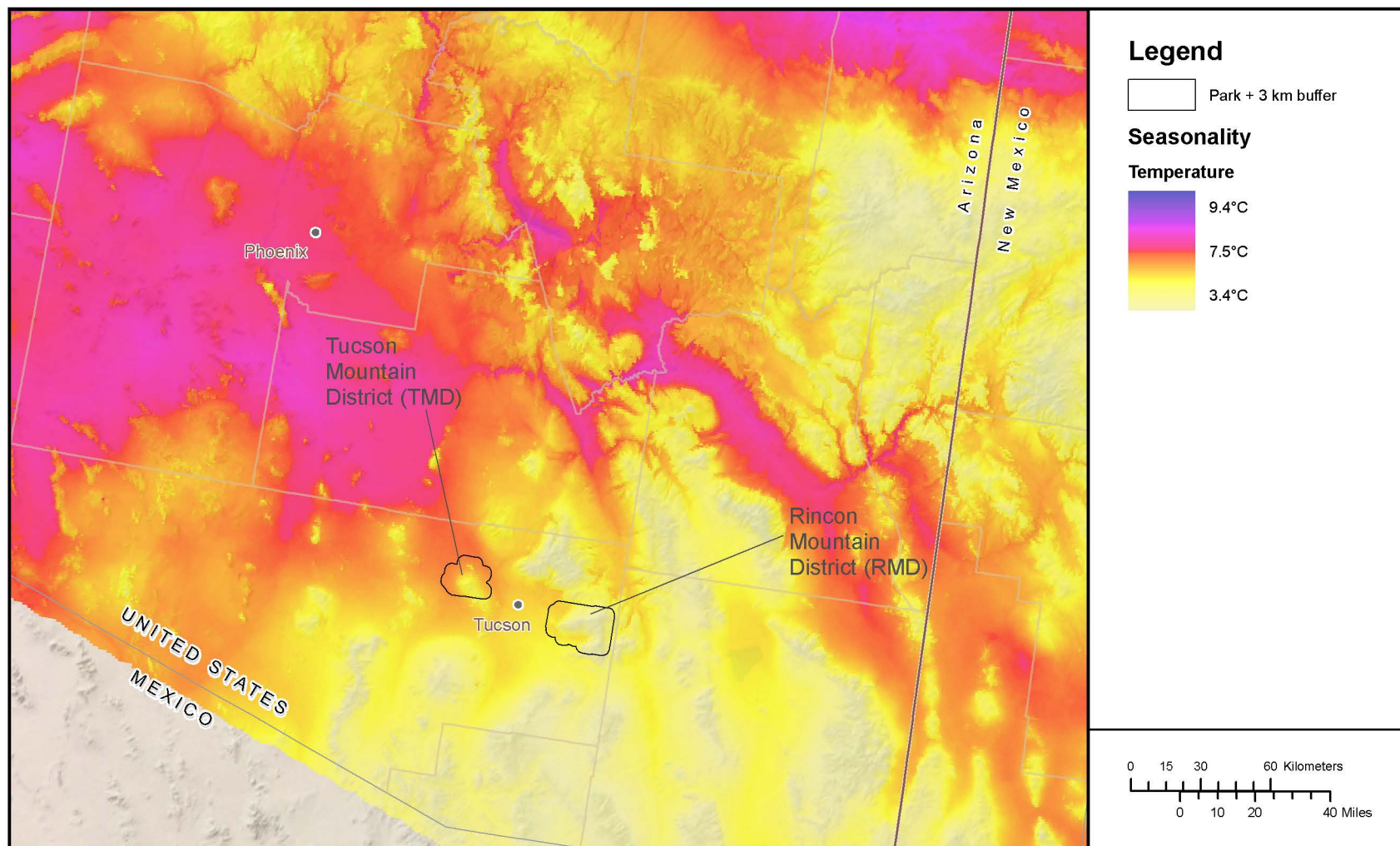
Map 8. Minimum temperature of the coldest month (1970-2000 normals) in the local area surrounding Saguaro National Park. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = -4.2°C and maximum = 5.7°C.



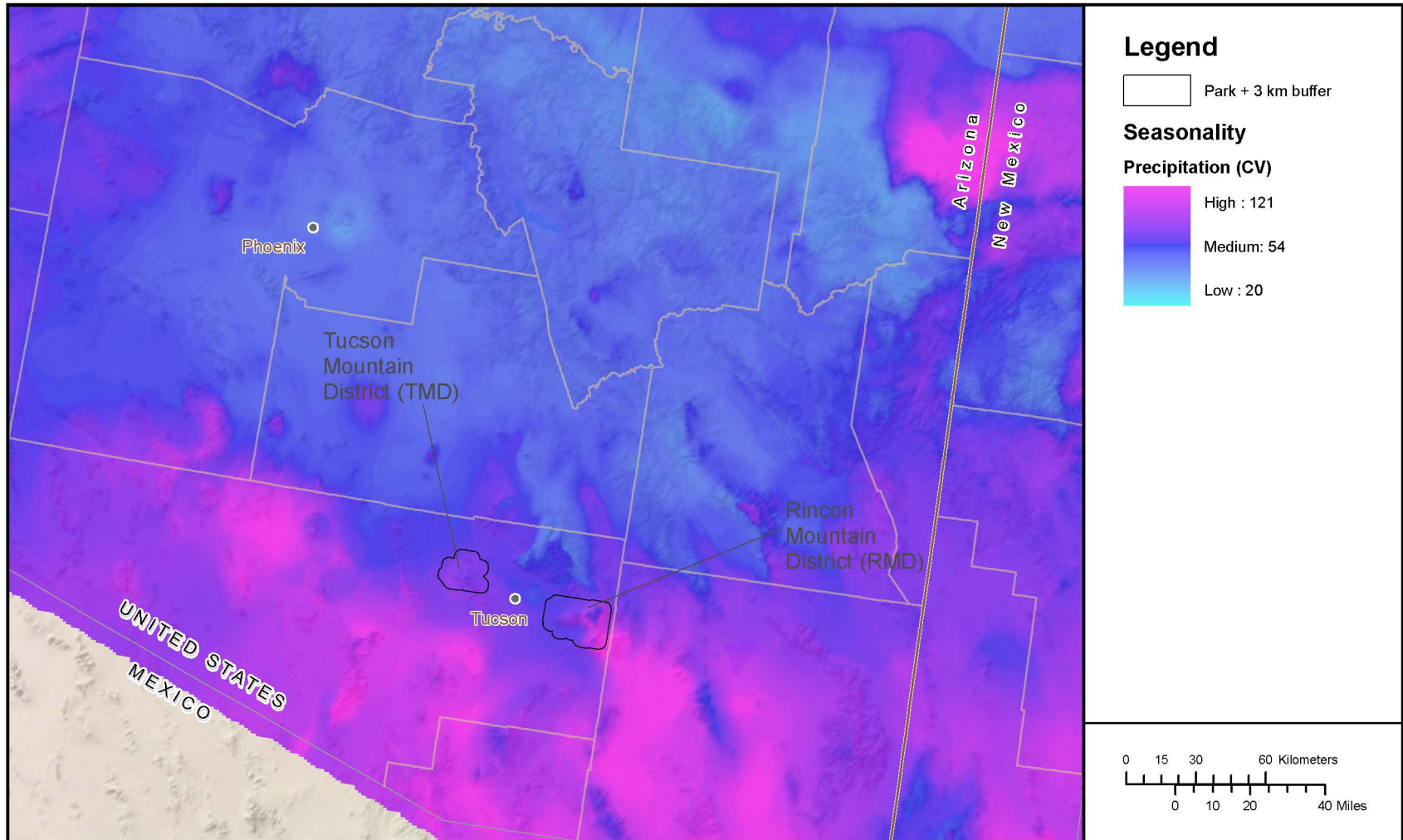
Map 9. Maximum temperature of the warmest month (1970-2000 normals) in the local area surrounding Saguaro National Park. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = 22.7°C and maximum = 40.2°C.



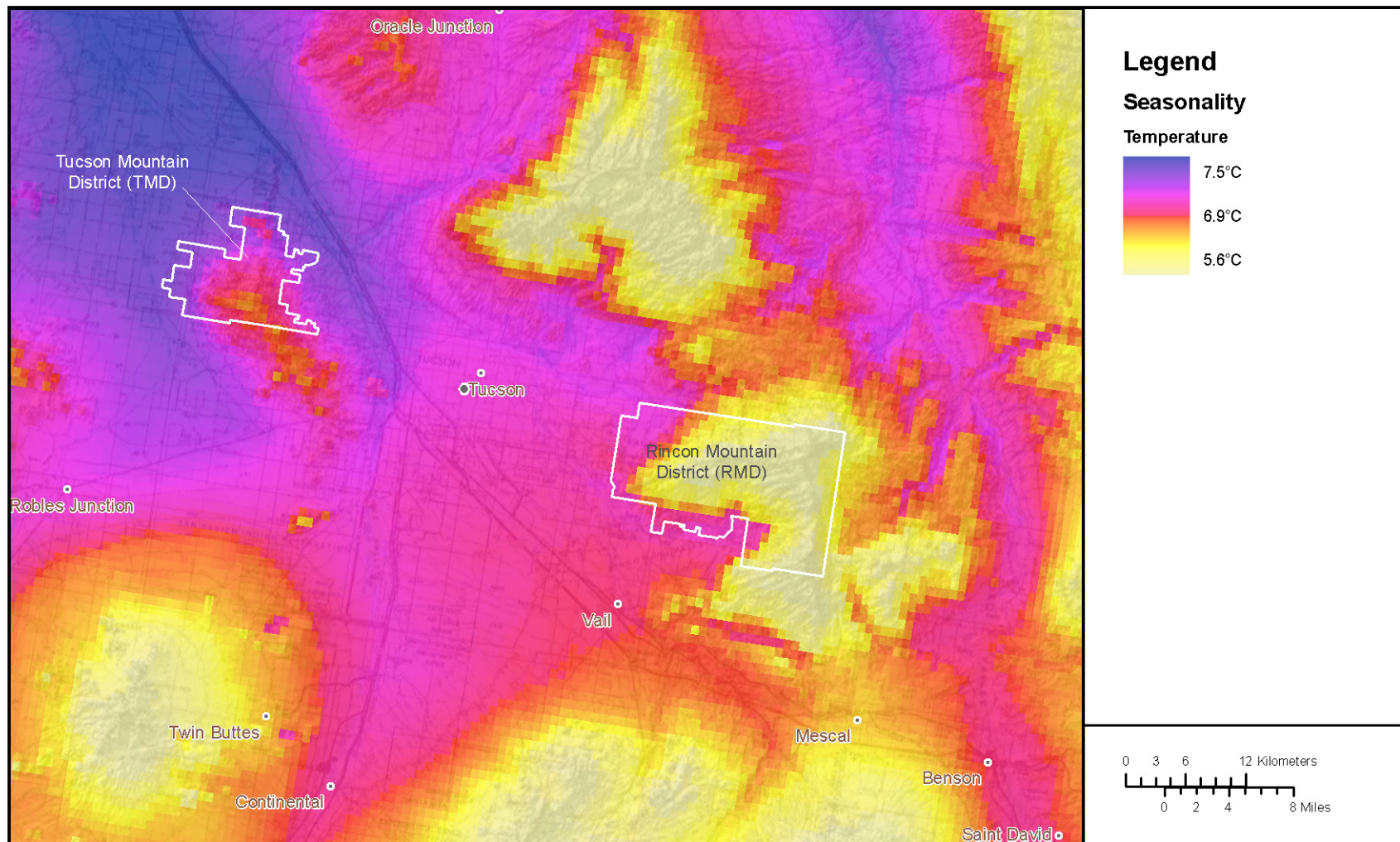
Map 10. Total annual precipitation (1970-2000 normals) in the local area surrounding Saguaro National Park. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = 262 mm and maximum = 1012 mm.



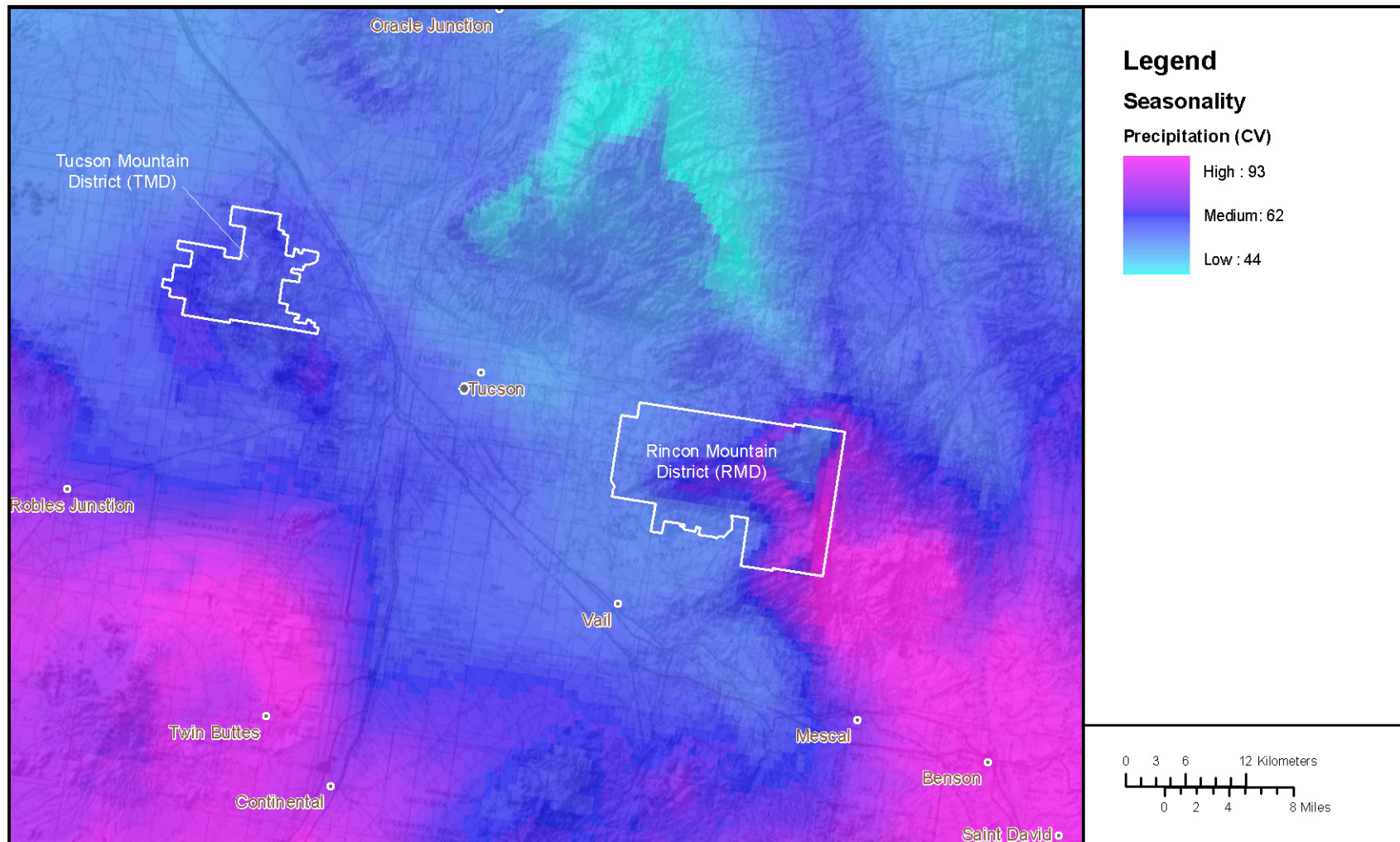
Map 11. Temperature seasonality (standard deviation in monthly mean temperatures, based on 1970-2000 normals) for Saguaro National Park and ecoregional vicinity. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = 3.4°C and maximum = 9.4°C.



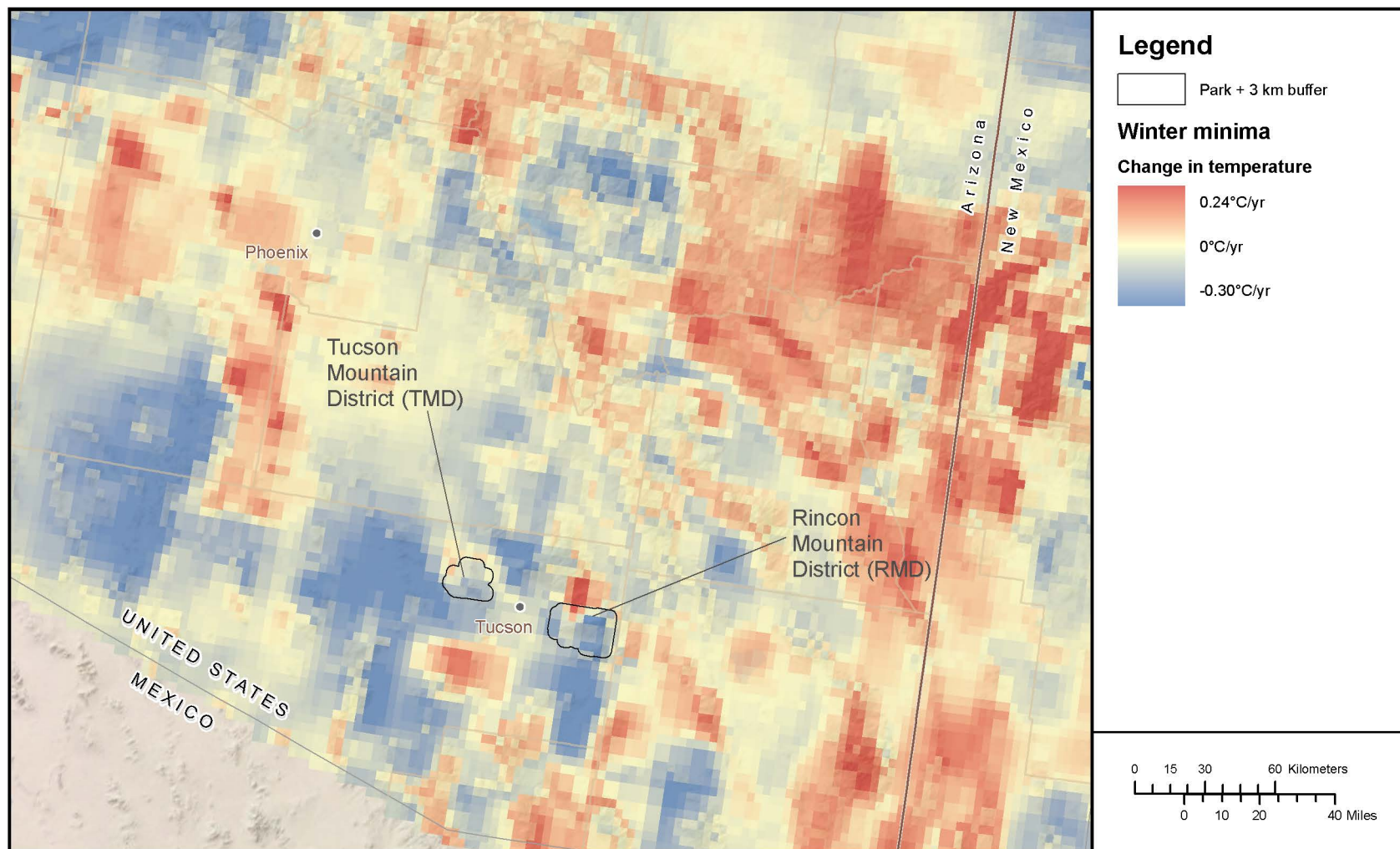
Map 12. Precipitation seasonality (coefficient of variation in monthly precipitation, based on 1970-2000 normals) for Saguaro National Park and ecoregional vicinity. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = 20 and maximum = 121.



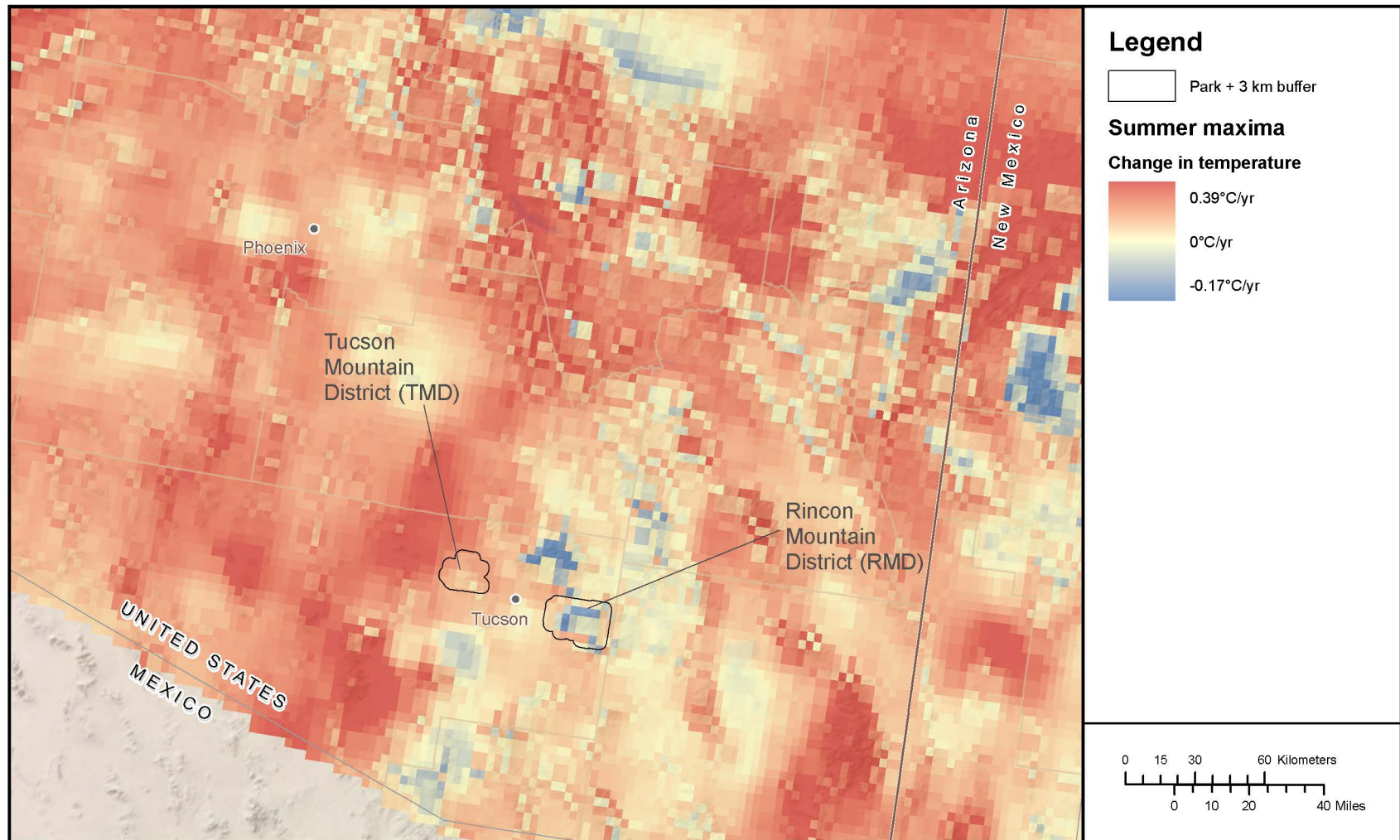
Map 13. Temperature seasonality (standard deviation in monthly mean temperatures, based on 1970-2000 normals) in the local area surrounding Saguaro National Park. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = 5.6°C and maximum = 7.5°C.



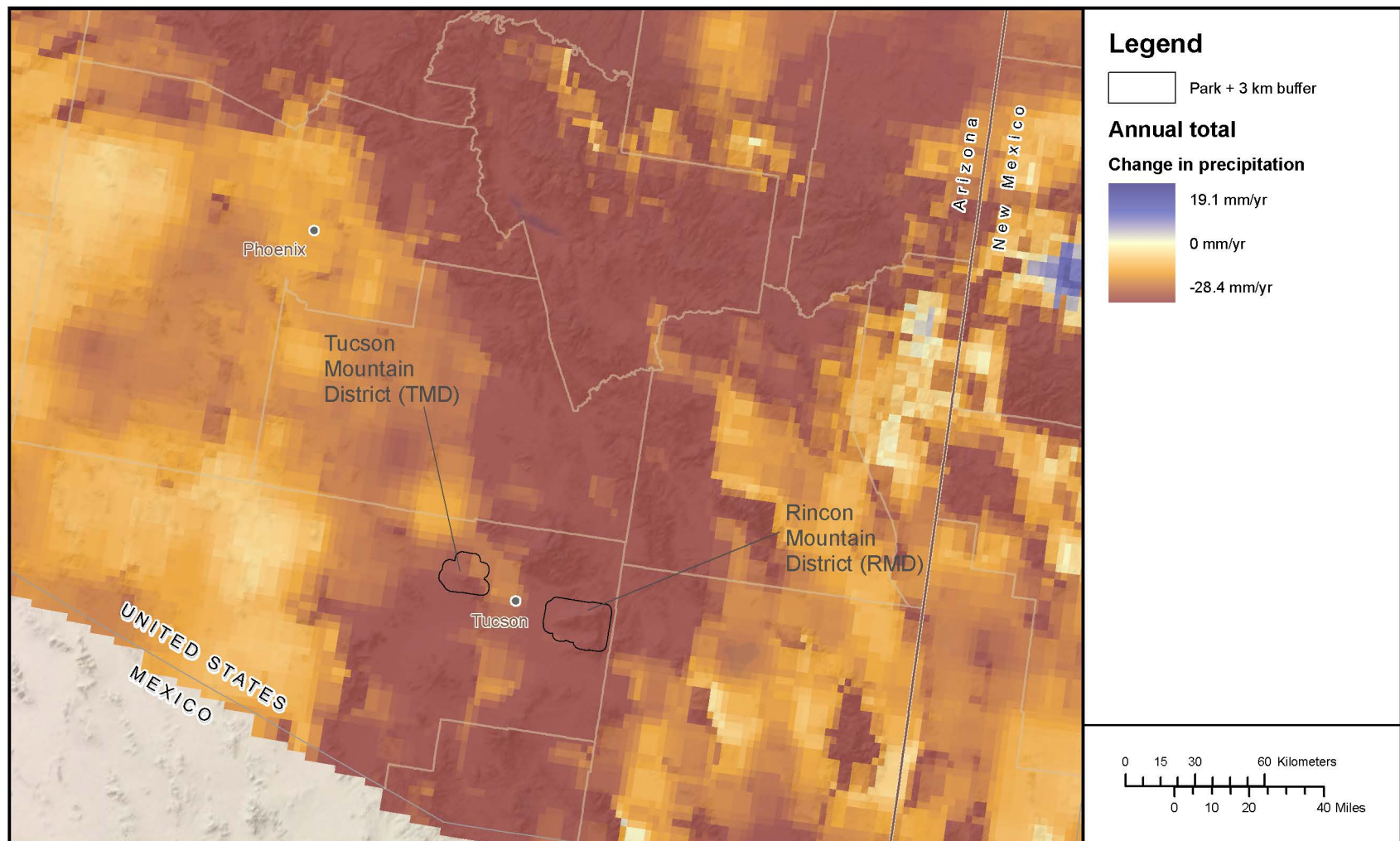
Map 14. Precipitation seasonality (coefficient of variation in monthly precipitation, based on 1970-2000 normals) in the local area surrounding Saguaro National Park. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = 44 and maximum = 93.



Map 15. Change in minimum temperature of the coldest month per year (1980-2010) for Saguaro National Park and ecoregional vicinity. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = -0.30°C/yr and maximum = 0.24°C/yr.

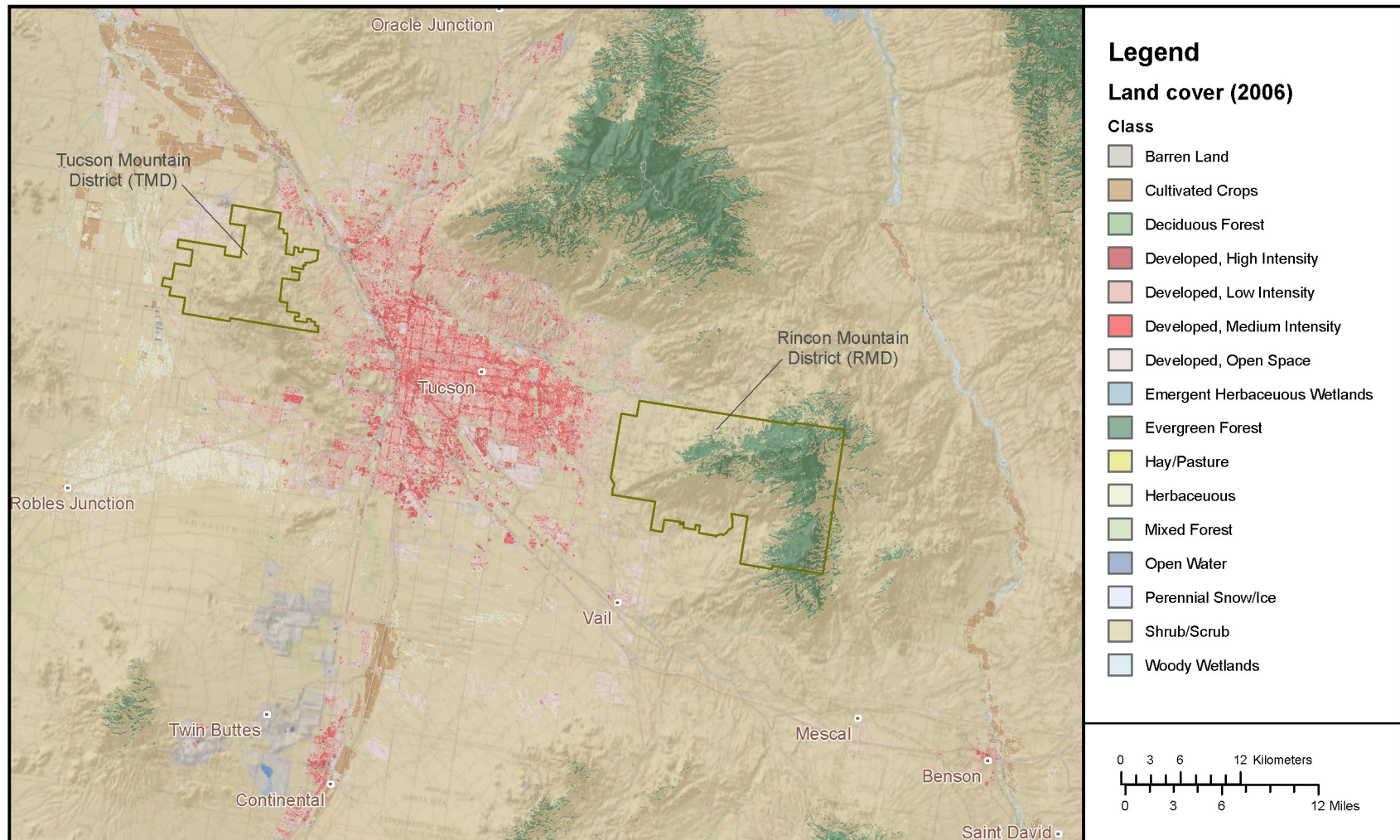


Map 16. Change in maximum temperature of the warmest month per year (1980-2010) for Saguaro National Park and ecoregional vicinity. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = -0.17°C/yr and maximum = 0.39°C/yr.

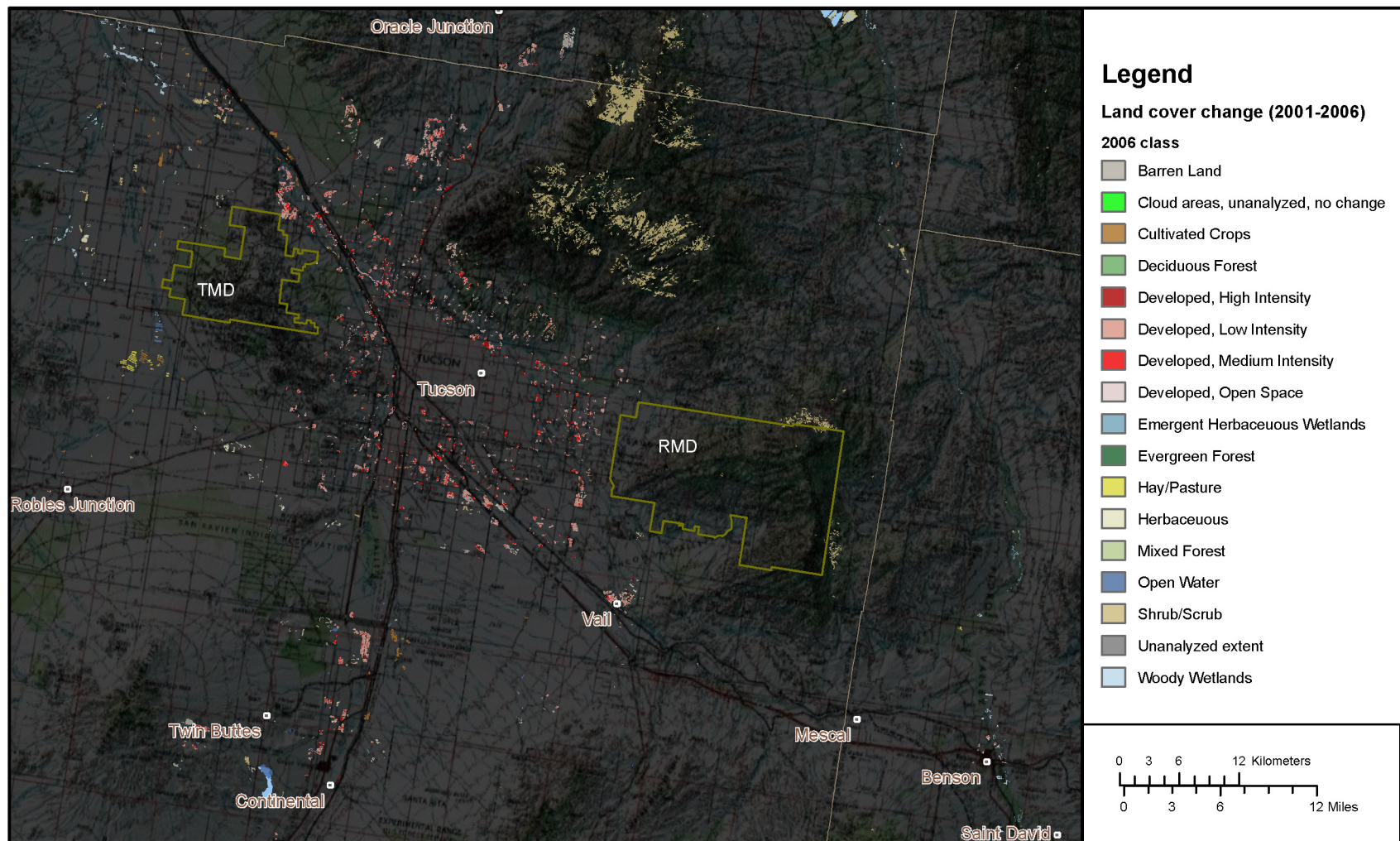


Map 17. Change in total annual precipitation per year (1980-2010) for Saguaro National Park and ecoregional vicinity. Source climate data obtained from PRISM (<http://www.prism.oregonstate.edu/>). In map extent, minimum = -28.4°C/yr and maximum = 19.1°C/yr.

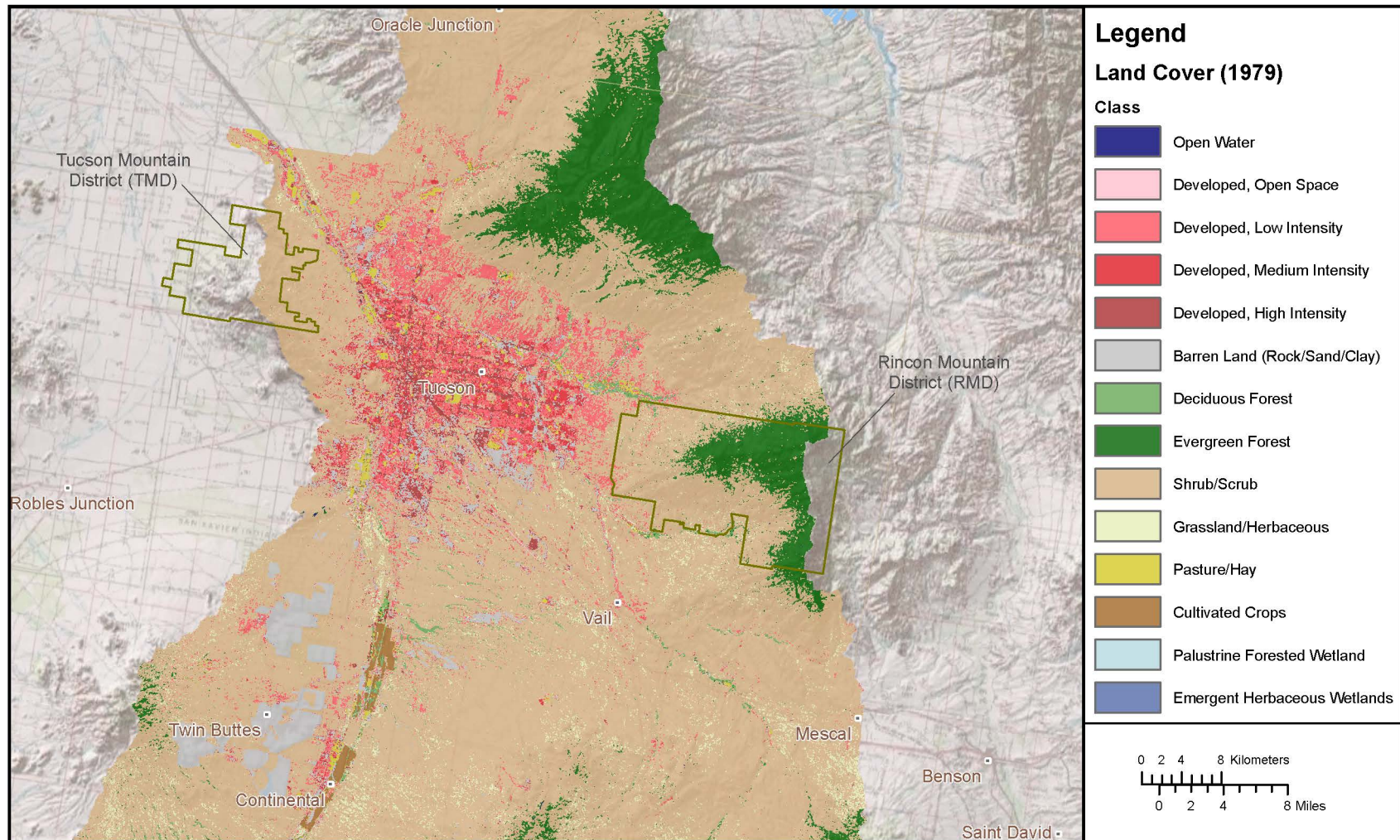
Land Cover



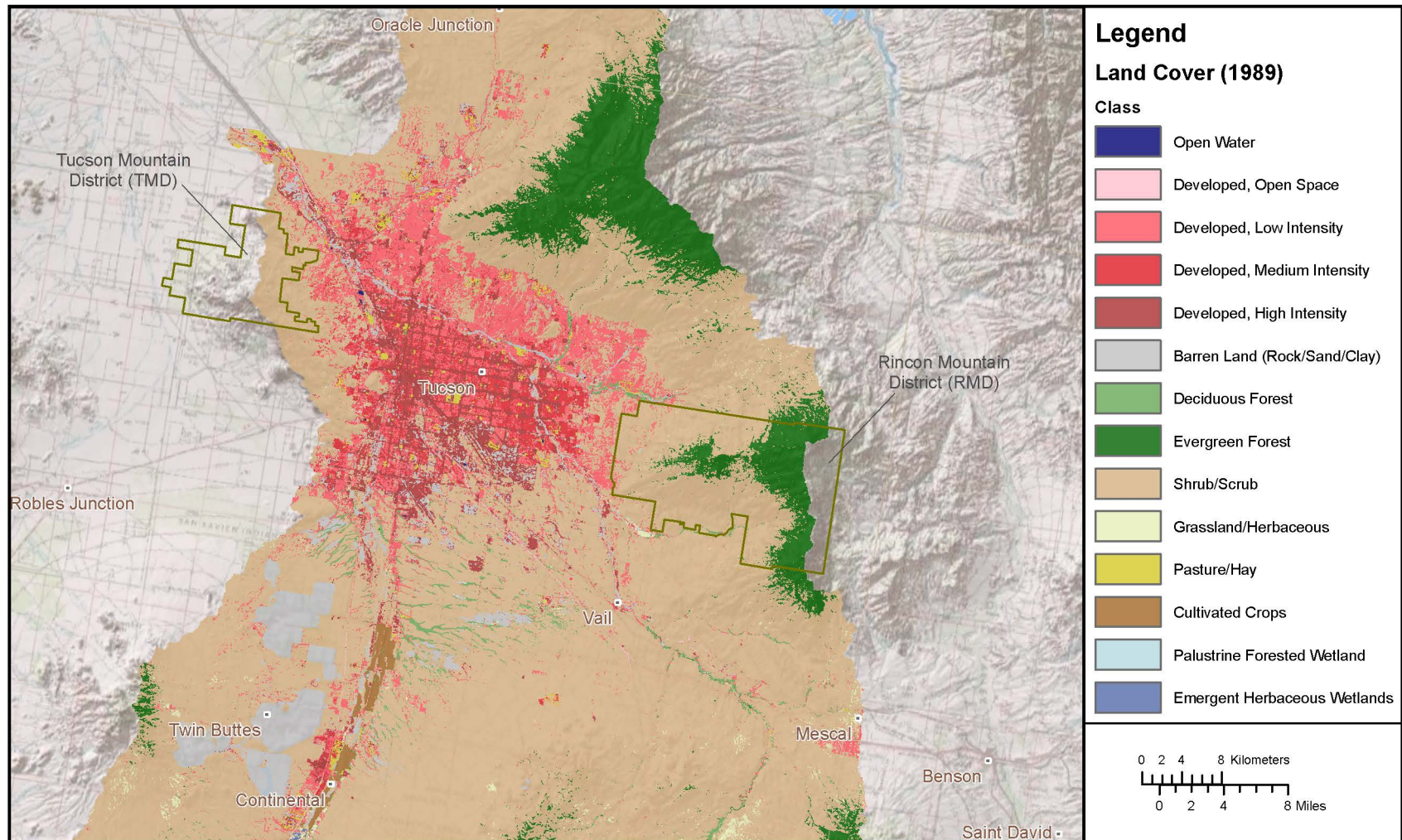
Map 18. Land cover (Anderson level II, National Land Cover Dataset 2006) in the local area surrounding Saguaro National Park. Data provided through NPScape.



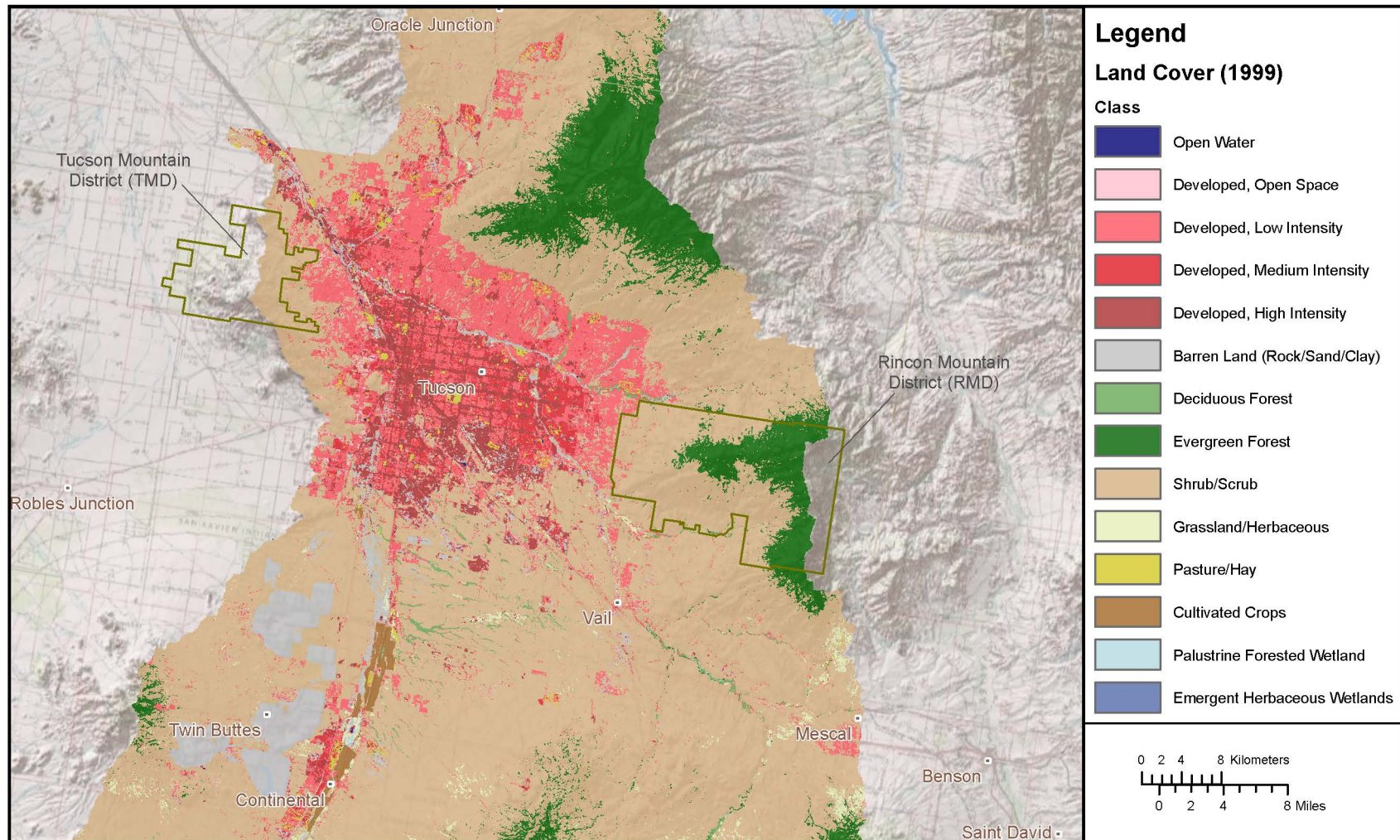
Map 19. Land cover change (Anderson level II, National Land Cover Dataset, 2001 to 2006), shown in relation to the 2006 “changed to” land cover class, in the local area surrounding Saguaro National Park. Data provided through NPScape.



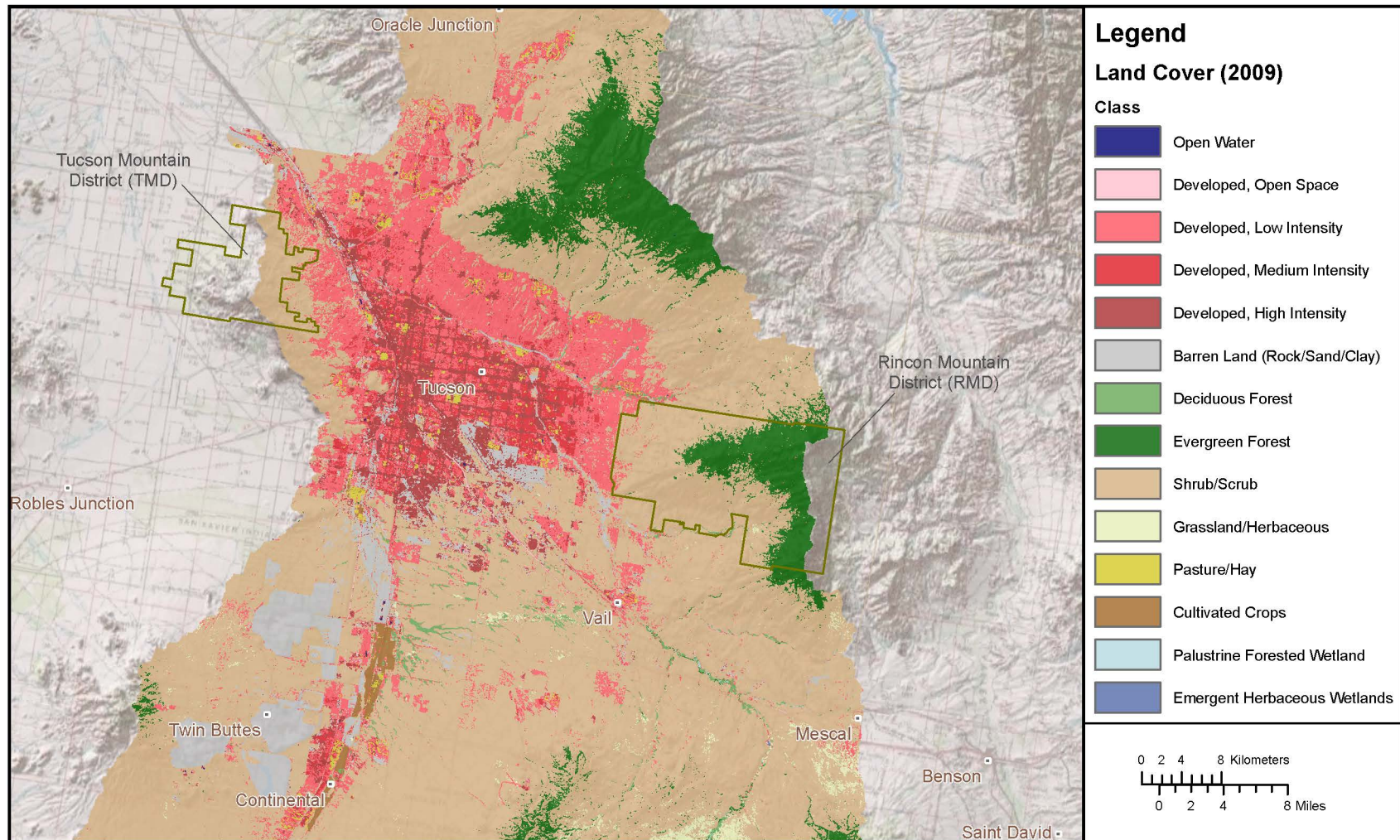
Map 20. Land cover (Anderson level II, year 1979) in the local area surrounding Saguaro National Park. Data obtained for the Santa Cruz watershed (only) from Villarreal et al. (2011): <http://pubs.usgs.gov/of/2011/1131/>.



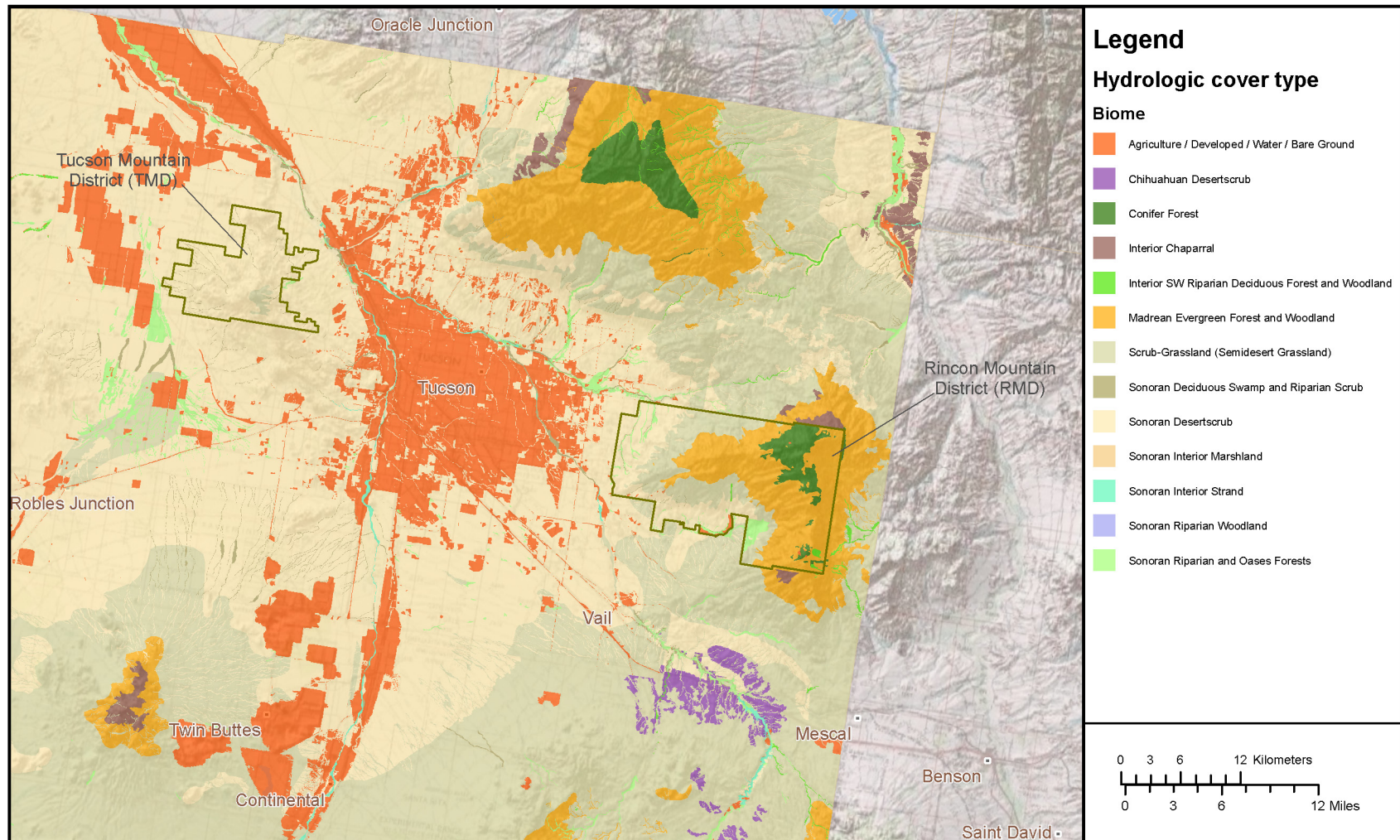
Map 21. Land cover (Anderson level II, year 1989) in the local area surrounding Saguaro National Park. Data obtained for the Santa Cruz watershed (only) from Villarreal et al. (2011): <http://pubs.usgs.gov/of/2011/1131/>.



Map 22. Land cover (Anderson level II, year 1999) in the local area surrounding Saguaro National Park. Data obtained for the Santa Cruz watershed (only) from Villarreal et al. (2011): <http://pubs.usgs.gov/of/2011/1131/>.

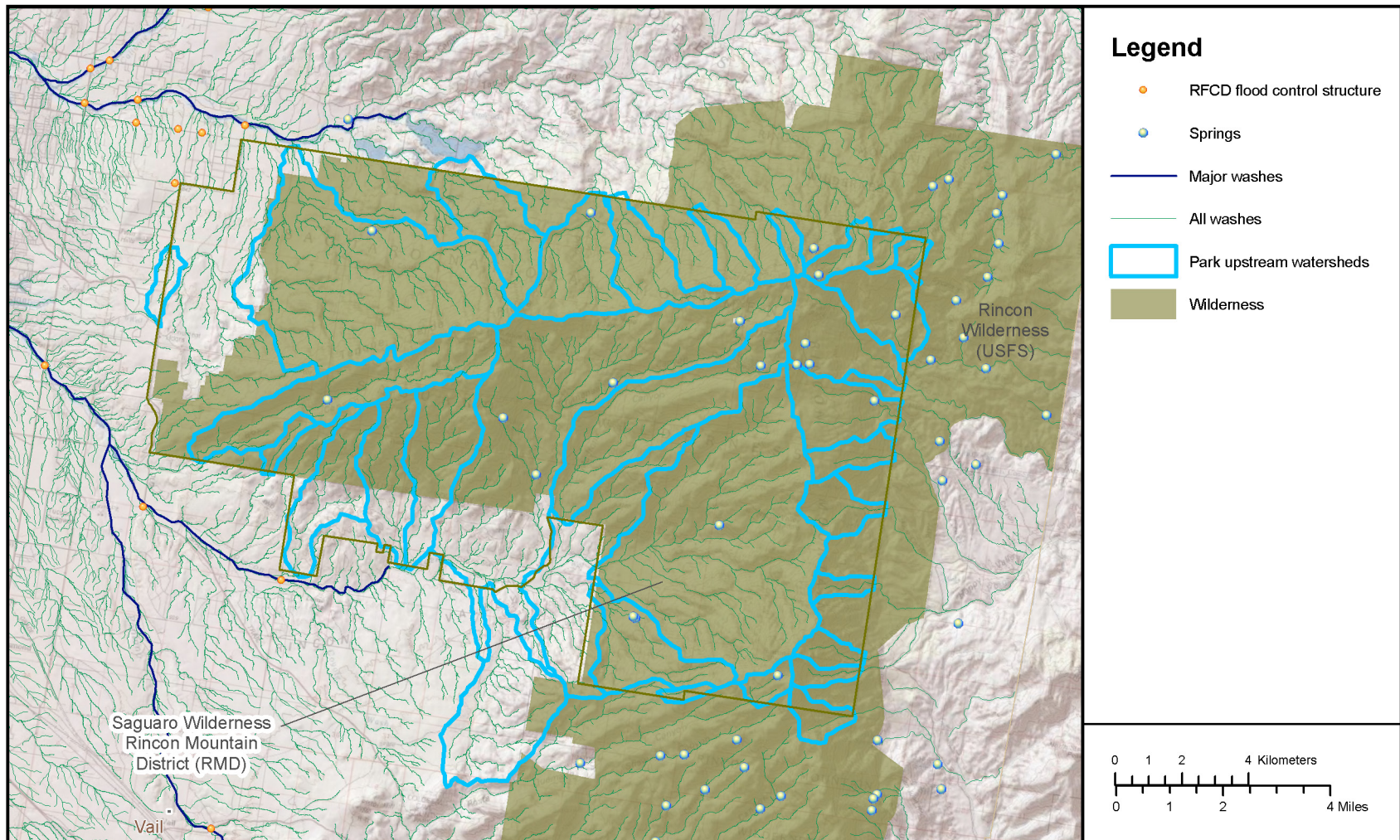


Map 23. Land cover (Anderson level II, year 2009) in the local area surrounding Saguaro National Park. Data obtained for the Santa Cruz watershed (only) from Villarreal et al. (2011): <http://pubs.usgs.gov/of/2011/1131/>.

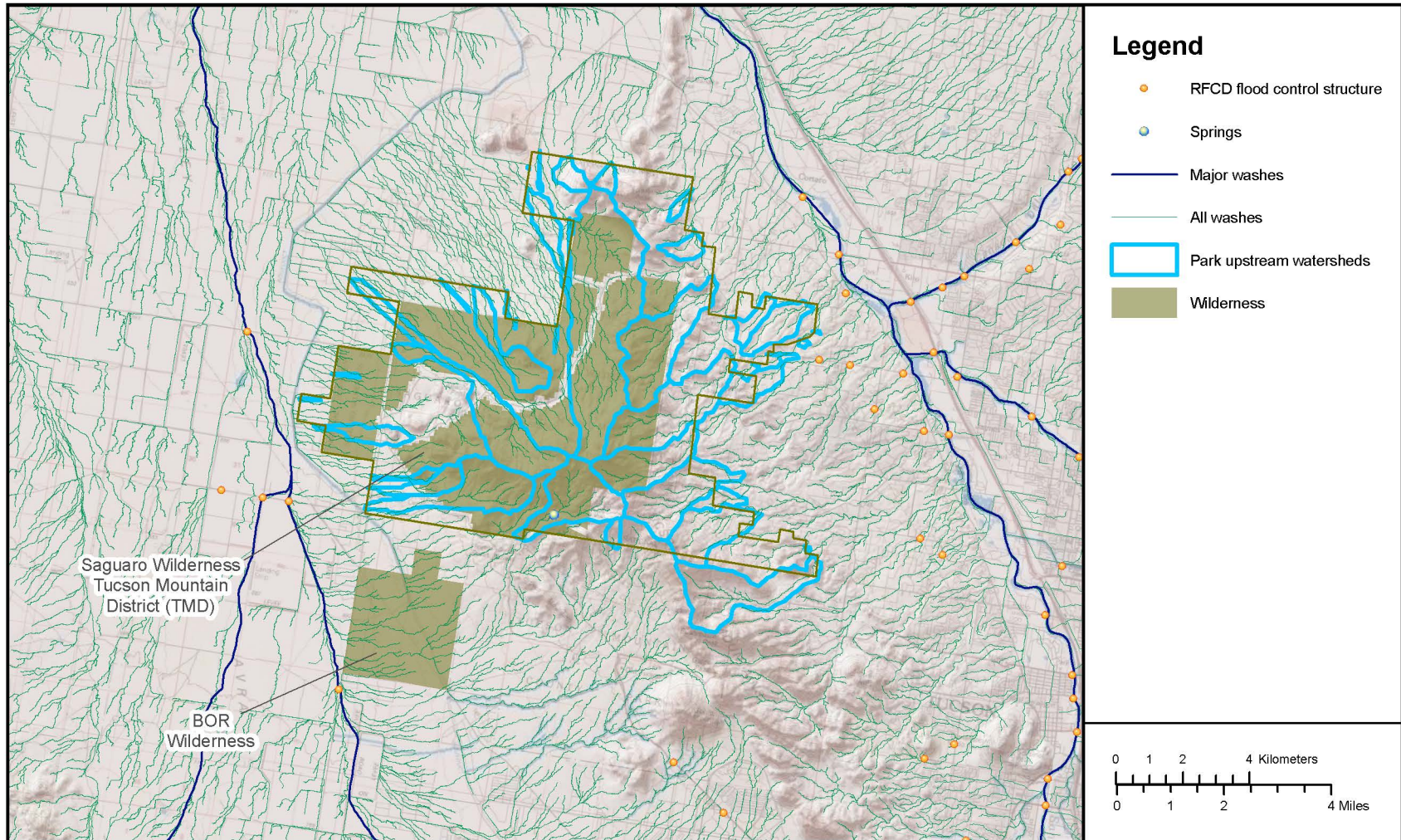


Map 24. Hydrologic land cover types (biome classification) in the local area surrounding Saguaro National Park. Data (dated 2008) obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

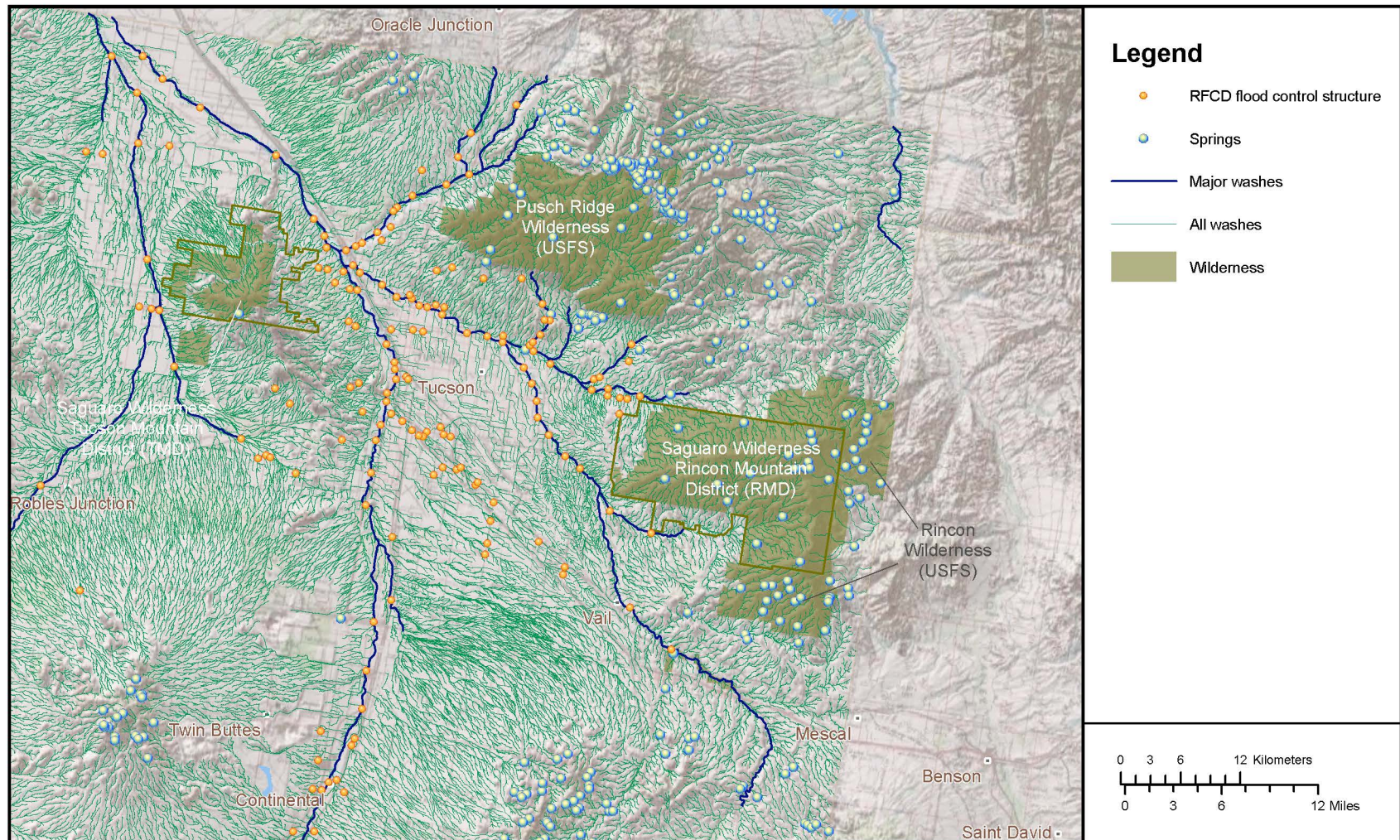
Hydrography & Connectivity



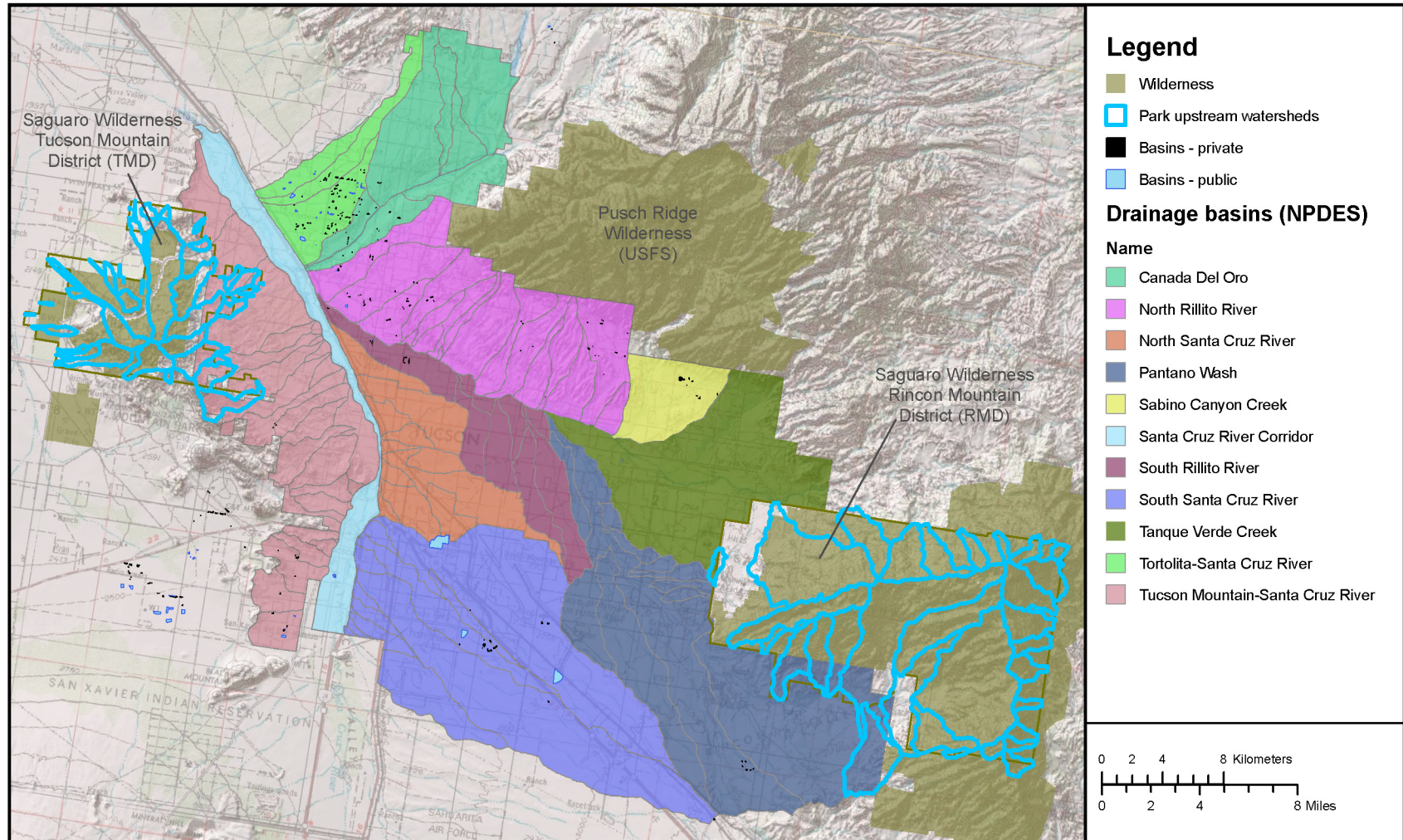
Map 25. Pima County wash network, springs, and flood control structures (source data obtained from the Pima County Information Technology Department, <http://gis.pima.gov/>) in the local area surrounding Rincon Mountain District. Park upstream watersheds provided by NPScape.



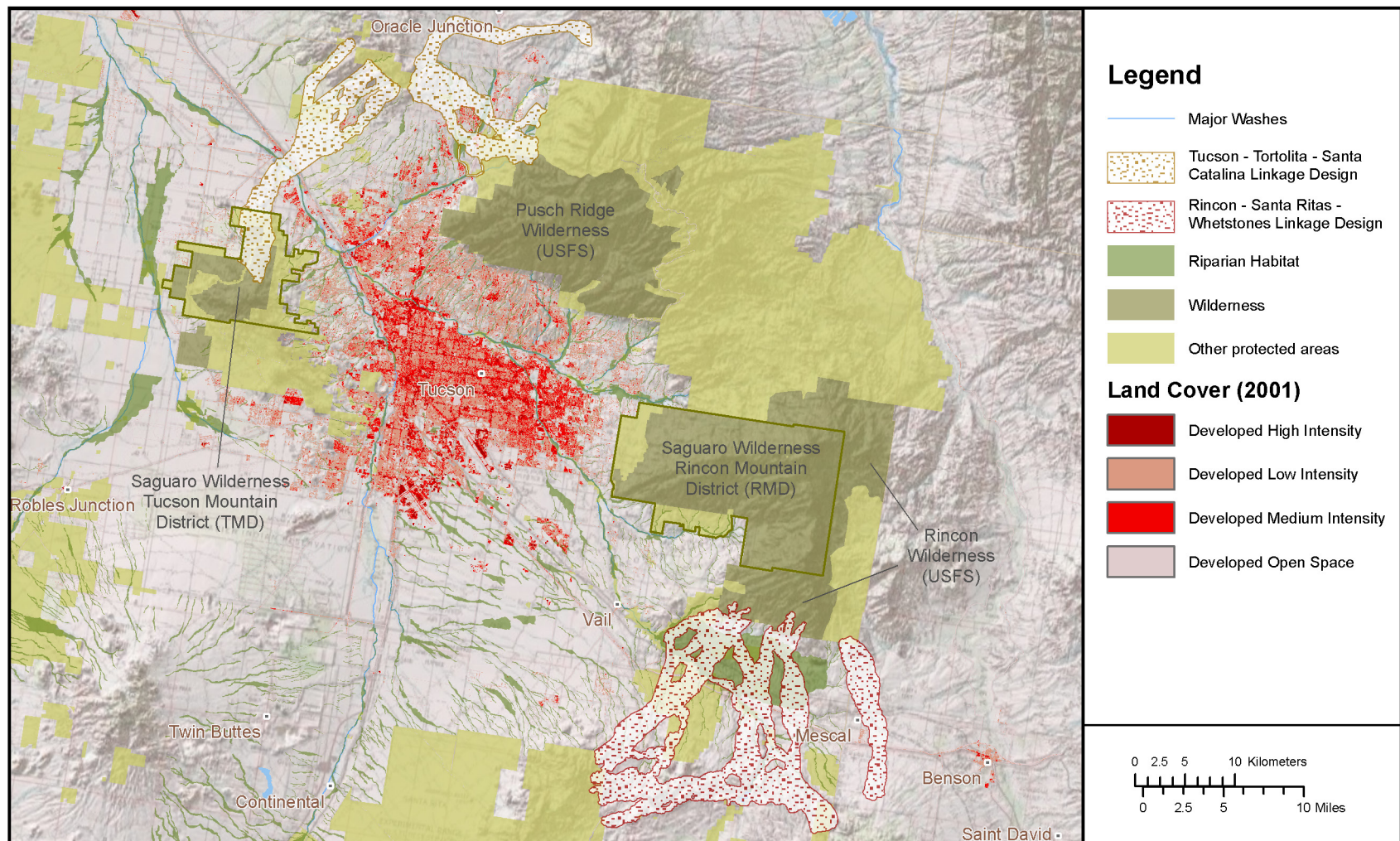
Map 26. Pima County wash network, springs, and flood control structures (source data obtained from the Pima County Information Technology Department, <http://gis.pima.gov/>) in the local area surrounding Tucson Mountain District. Park upstream watersheds provided by NPScape.



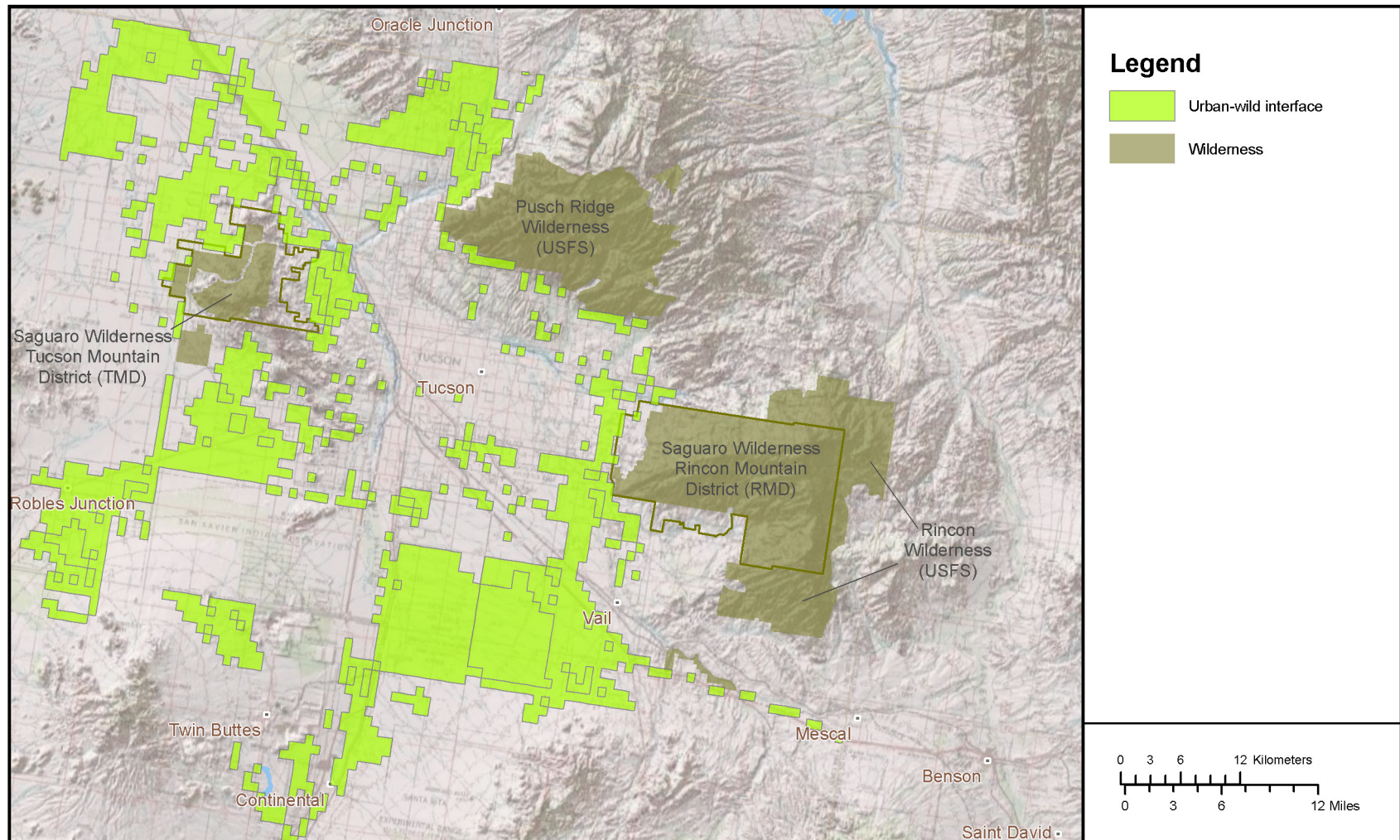
Map 27. Pima County wash network, springs, and flood control structures in the local area surrounding Saguaro National Park. All source data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



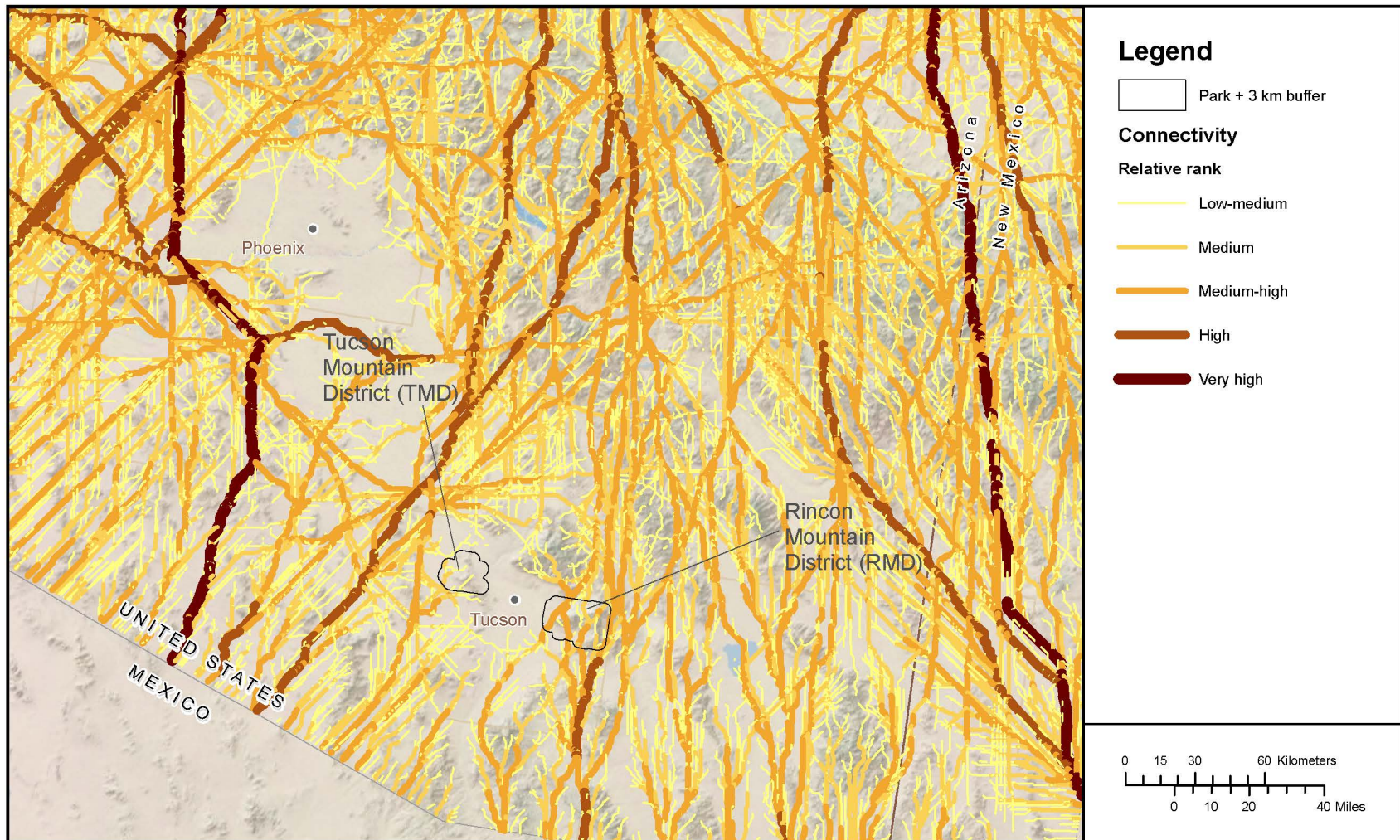
Map 28. Pima County drainage basins and public vs. private detention and retention basins (source data obtained from the Pima County Information Technology Department, <http://gis.pima.gov/>) in the local area surrounding Saguaro National Park. Park upstream watersheds provided by NPScape.



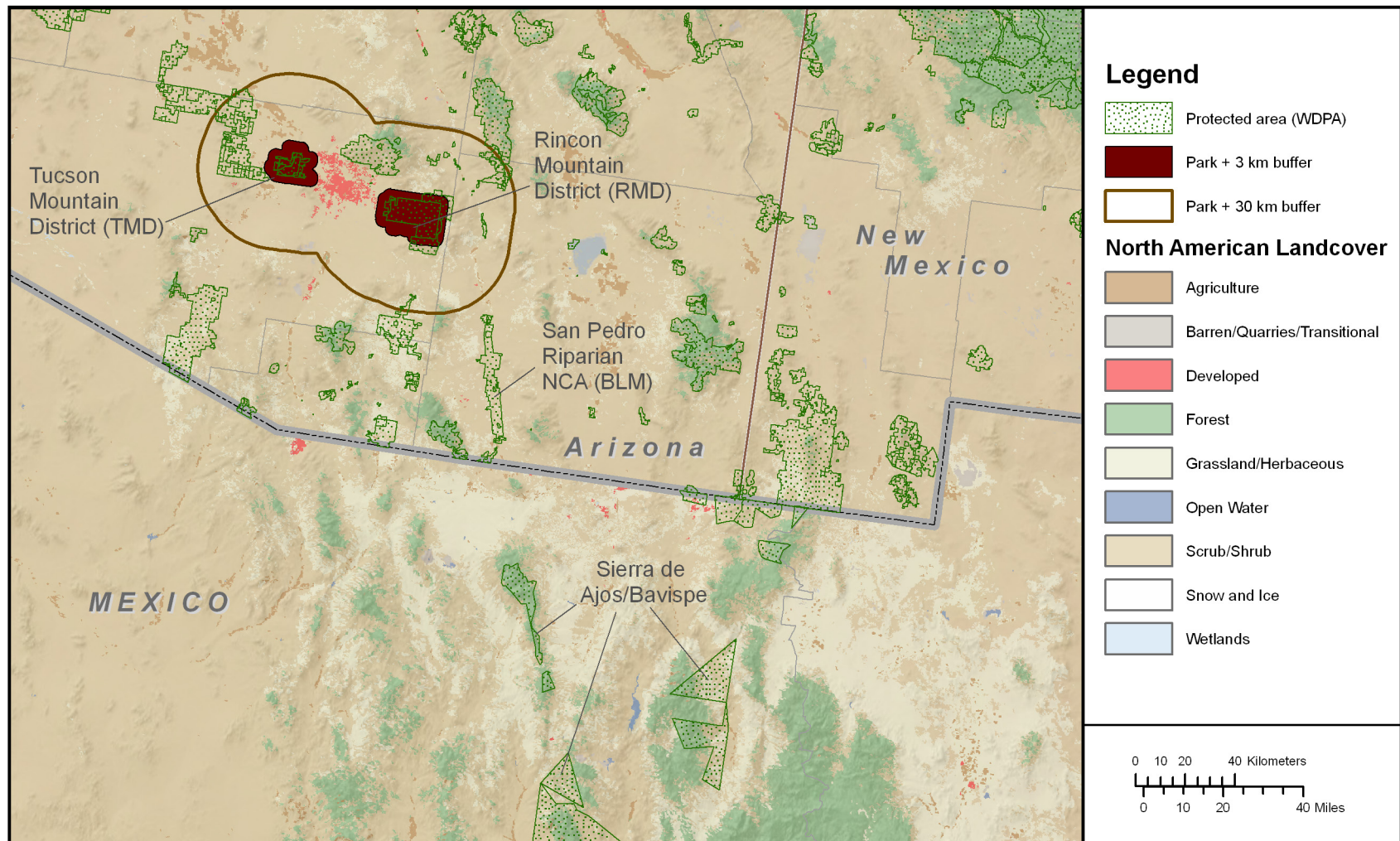
Map 29. Key landscape features enabling potential wildlife movements between Saguaro National Park and surrounding protected areas. Source data: Wildlife linkage designs (Arizona Wildlife Linkages Assessment; <http://corridordesign.org/linkages/arizona>); land cover (NPScape land cover from the National Land Cover Dataset); Washes, riparian habitat, wilderness and other protected areas (Pima County Information Technology Department, <http://gis.pima.gov/>).



Map 30. Pima County urban-wildland interface in the local area surrounding Saguaro National Park. Wilderness and urban-wild interface data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

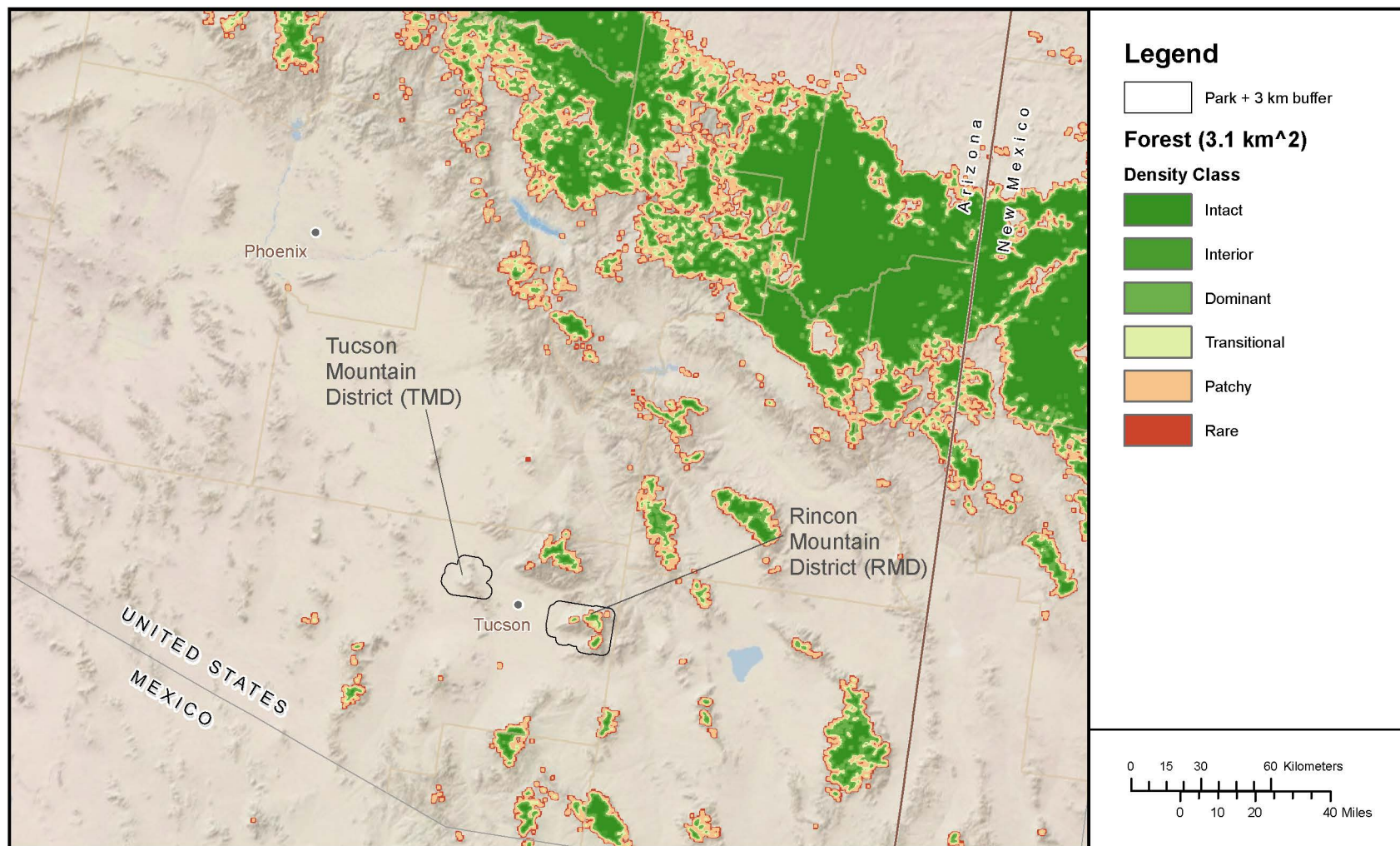


Map 31. Structural connectivity, based on the degree of naturalness, by Theobald et al. (2012). The relative ranks reflect the importance of areas for connectivity at a national-scale; thicker/darker lines are more important for maintaining national-level connectivity. Note that the lines are not corridors per se, but rather simplifications of how important general areas are for connectivity.

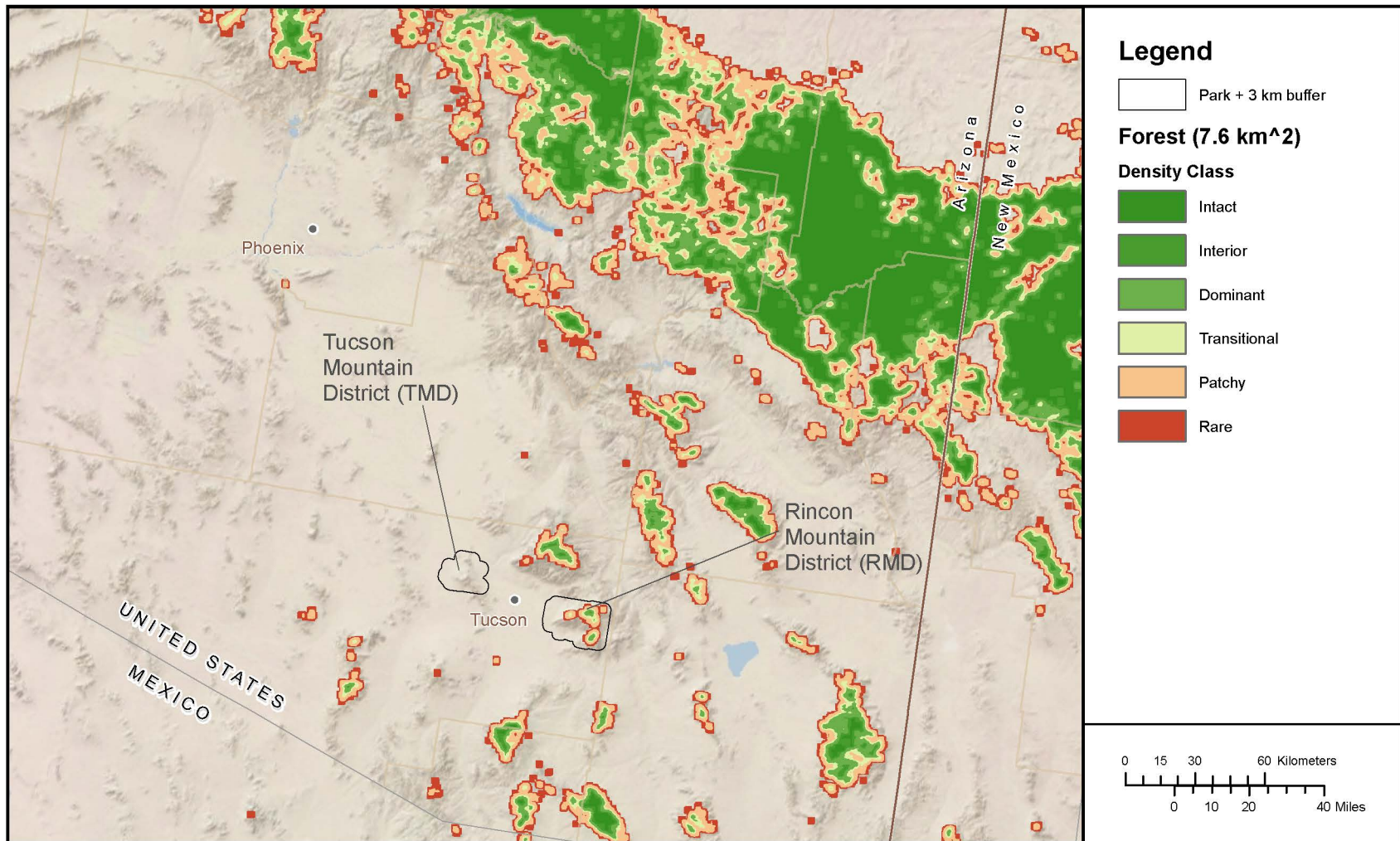


Map 32. Broad-scale features enabling potential wildlife movements between Saguaro National Park and surrounding protected areas. Source data: NPScape protected areas from the World Protected Areas Database and NPScape land cover from the North American Land Change Monitoring System.

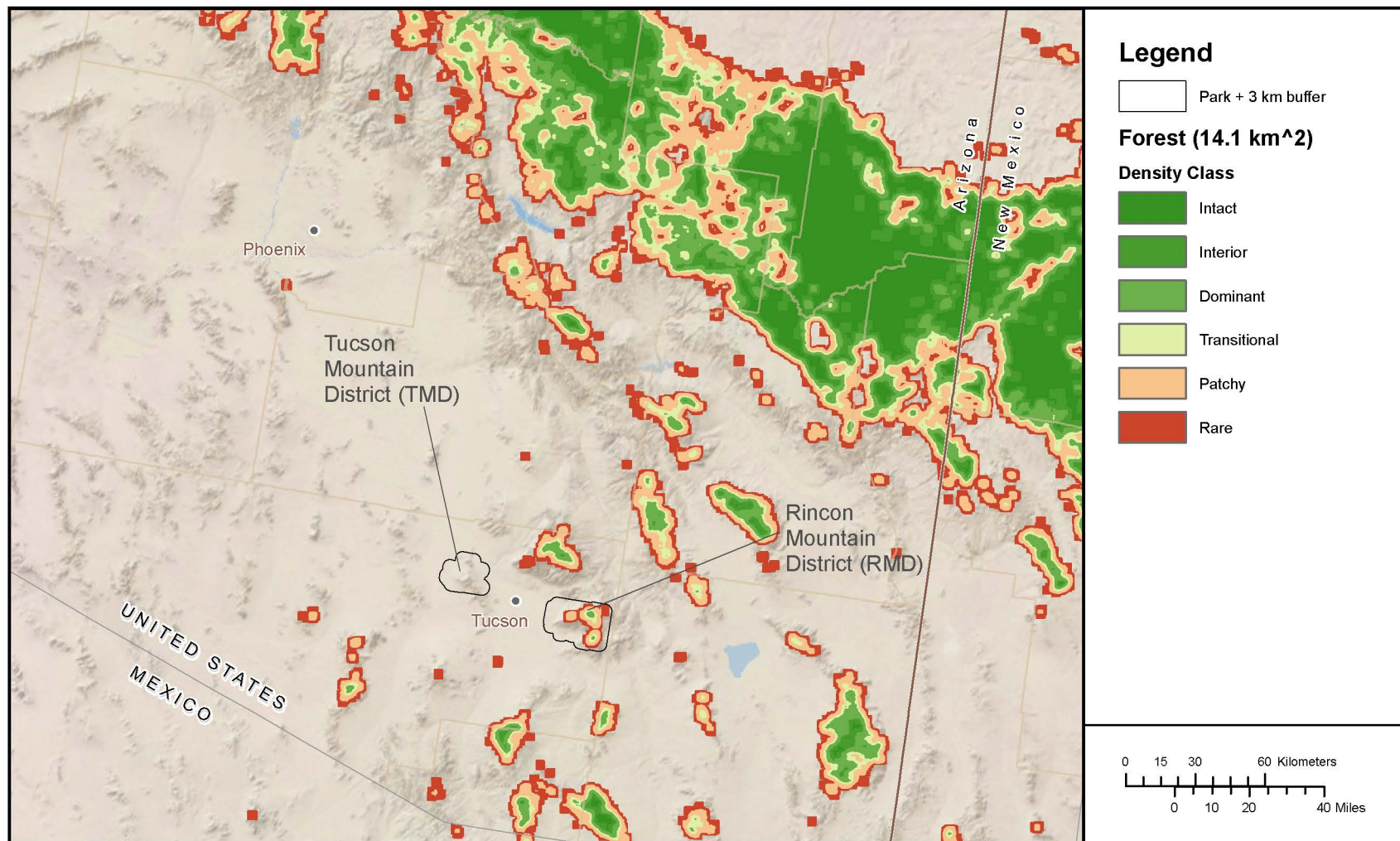
Forest & Grassland Area Density



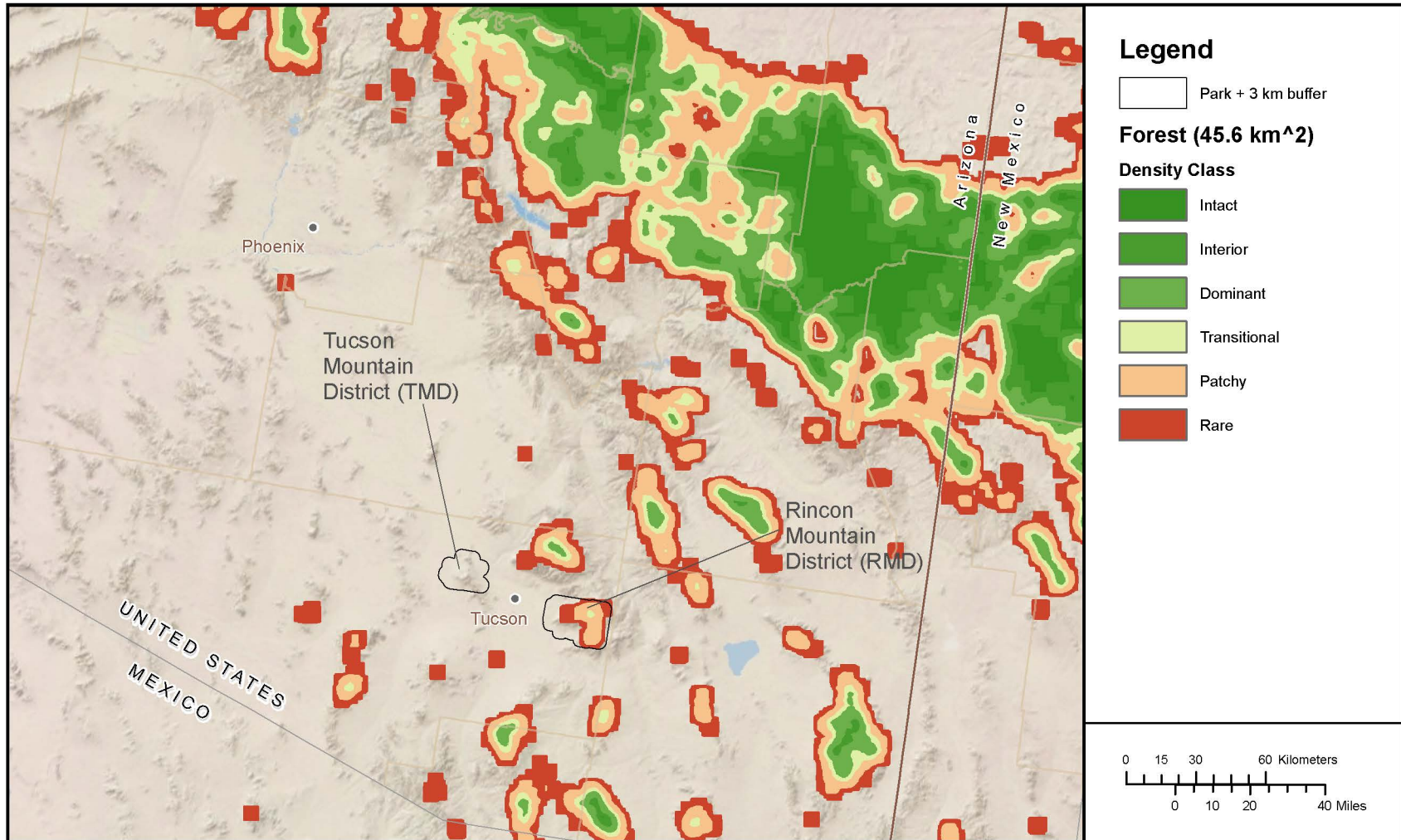
Map 33. Forest density computed by NPScape using a moving window of 3.1 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on forest. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.



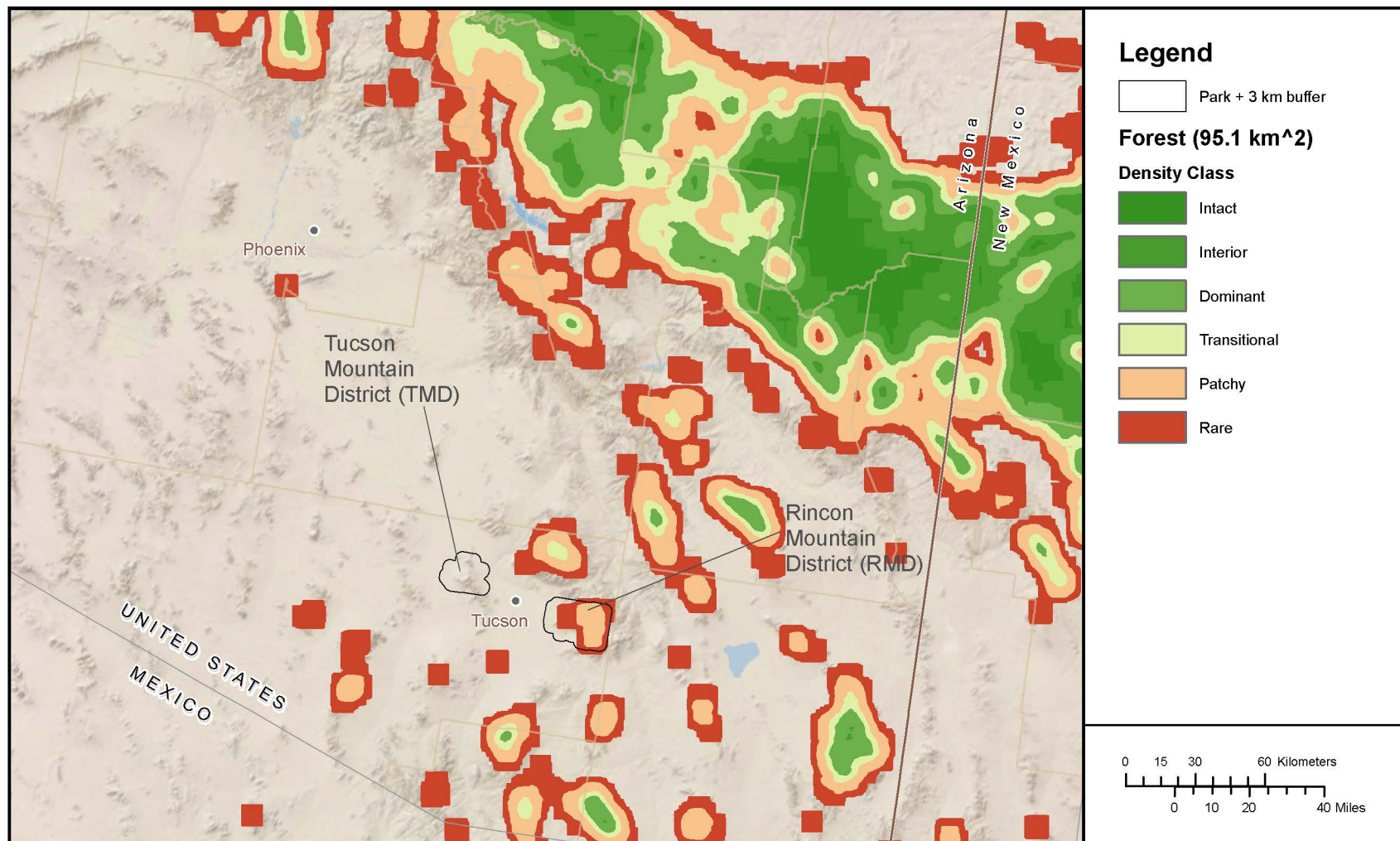
Map 34. Forest density computed by NPScape using a moving window of 7.6 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on forest. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.



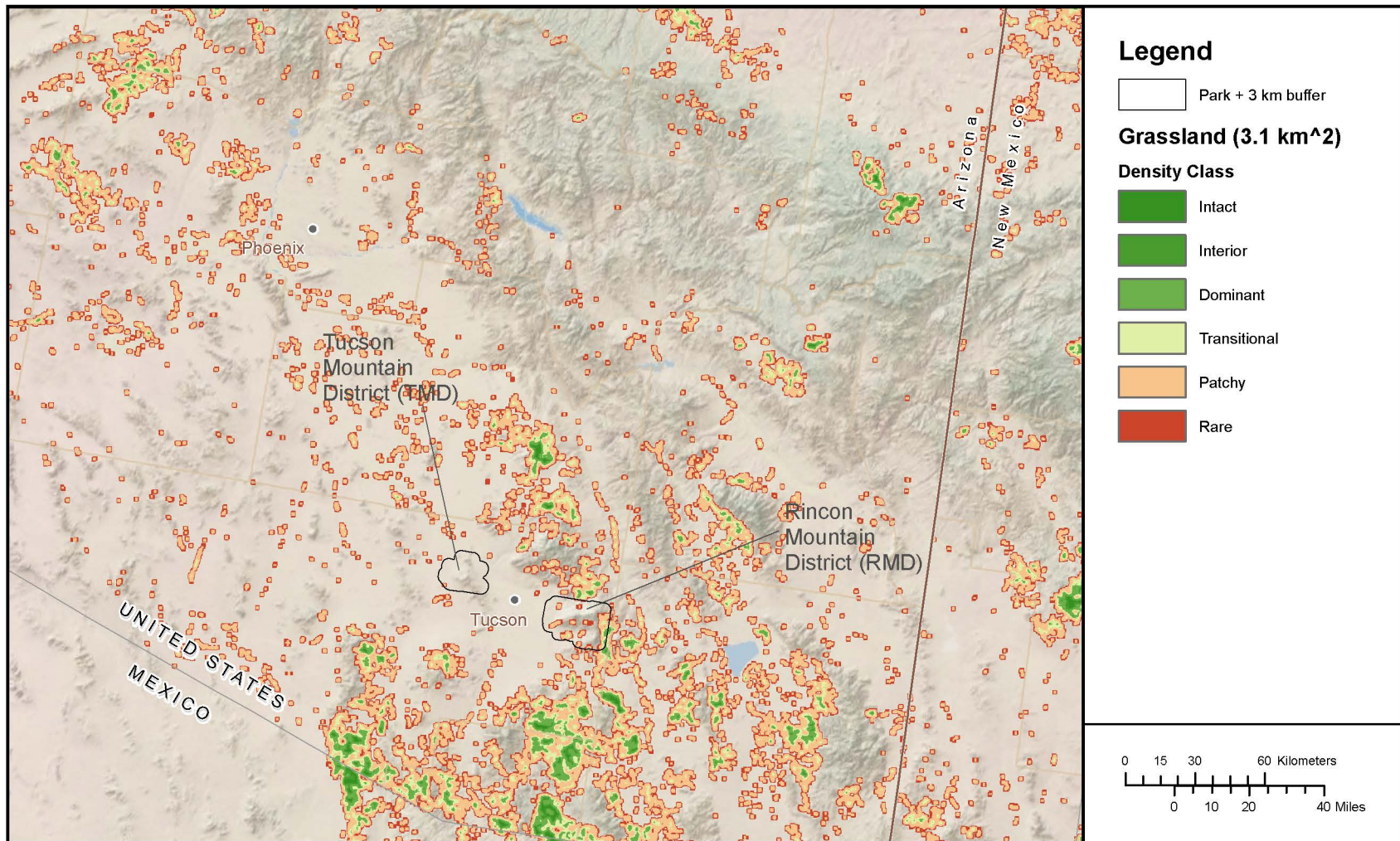
Map 35. Forest density computed by NPScape using a moving window of 14.1 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on forest. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.



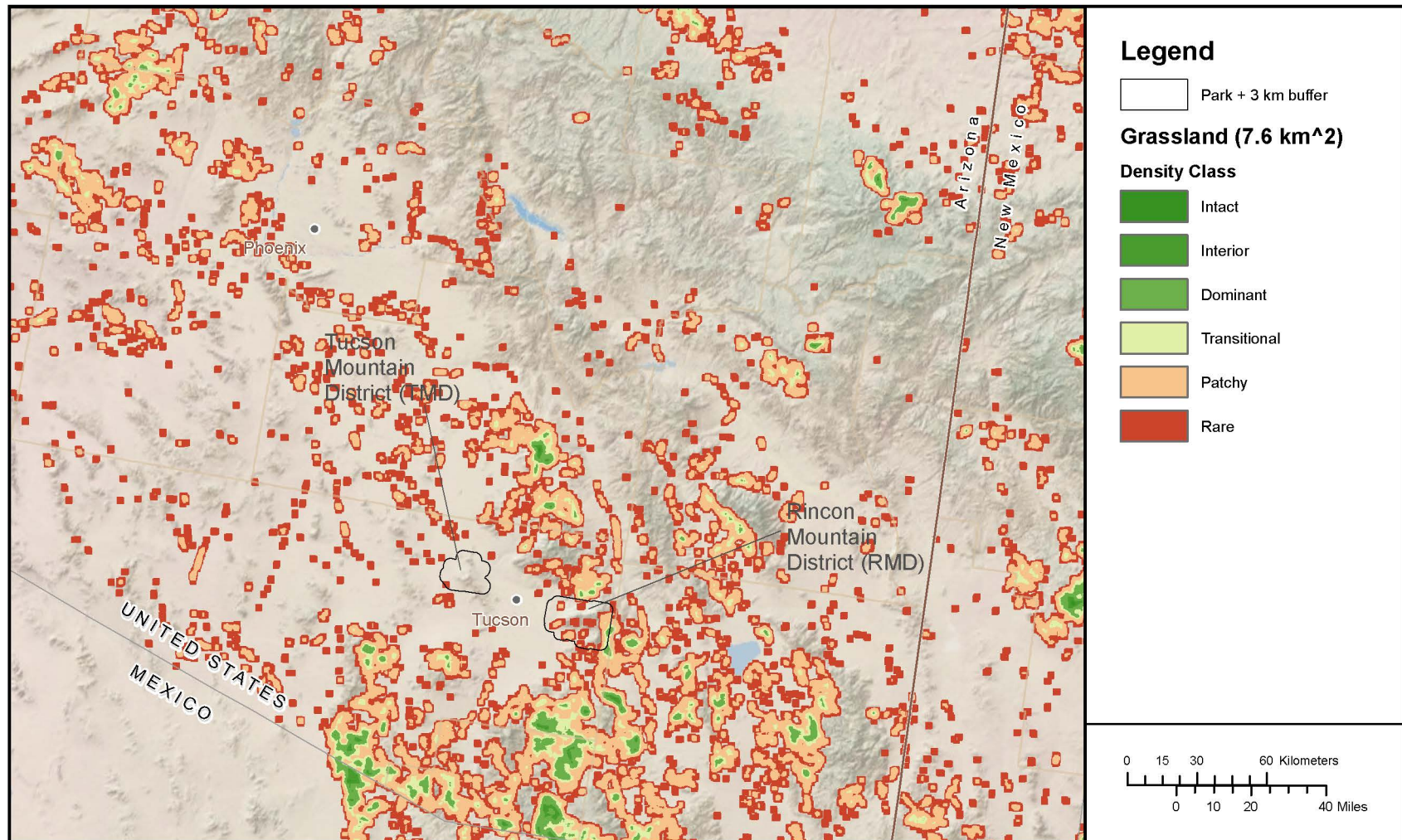
Map 36. Forest density computed by NPScape using a moving window of 45.6 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on forest. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.



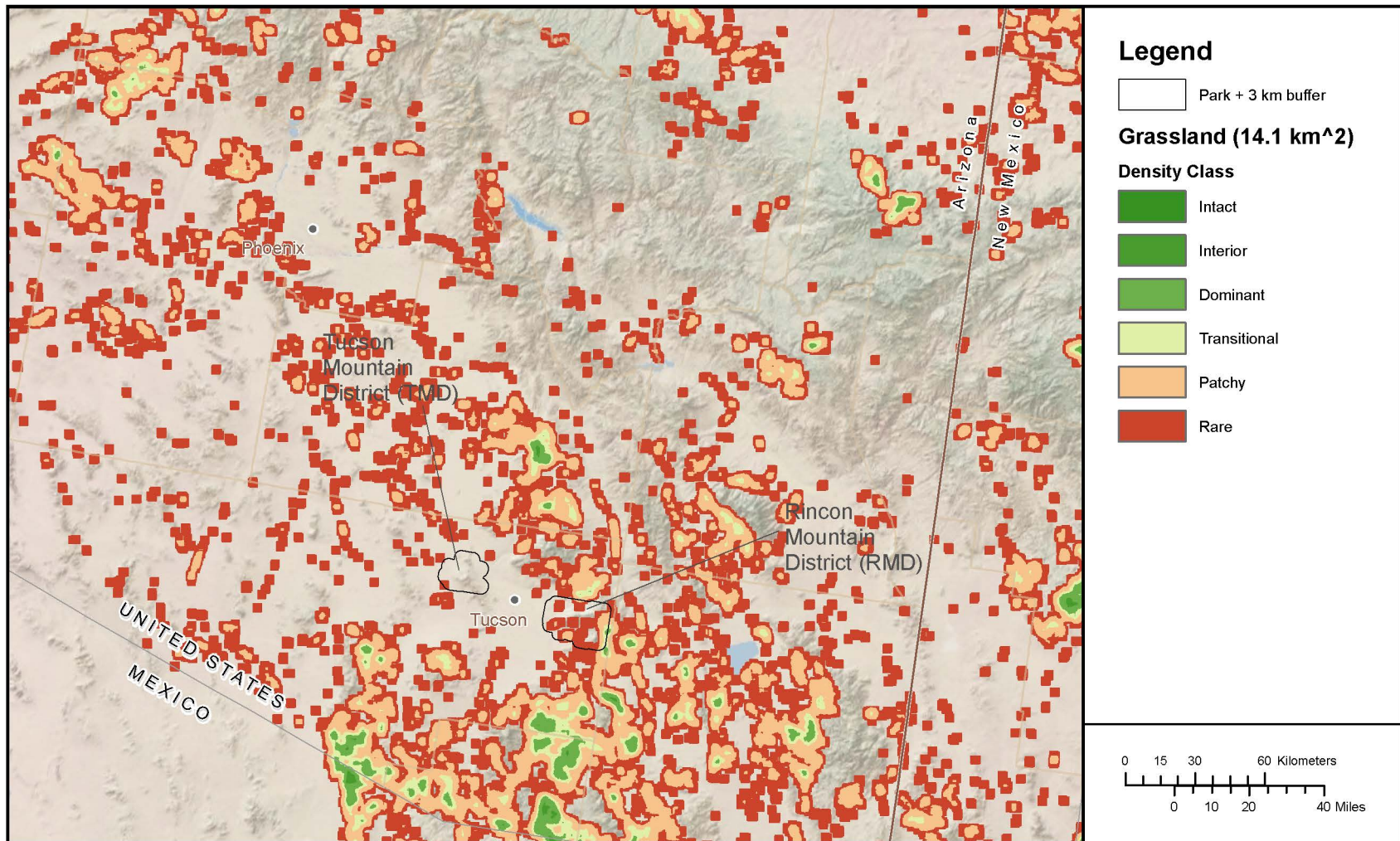
Map 37. Forest density computed by NPScape using a moving window of 95.1 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on forest. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.



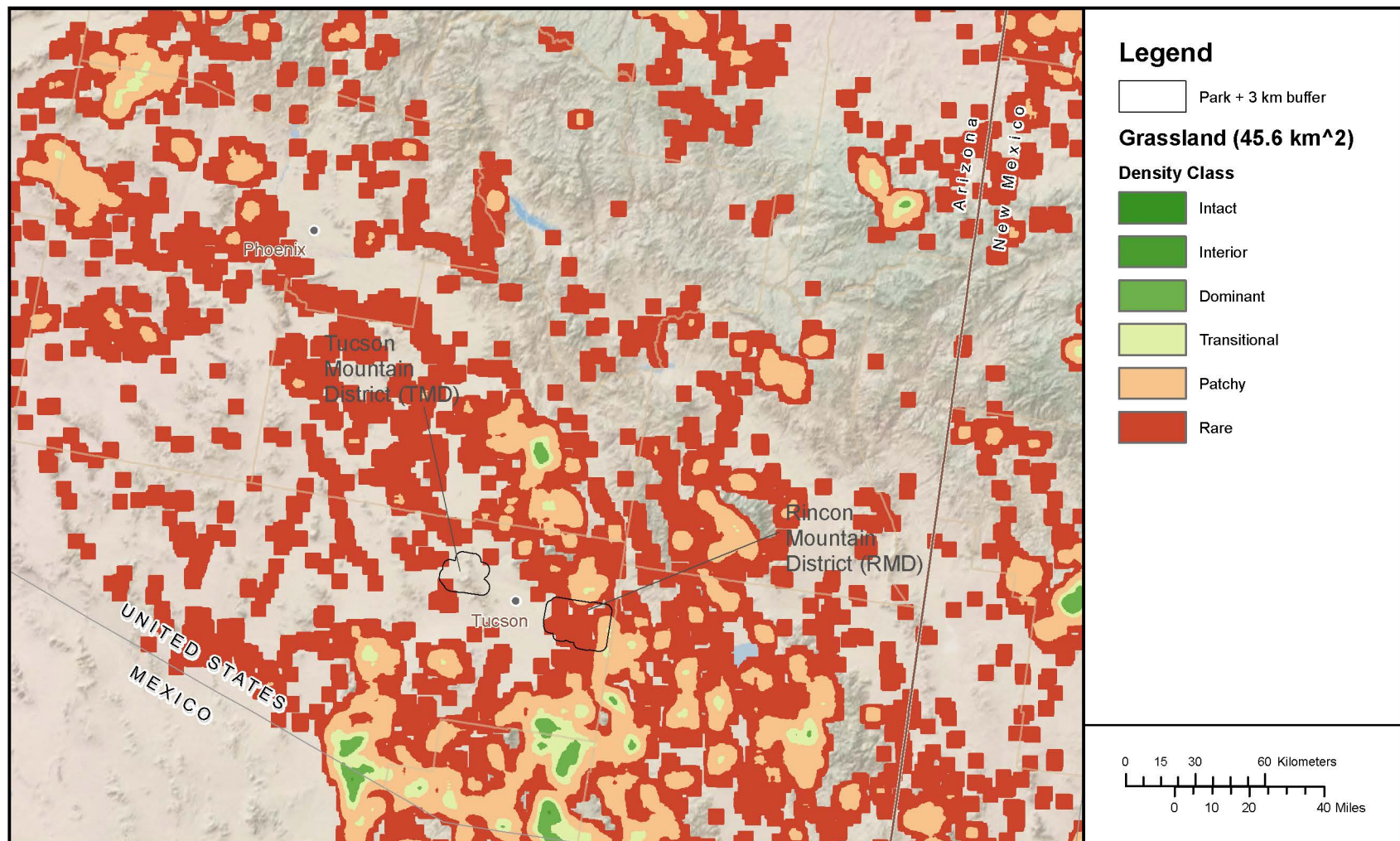
Map 38. Grassland density computed by NPScape using a moving window of 3.1 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on grassland. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.



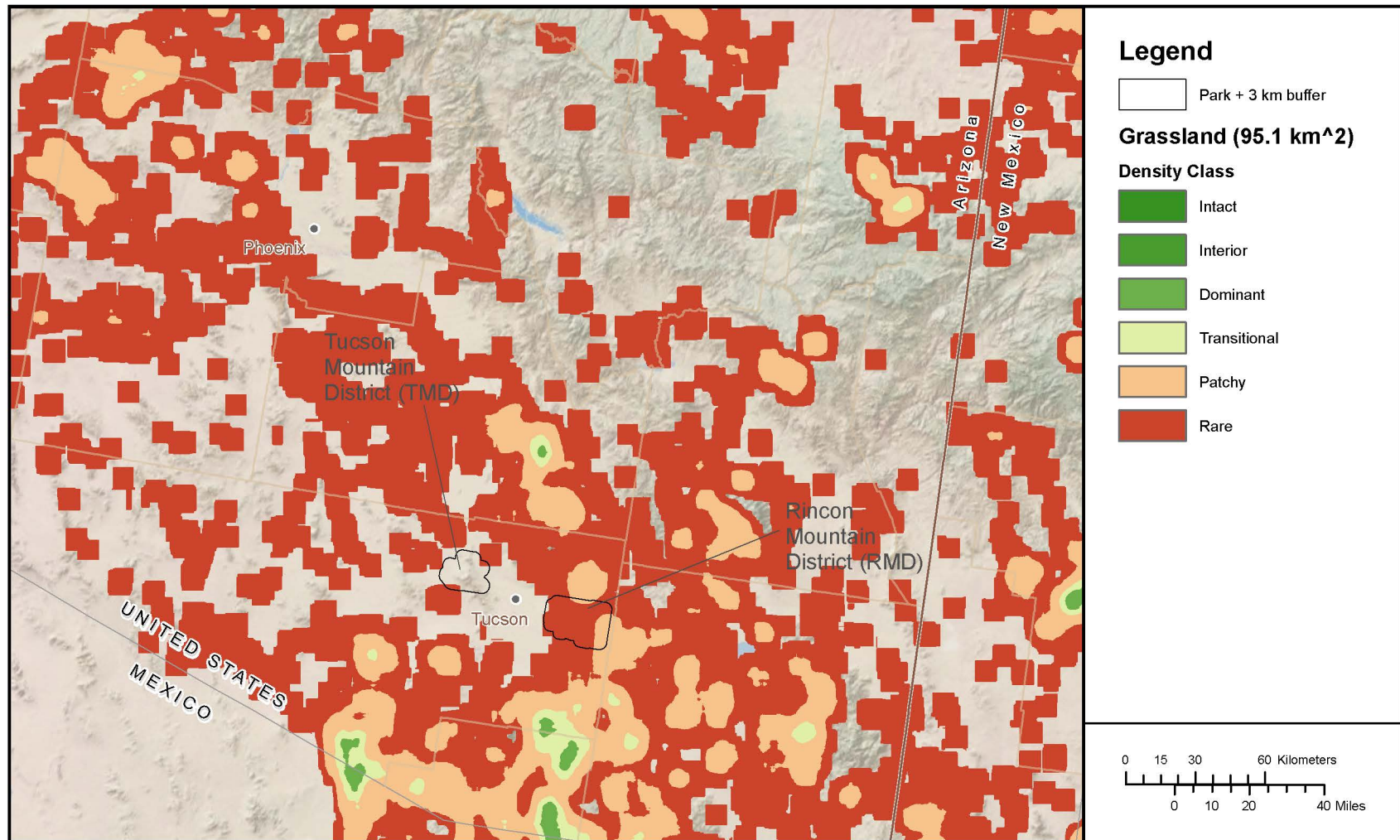
Map 39. Grassland density computed by NPScape using a moving window of 7.6 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on grassland. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.



Map 40. Grassland density computed by NPScape using a moving window of 14.1 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on grassland. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.

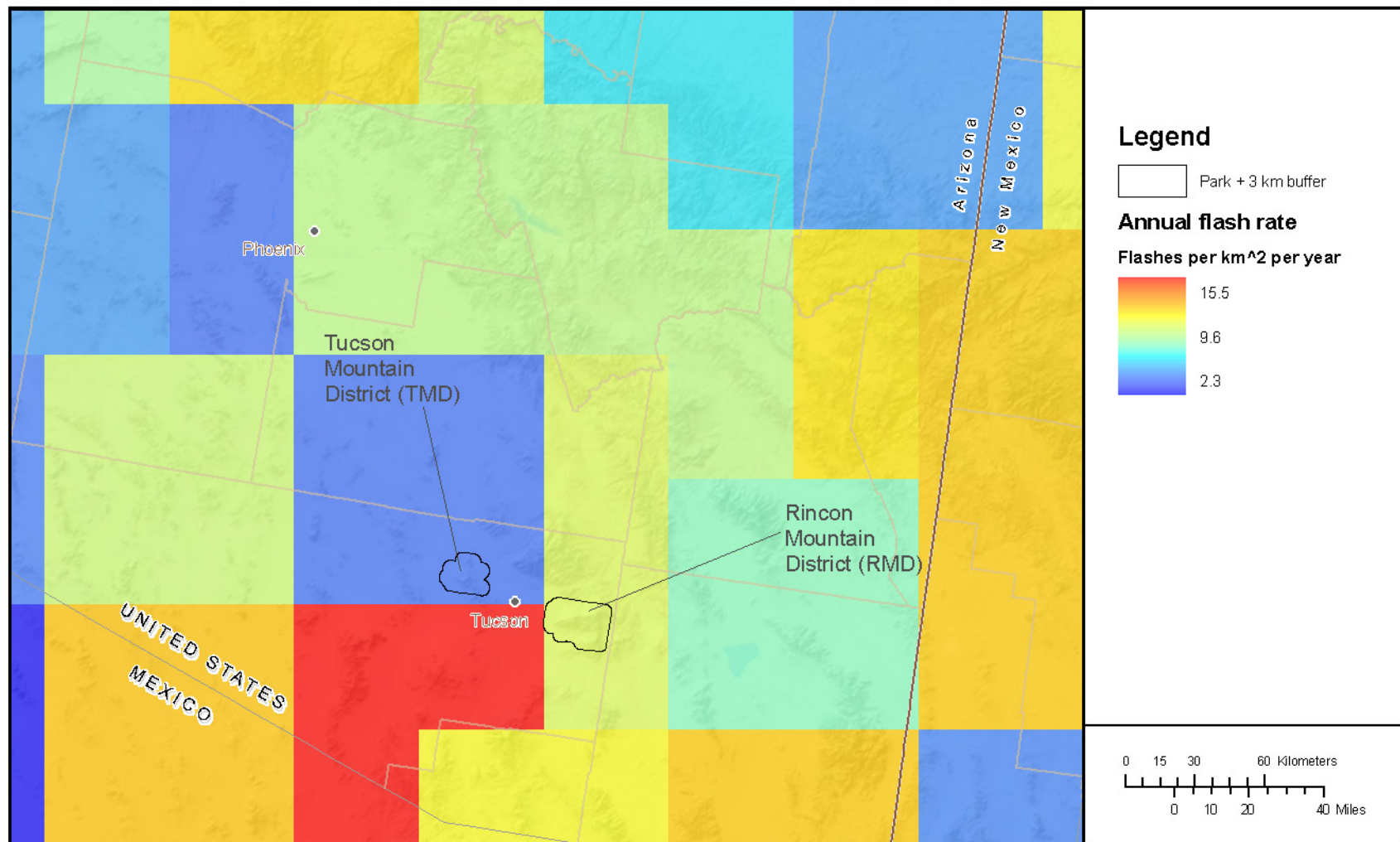


Map 41. Grassland density computed by NPScape using a moving window of 45.6 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on grassland. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.

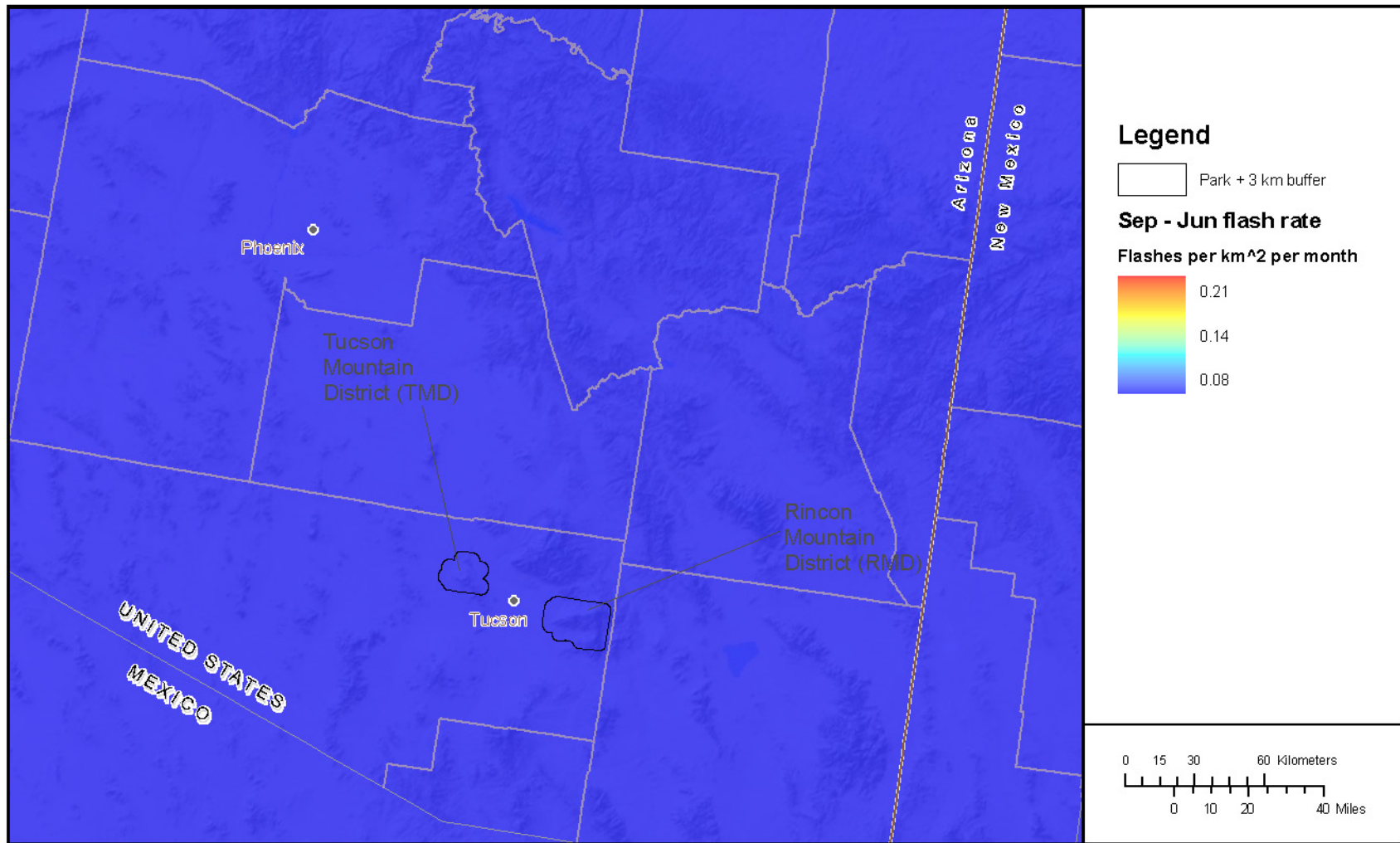


Map 42. Grassland density computed by NPScape using a moving window of 95.1 km². Density classes vary from rare to intact. Results are to be interpreted for species or resources that operate at approximately the scale of the moving window, and depend to varying degrees on grassland. Source data: NPScape area density based on land cover data from the North American Land Change Monitoring System.

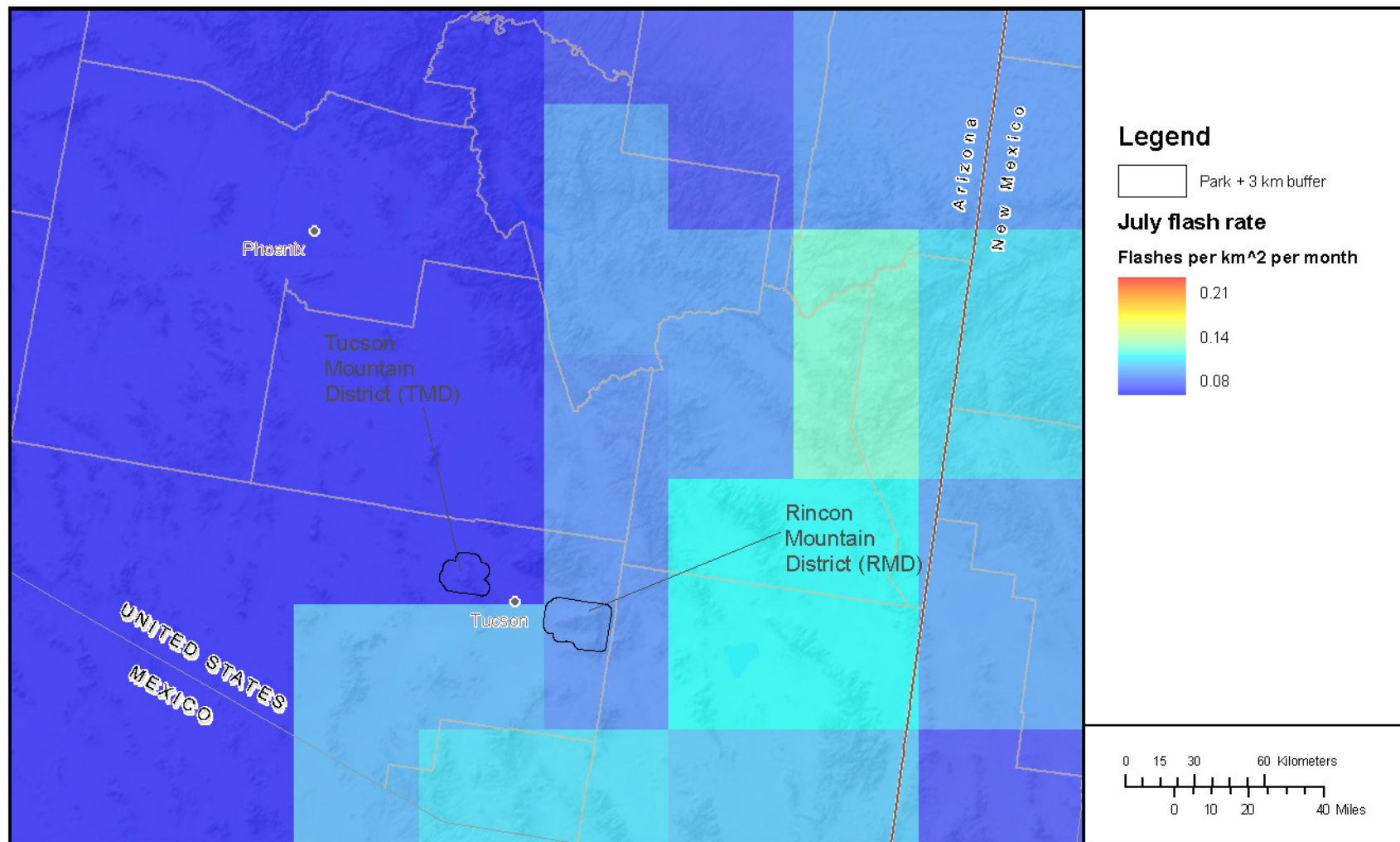
Lightning



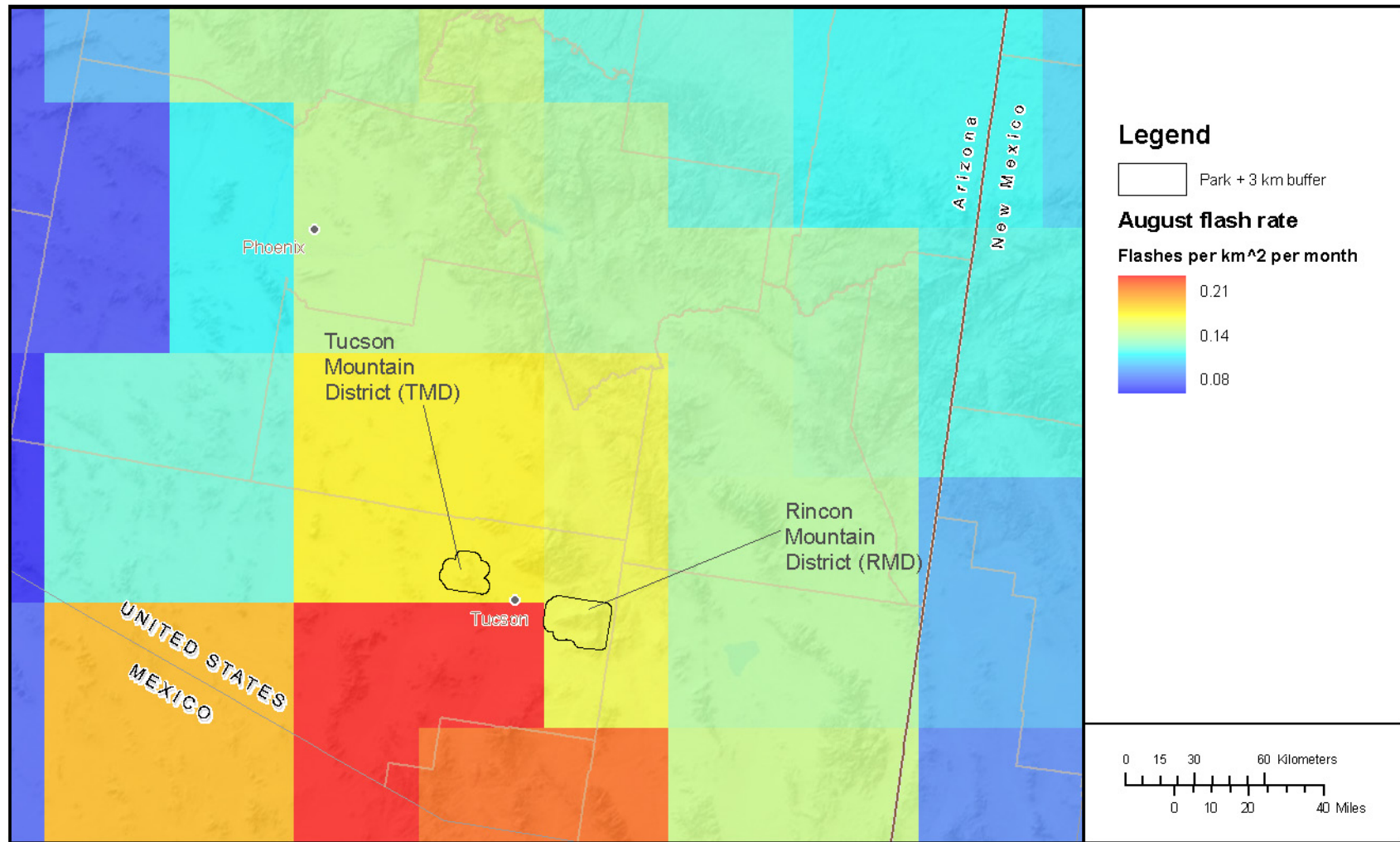
Map 43. Annual flash rate (number of flashes per km² per year) for Saguaro National Park and ecoregional vicinity. Data obtained from the NASA Optical Transient Detector (OTD), May 1995 through April 2000. In map extent, minimum = 2.3 flashes per km² per yr and maximum = 15.5 flashes per km² per yr.



Map 44. Monthly flash rate (number of flashes per km² per month; September through June when there is little to no flash activity) for Saguaro National Park and ecoregional vicinity. Data obtained from the NASA Optical Transient Detector (OTD), May 1995 through April 2000. In map extent, all values ≤ 0.08 flashes per km² per month.

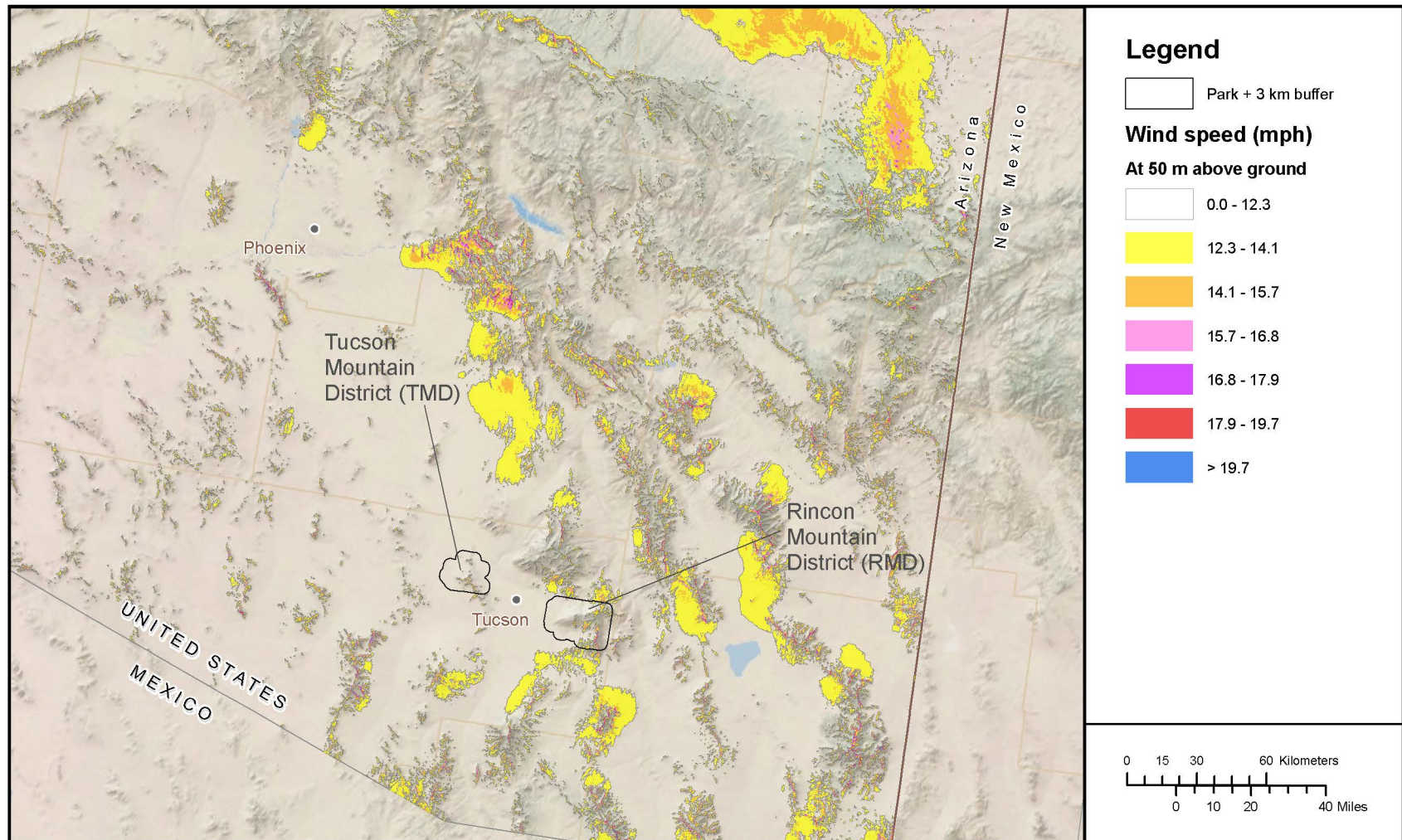


Map 45. Monthly flash rate (number of flashes per km² per month; July, when flash activity is modest) for Saguaro National Park and ecoregional vicinity. Data obtained from the NASA Optical Transient Detector (OTD), May 1995 through April 2000. In map extent, all values ≤ 0.14 flashes per km² per month.

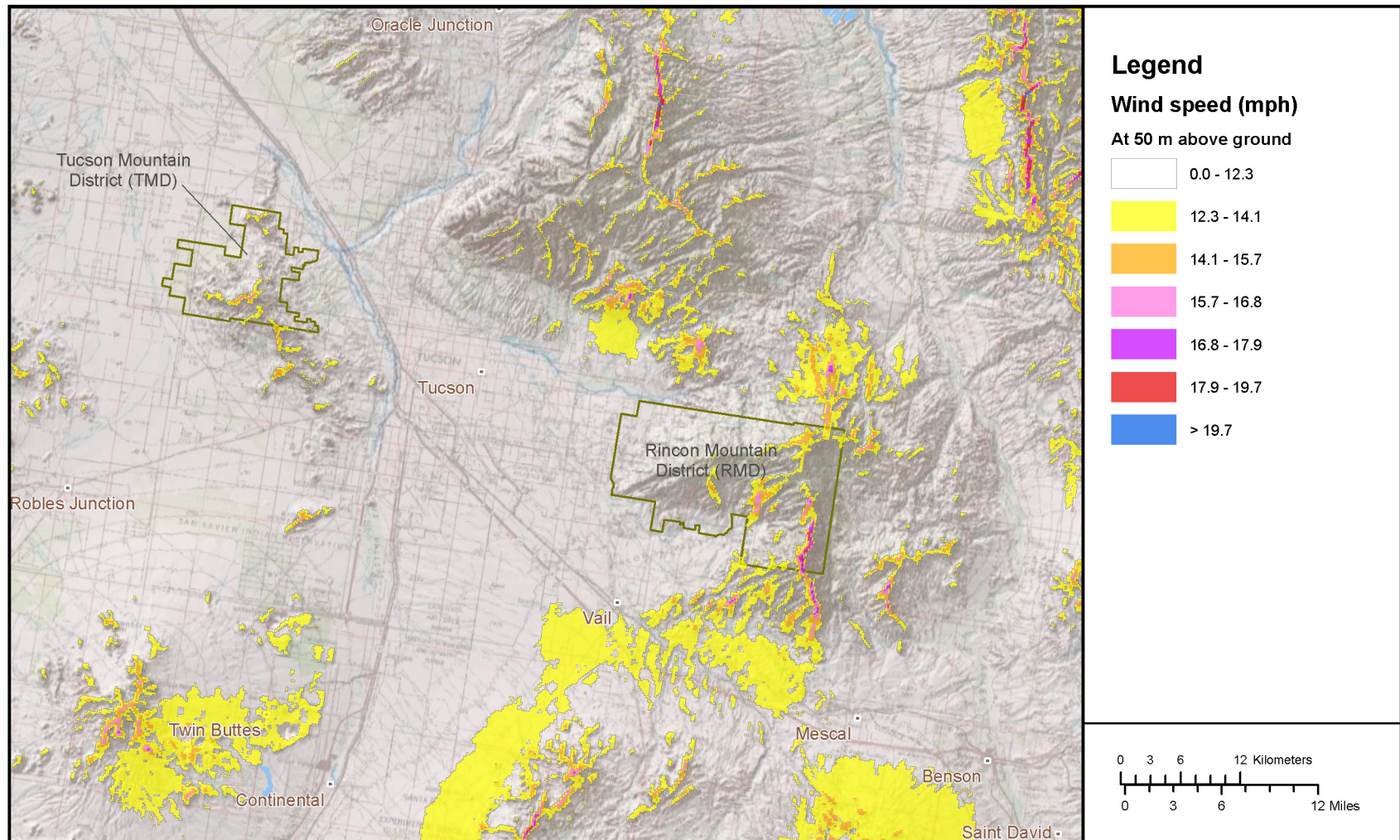


Map 46. Monthly flash rate (number of flashes per km² per month; August, when flash activity is at a peak) for Saguaro National Park and ecoregional vicinity. Data obtained from the NASA Optical Transient Detector (OTD), May 1995 through April 2000. In map extent, minimum = 0.08 flashes per km² per month and maximum = 0.21 flashes per km² per month.

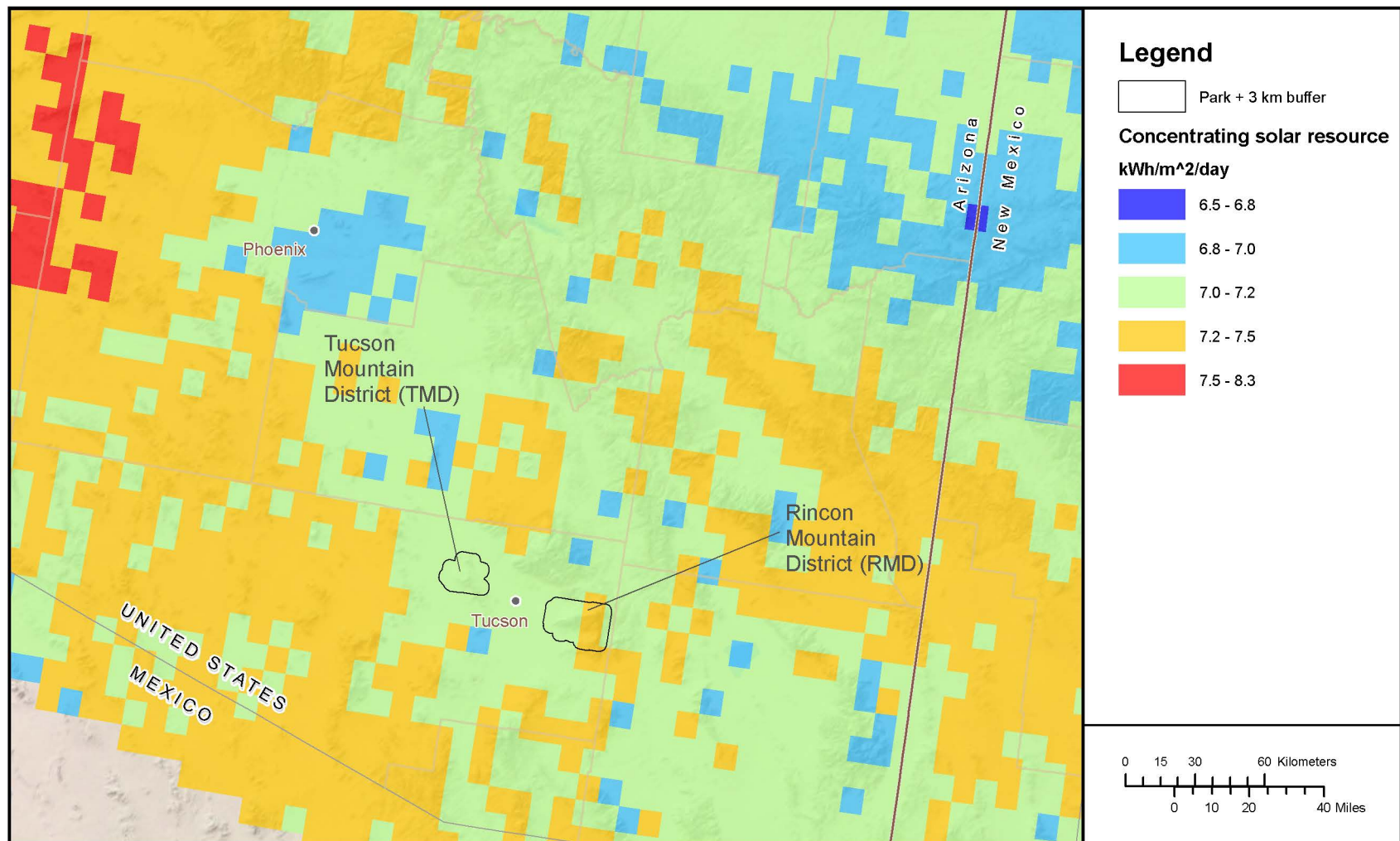
Renewable Energy



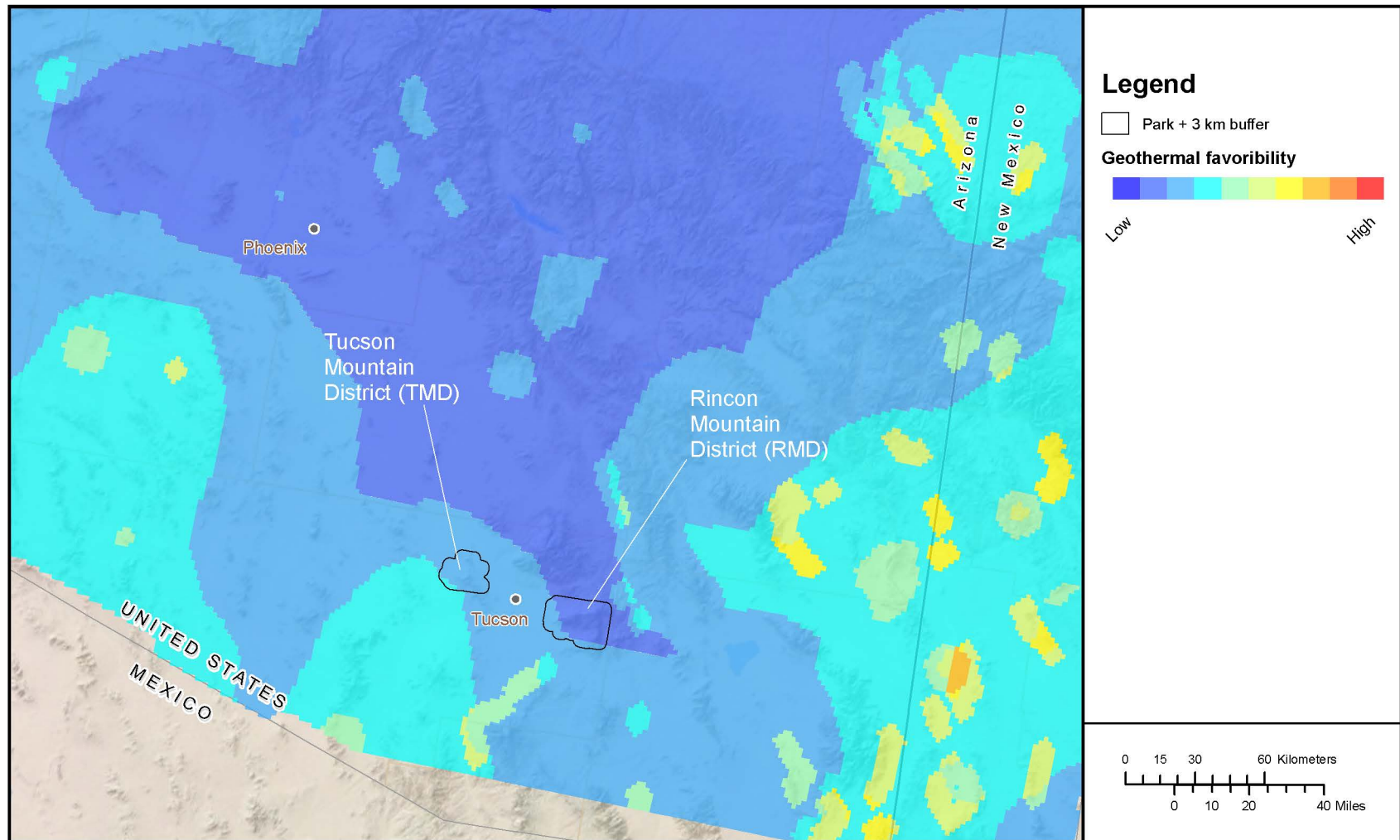
Map 47. Wind speeds at 50 m above ground for Saguaro National Park and ecoregional vicinity. Data obtained from the National Renewable Energy Laboratory (2003).



Map 48. Wind speeds at 50 m above ground in the local area surrounding Saguaro National Park. Data obtained from the National Renewable Energy Laboratory (2003).

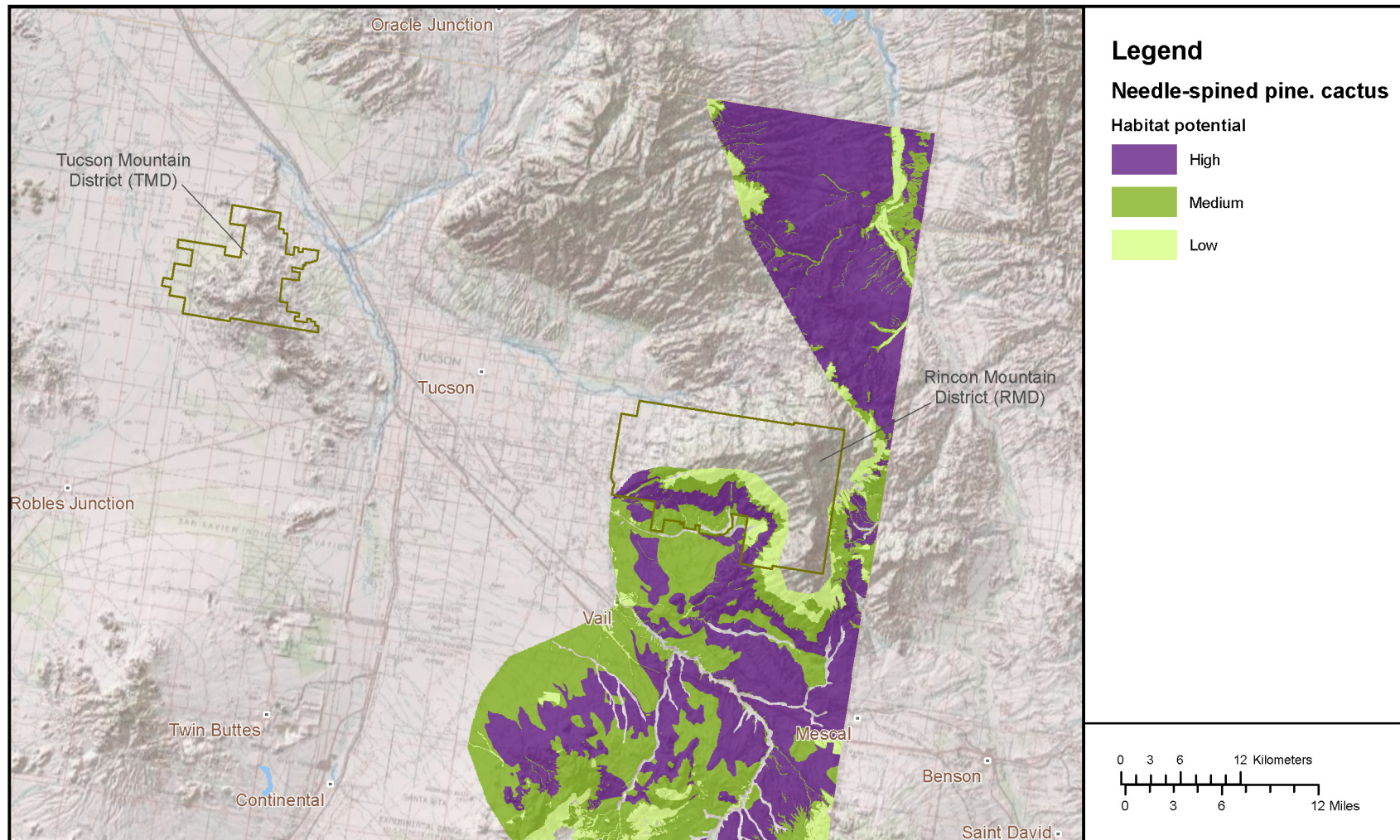


Map 49. Average annual direct normal solar resource in the local area surrounding Saguaro National Park. Data obtained from the National Renewable Energy Laboratory (2009).

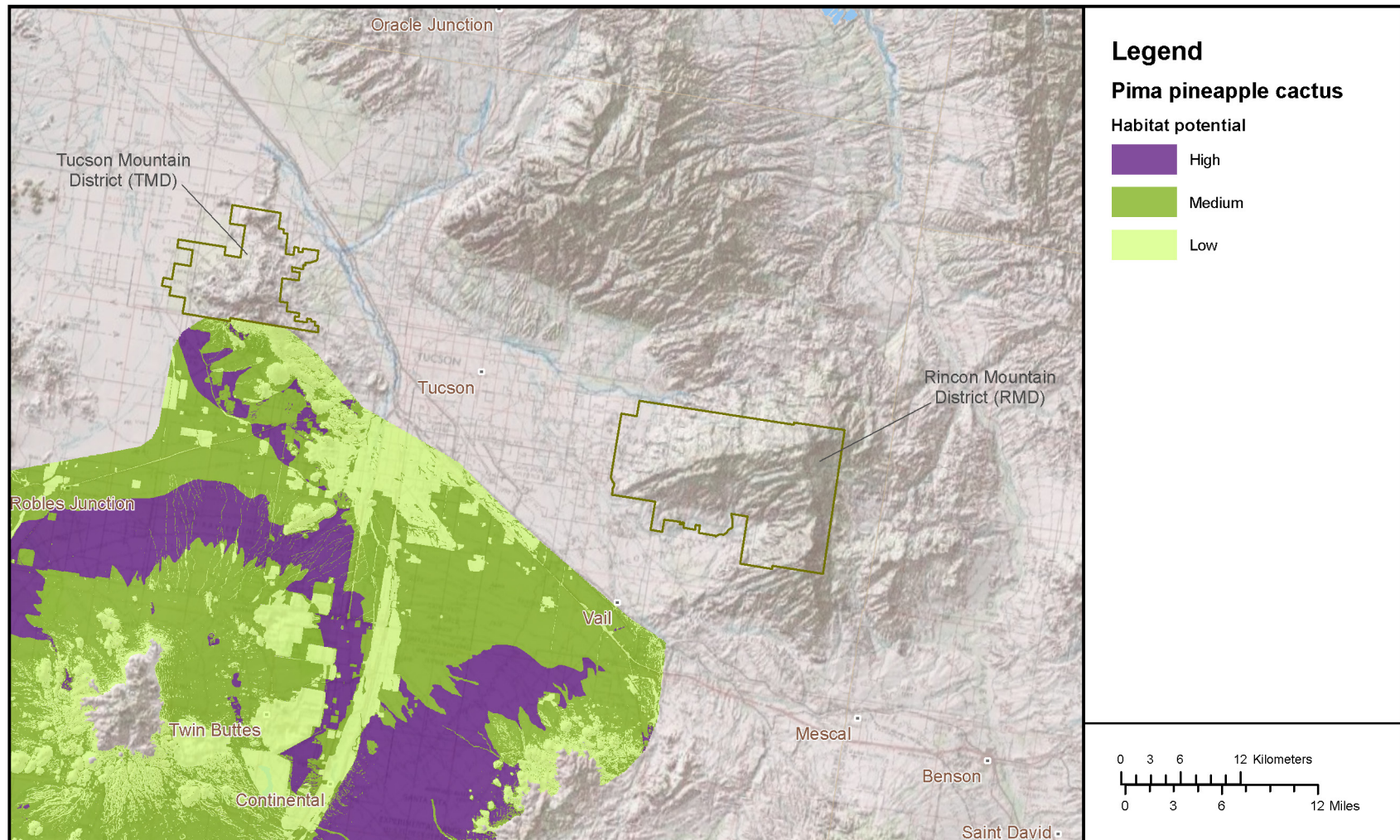


Map 50. Geothermal favorability, ranked qualitatively based on 12 USGS logistic regression models that correlate different geological and geophysical factors to the known presence of moderate (90 - 150° C) to high (> 150° C) temperature geothermal resources in the western United States (<http://pubs.usgs.gov/fs/2008/3082/>), in the local area surrounding Saguaro National Park.

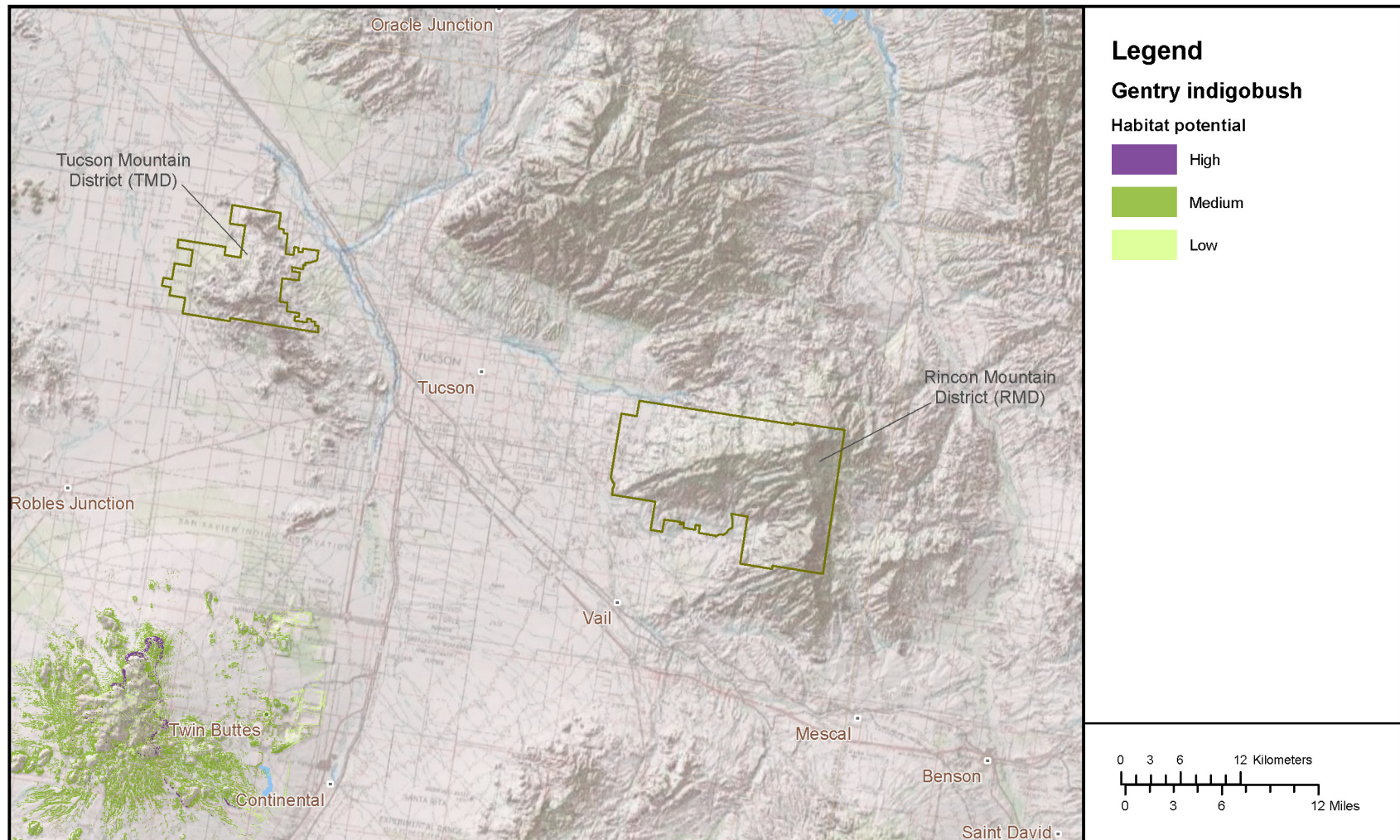
Vulnerable Species



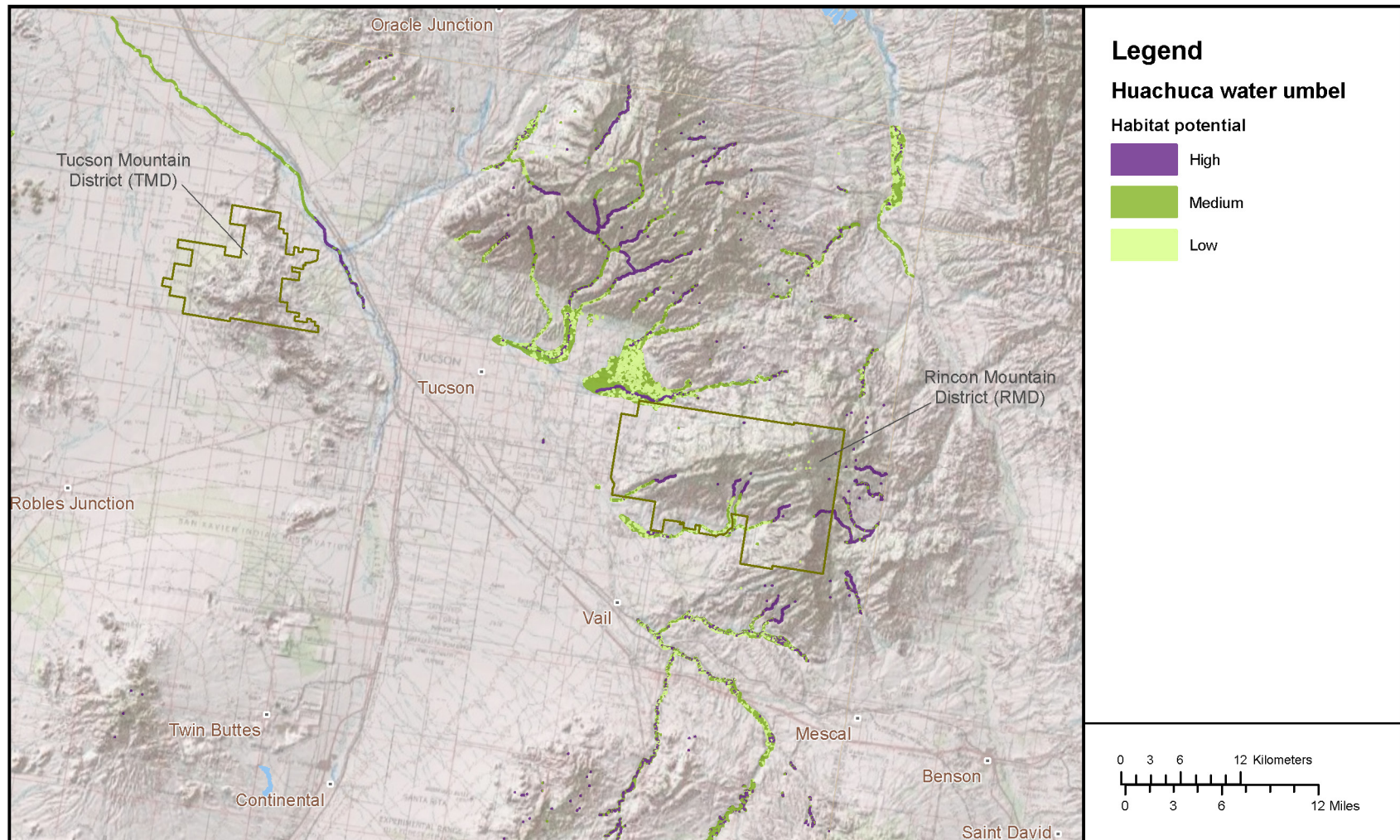
Map 51. Habitat suitability model for the needle-spined pineapple cactus, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



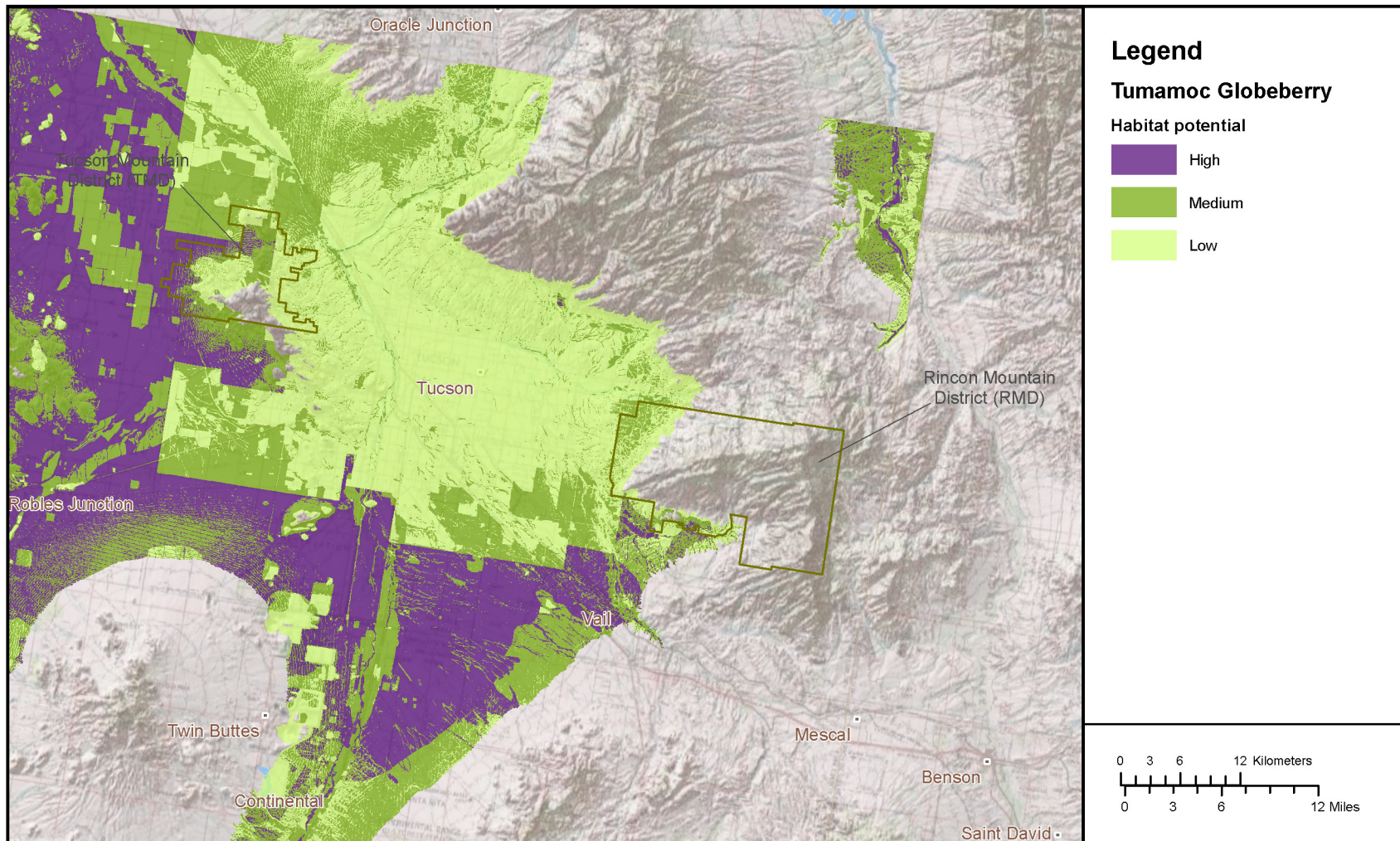
Map 52. Habitat suitability model for the Pima pineapple cactus, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



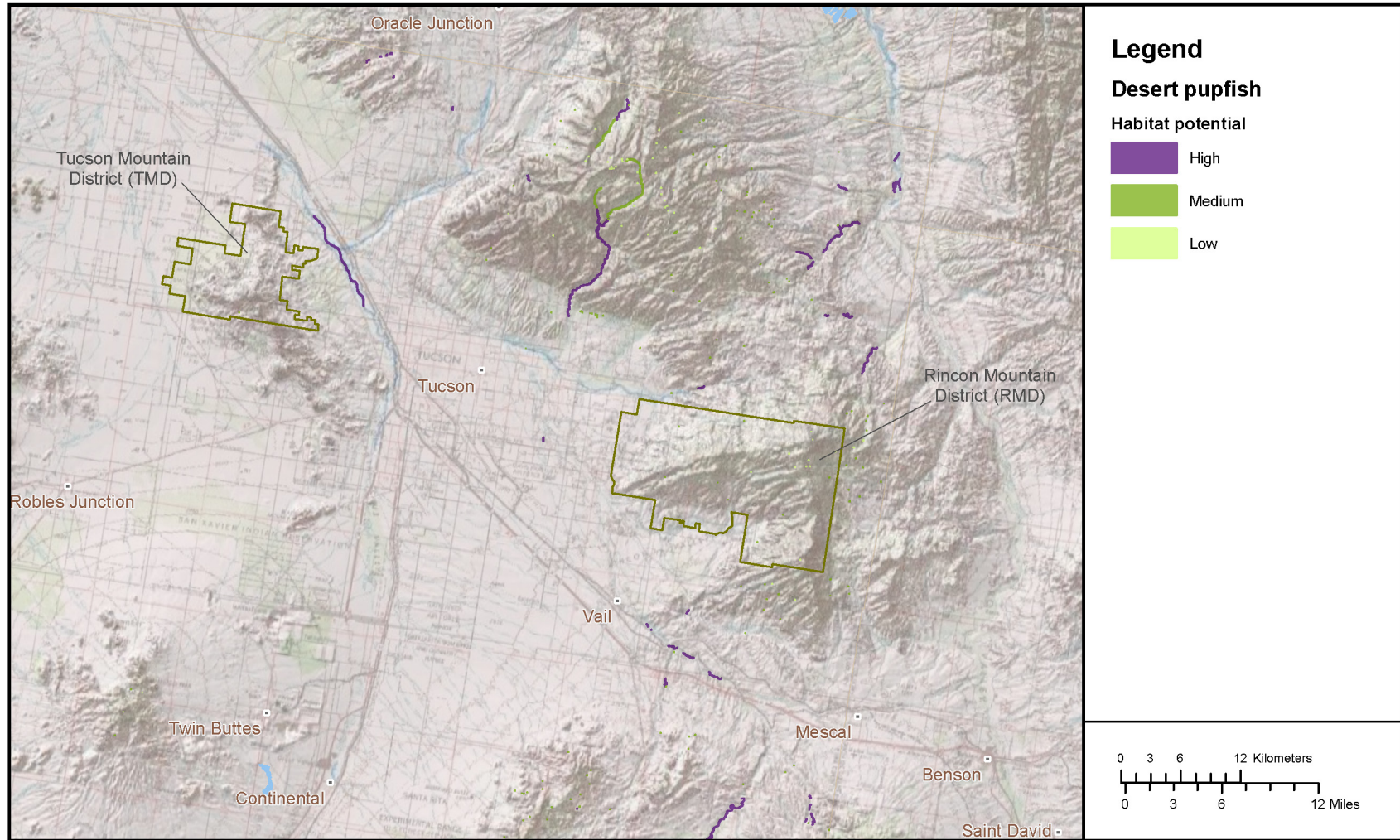
Map 53. Habitat suitability model for the Gentry indigobush, a vulnerable plant species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



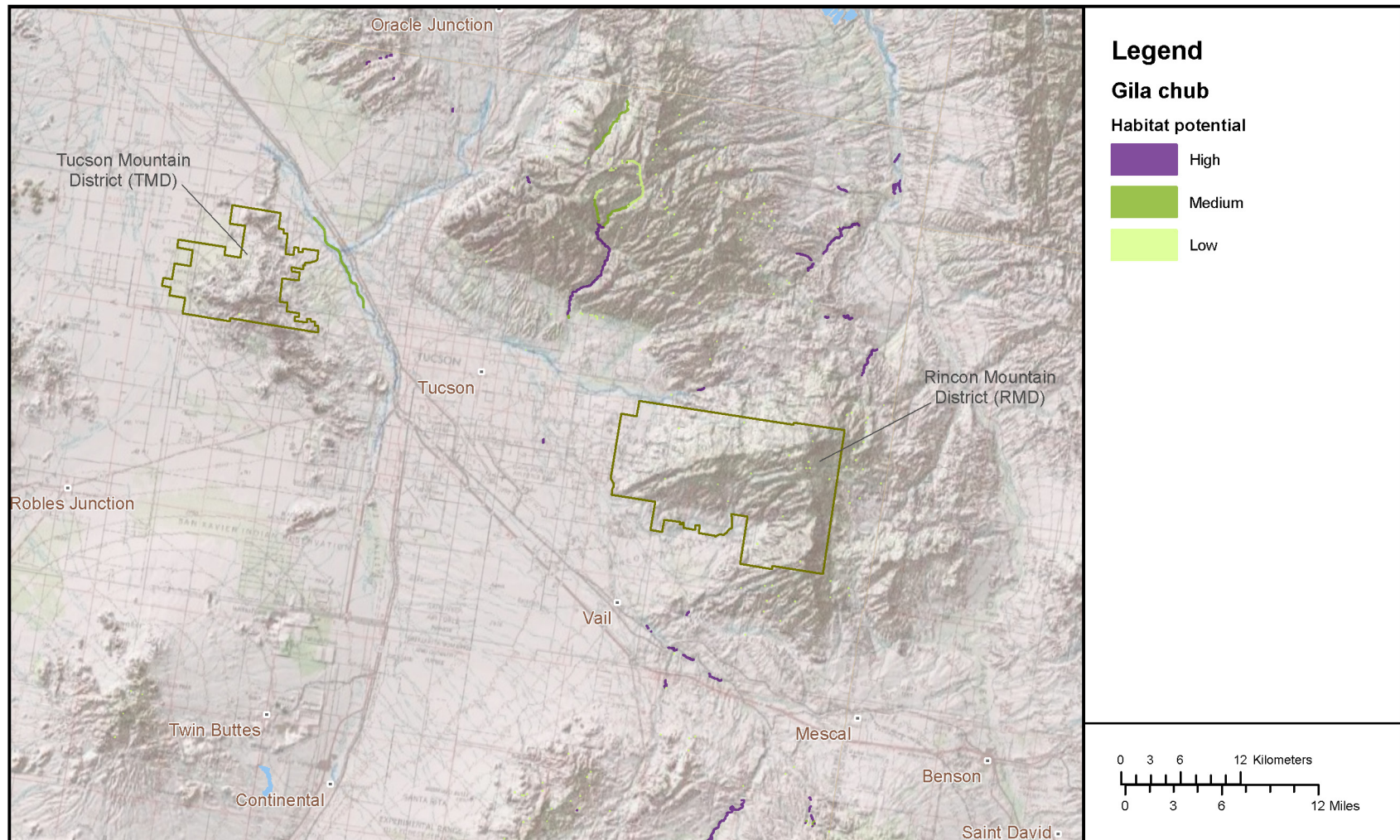
Map 54. Habitat suitability model for the Huachuca water umbel, a vulnerable aquatic plant species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



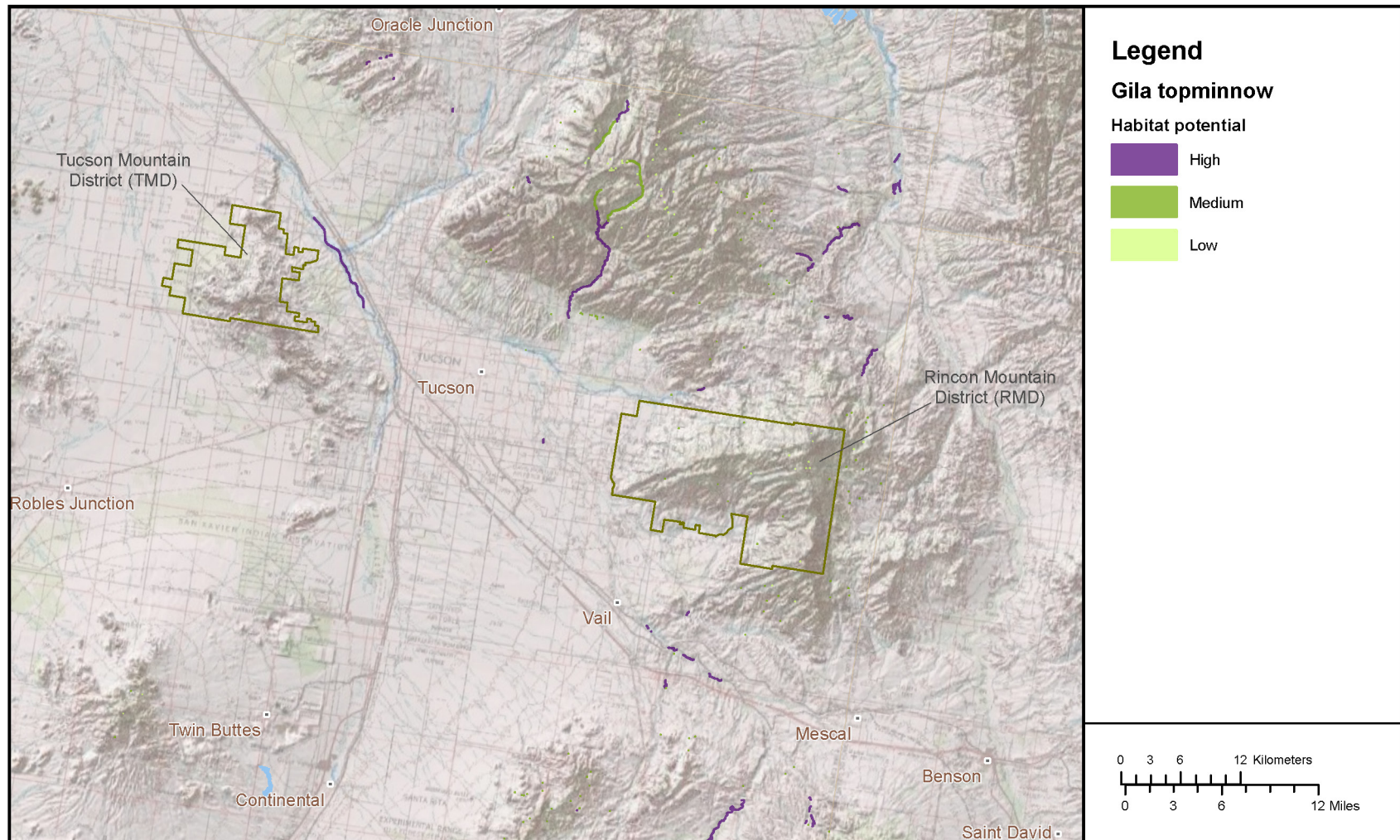
Map 55. Habitat suitability model for the Tumamoc globeberry, a vulnerable plant species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



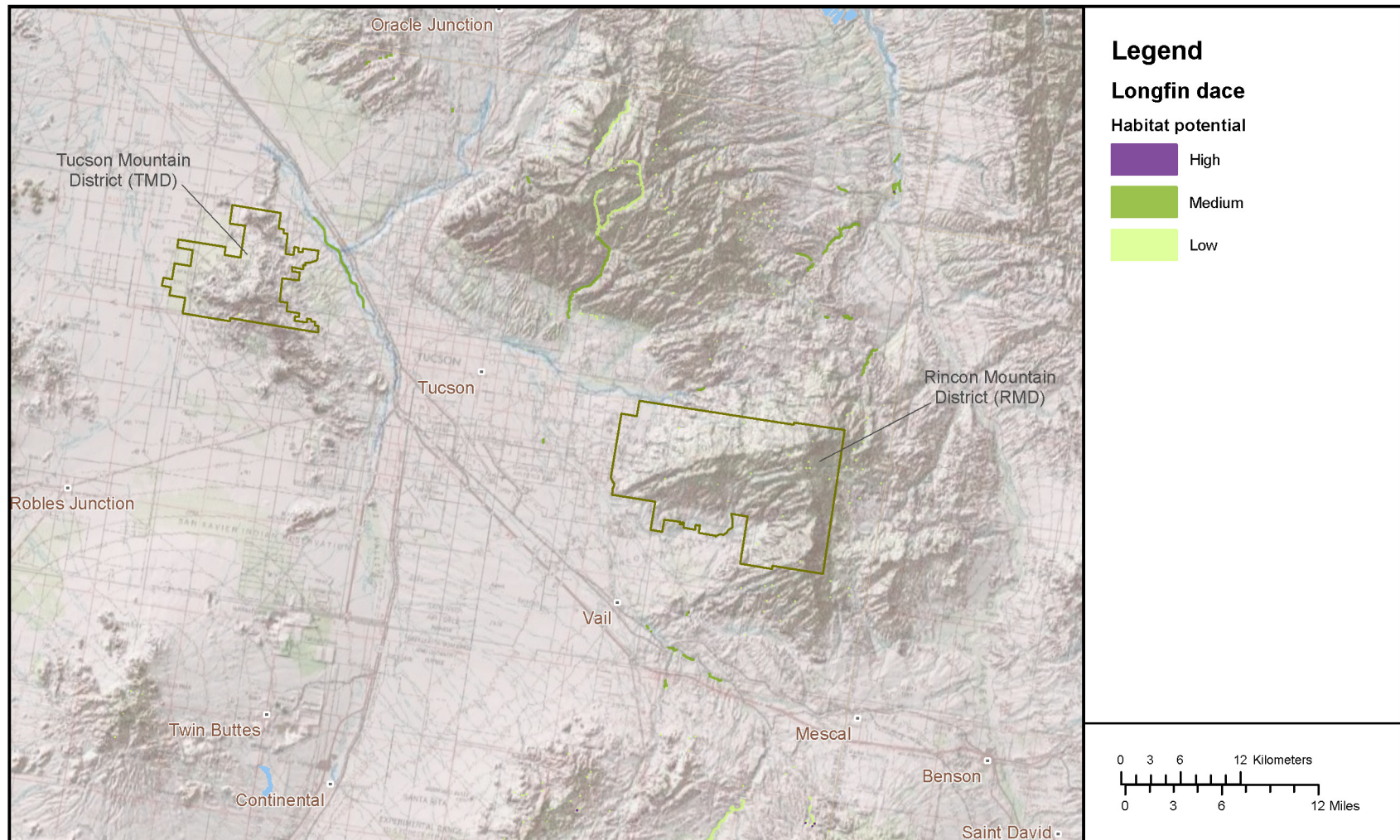
Map 56. Habitat suitability model for the desert pupfish, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



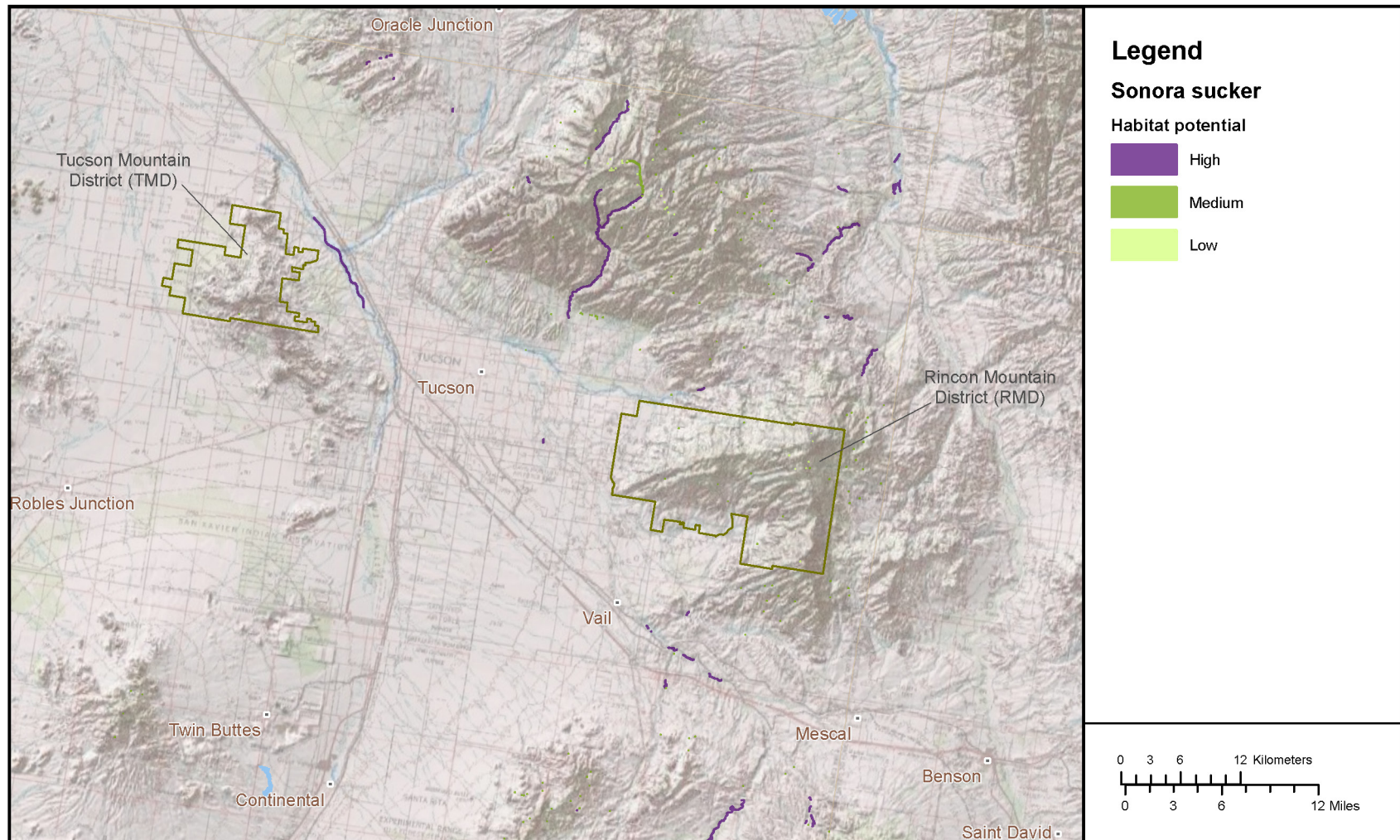
Map 57. Habitat suitability model for the Gila chub, a vulnerable fish species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2002) obtained from the Pima County Information Technology Department.



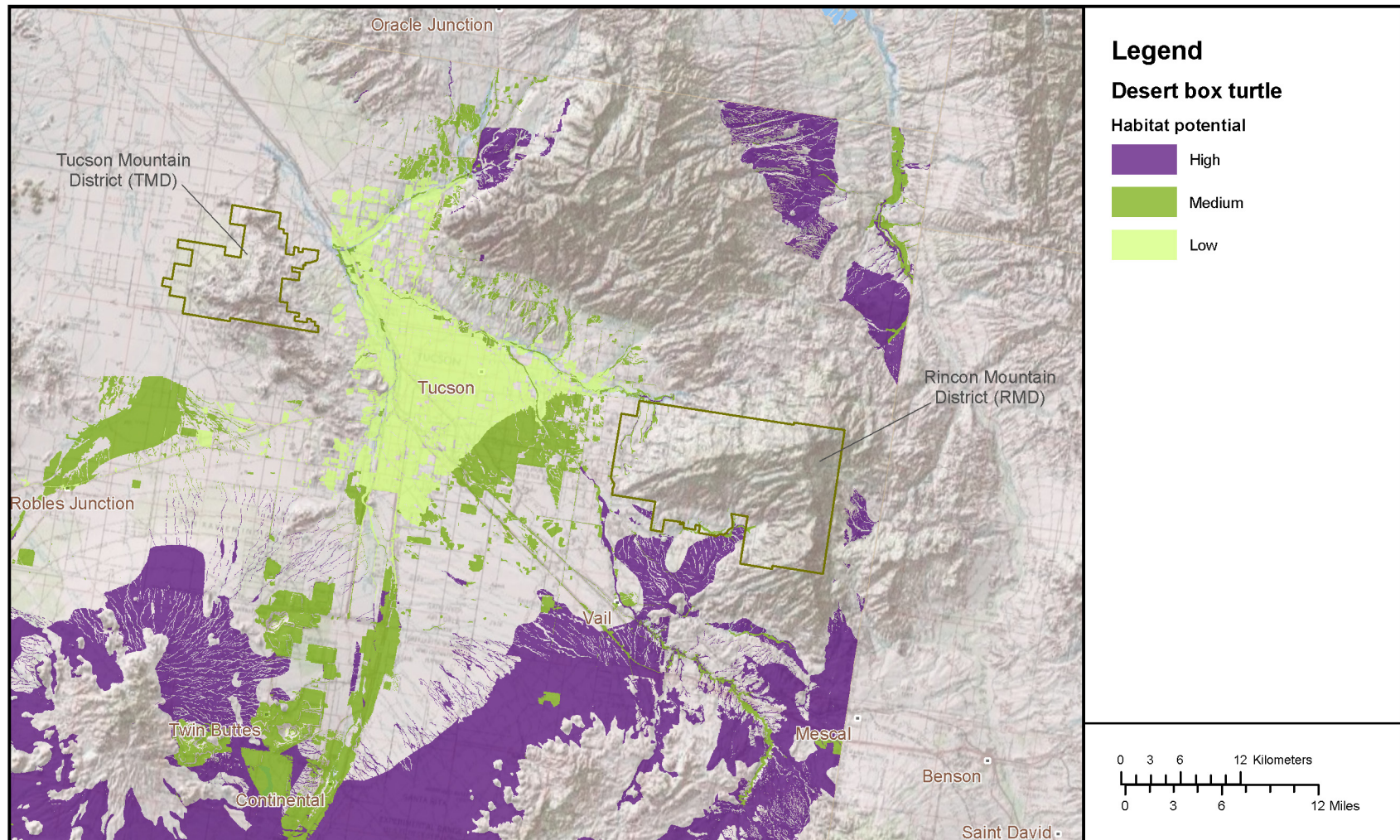
Map 58. Habitat suitability model for the Gila topminnow, a vulnerable fish species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



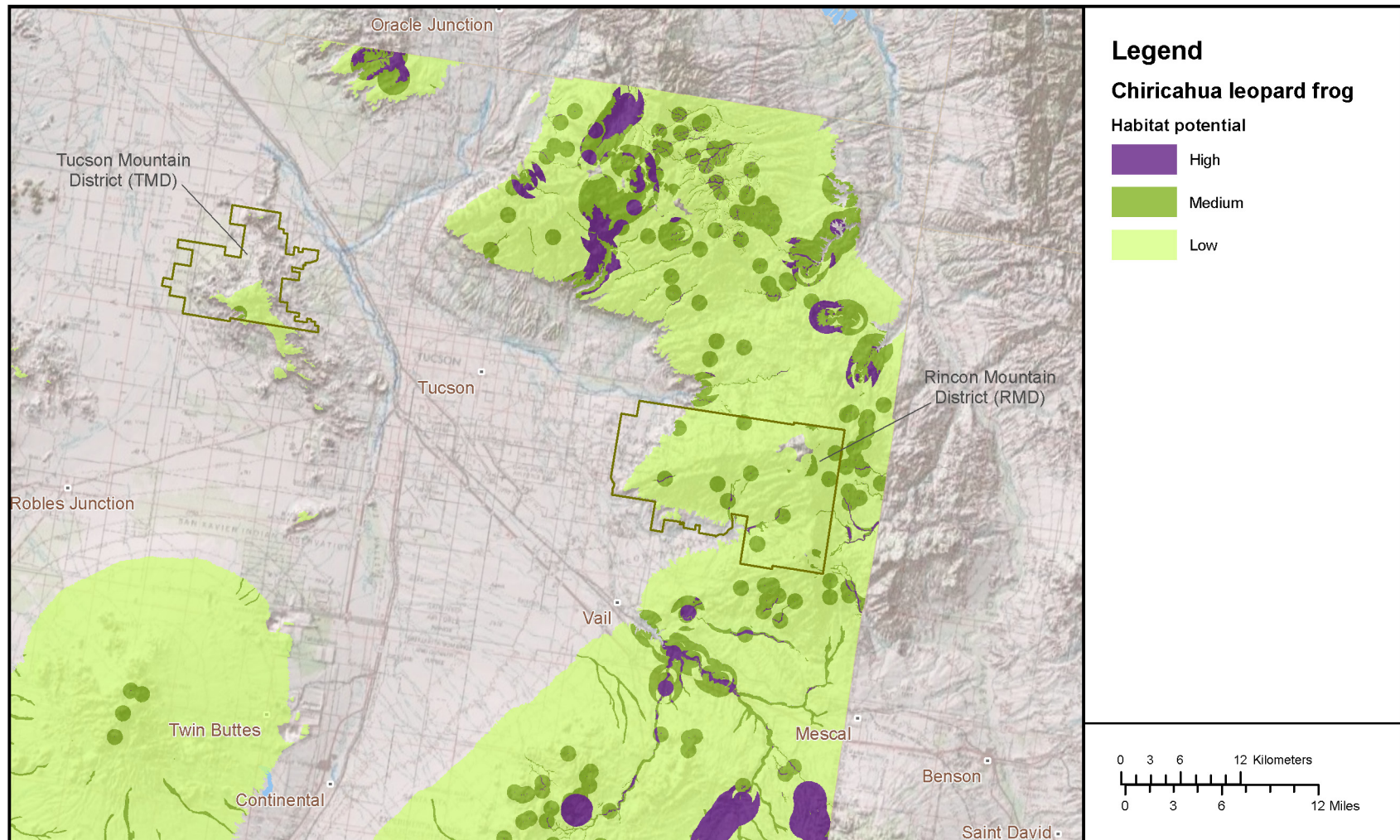
Map 59. Habitat suitability model for the longfin dace, a vulnerable fish species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



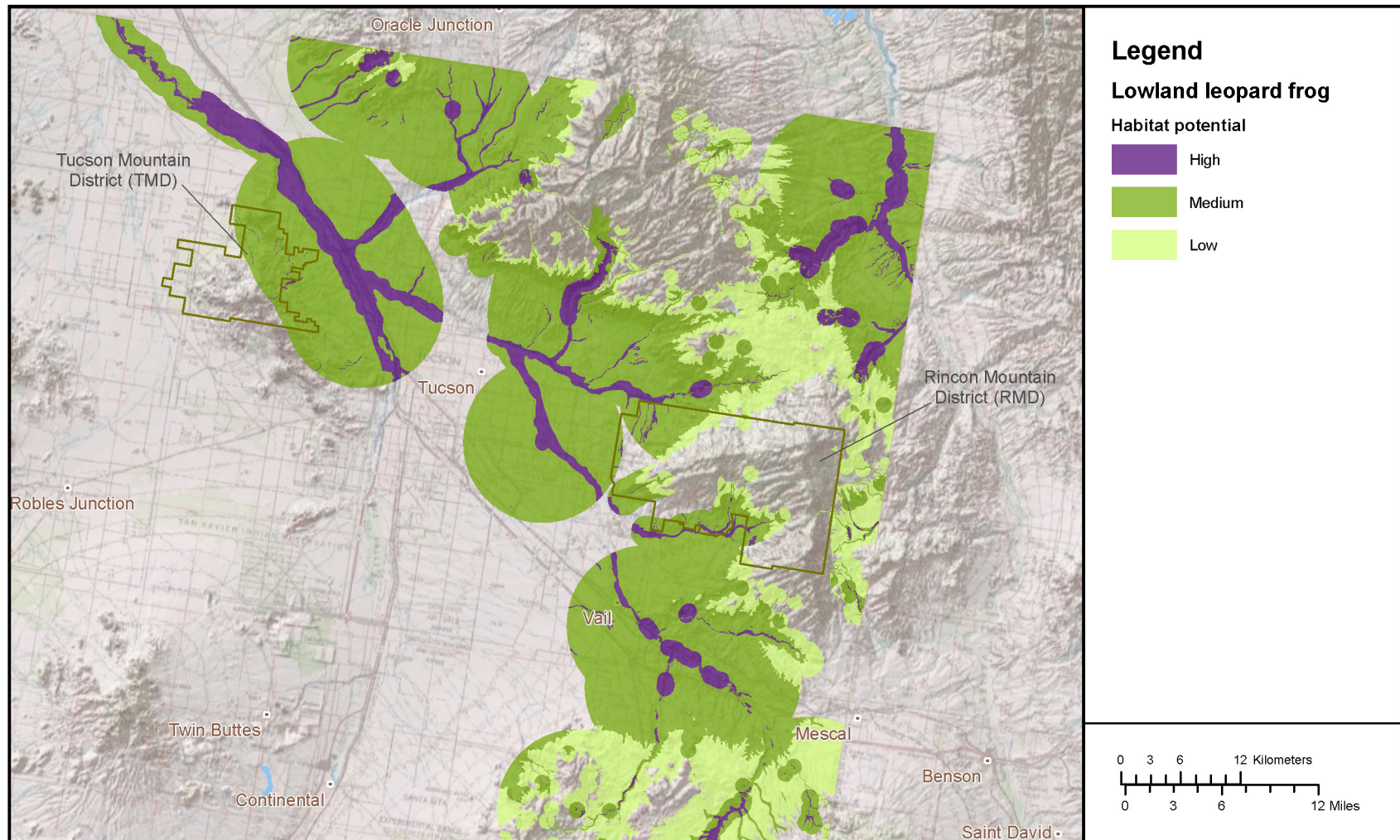
Map 60. Habitat suitability model for the Sonora sucker, a vulnerable fish species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



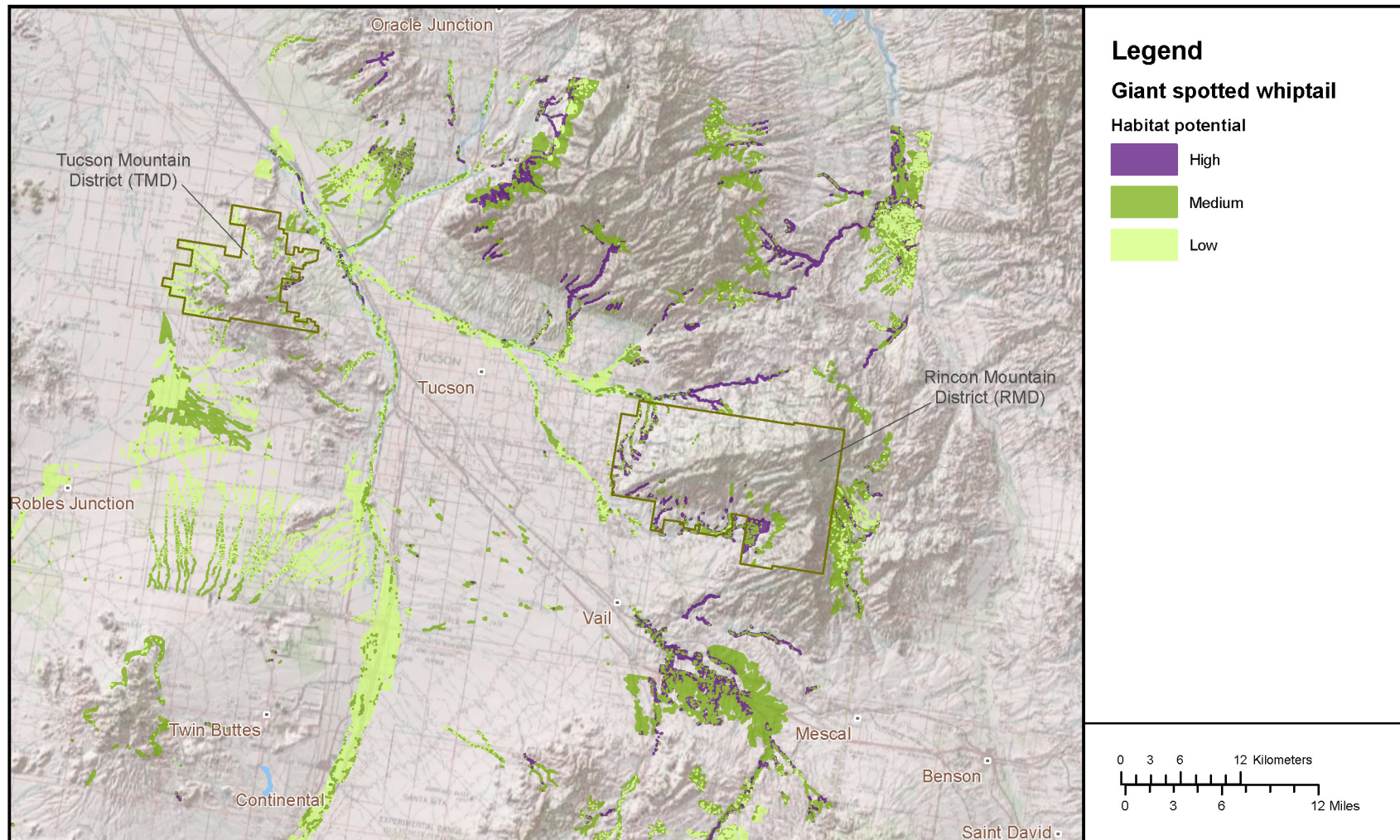
Map 61. Habitat suitability model for the desert box turtle, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



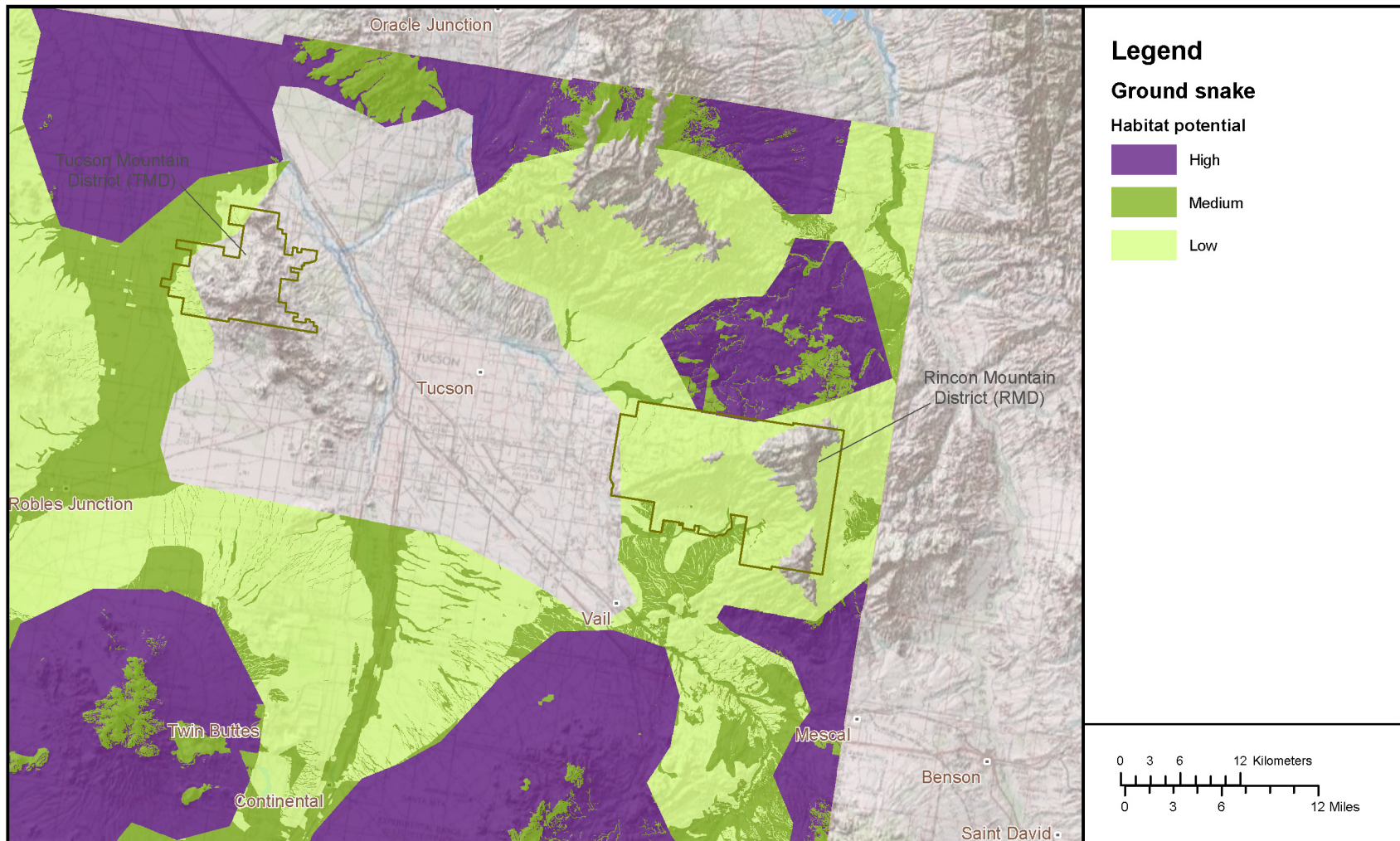
Map 62. Habitat suitability model for the Chiricahua leopard frog, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



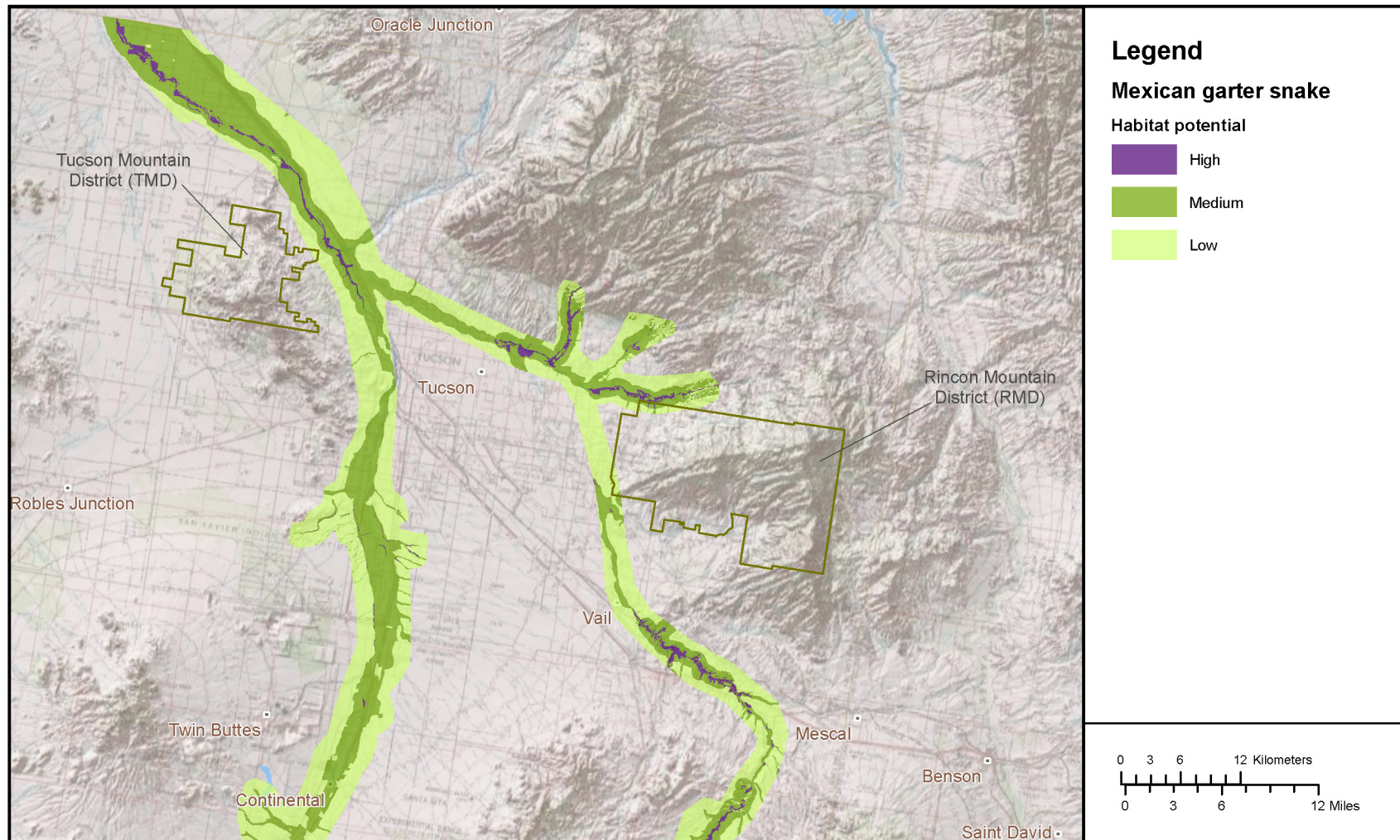
Map 63. Habitat suitability model for the lowland leopard frog, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



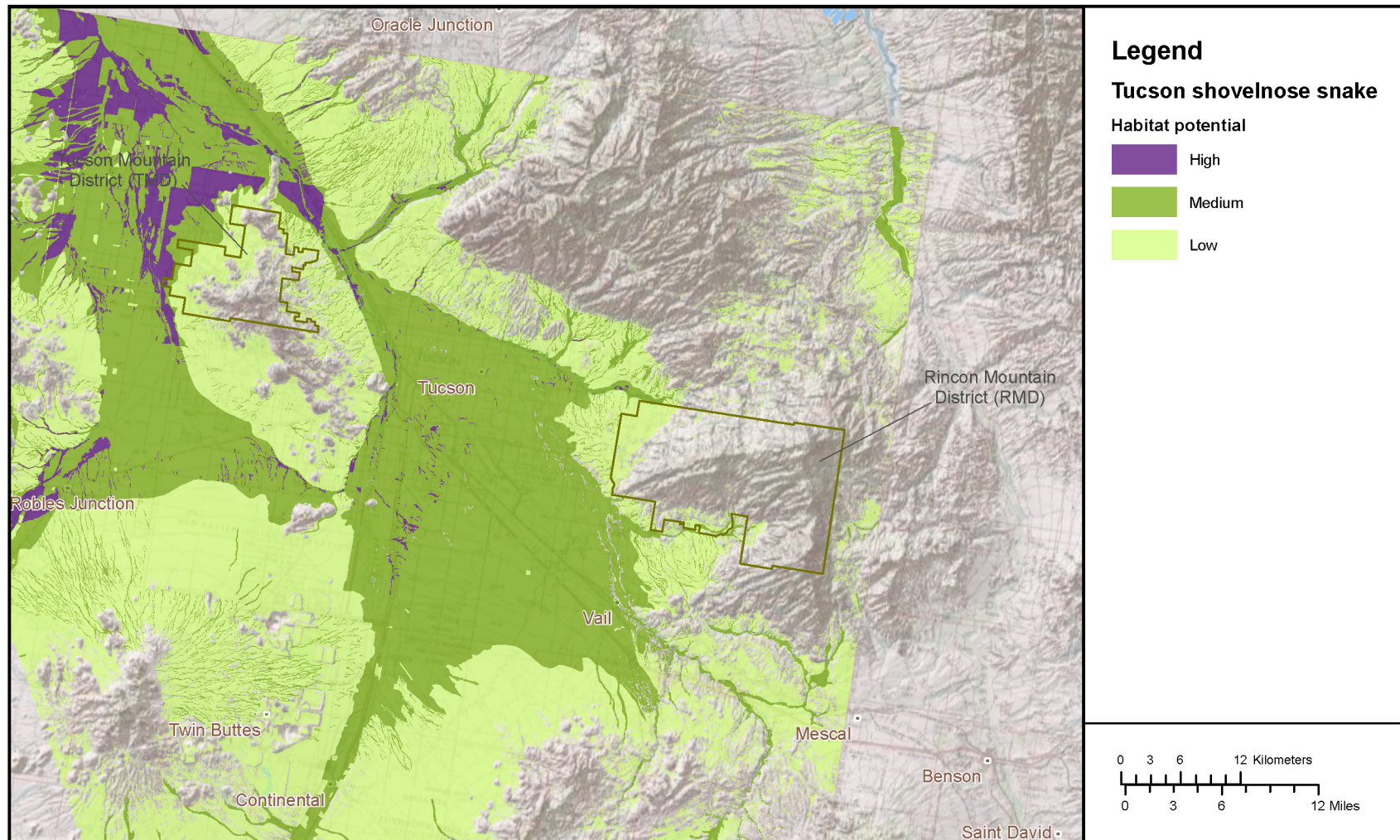
Map 64. Habitat suitability model for the giant spotted whiptail, a vulnerable lizard species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



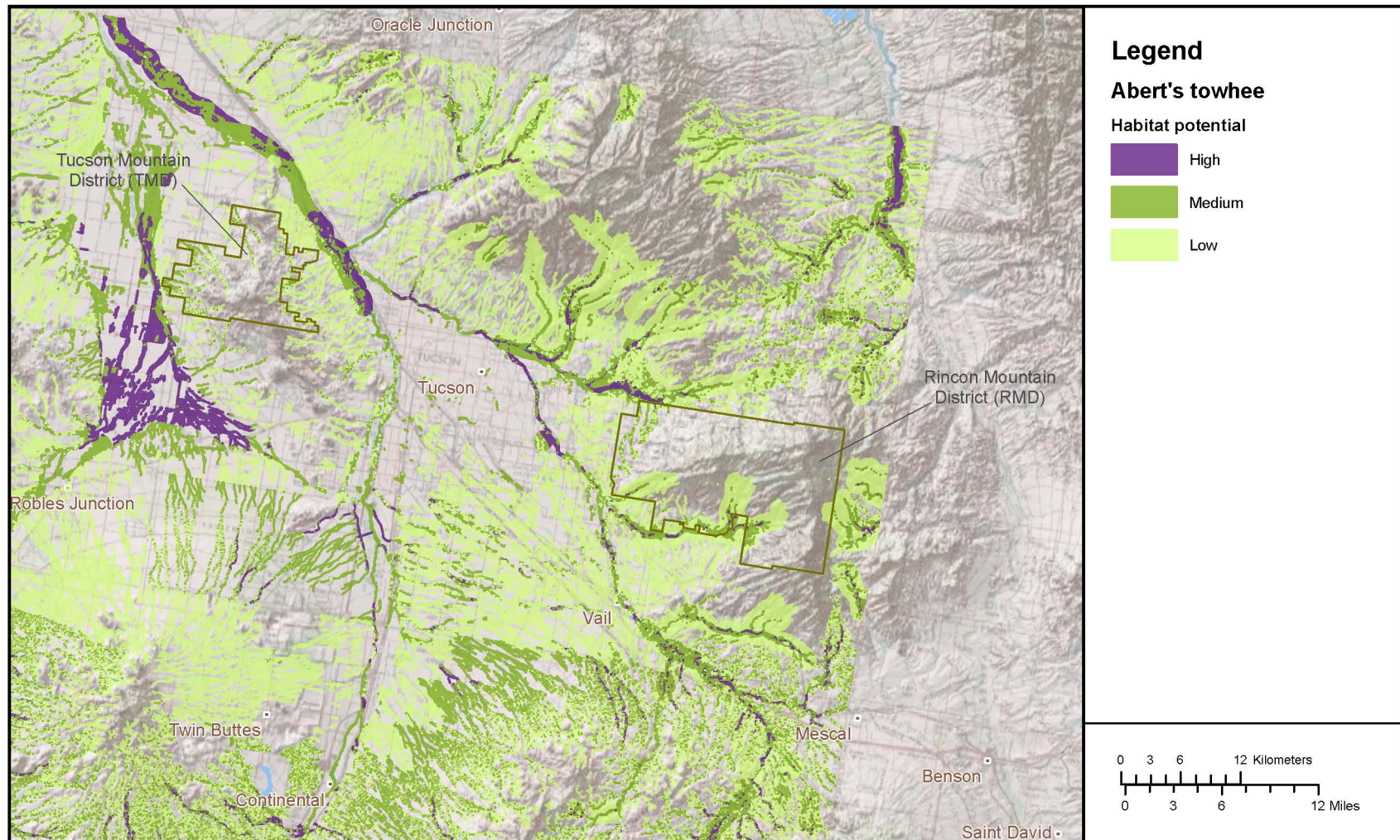
Map 65. Habitat suitability model for the ground snake, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



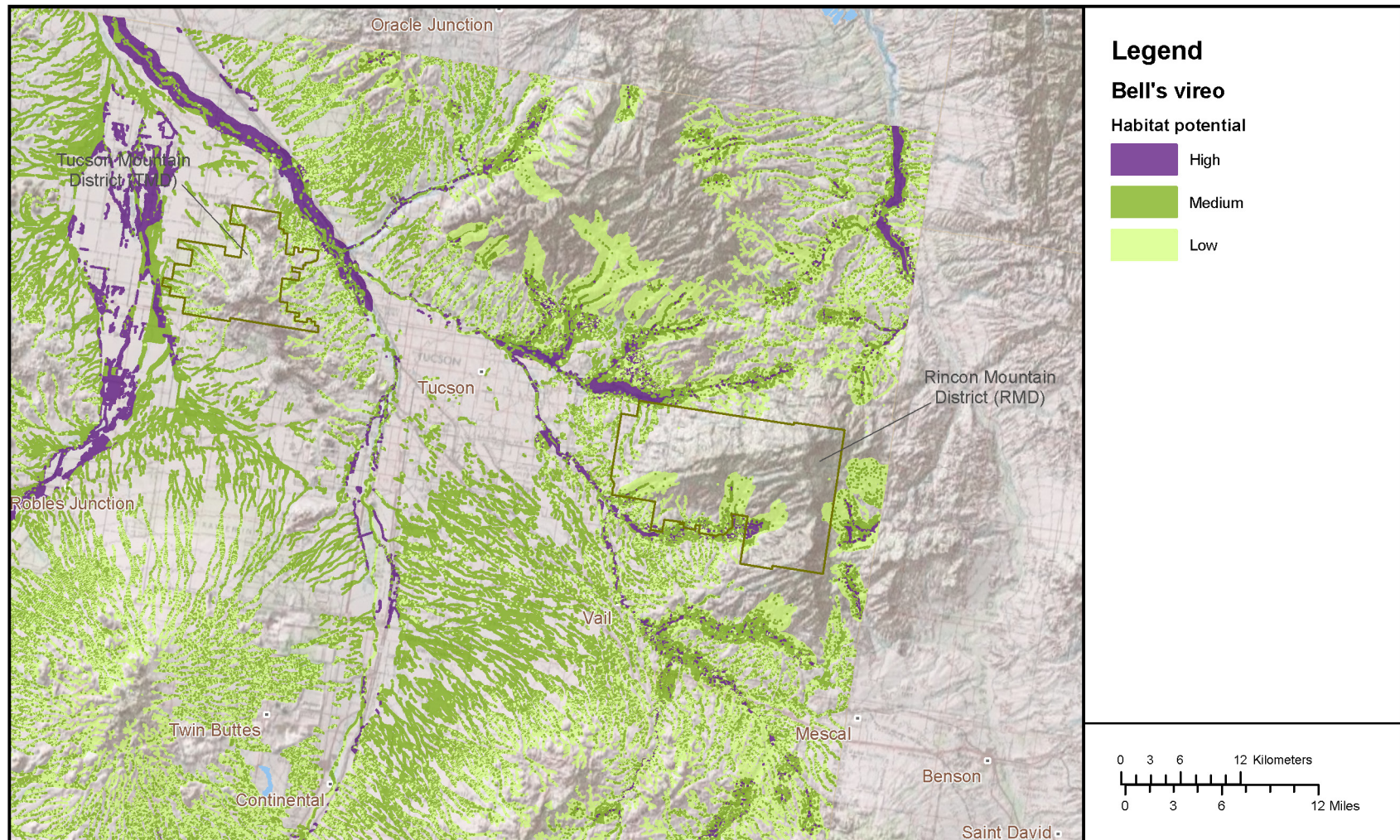
Map 66. Habitat suitability model for the Mexican garter snake, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



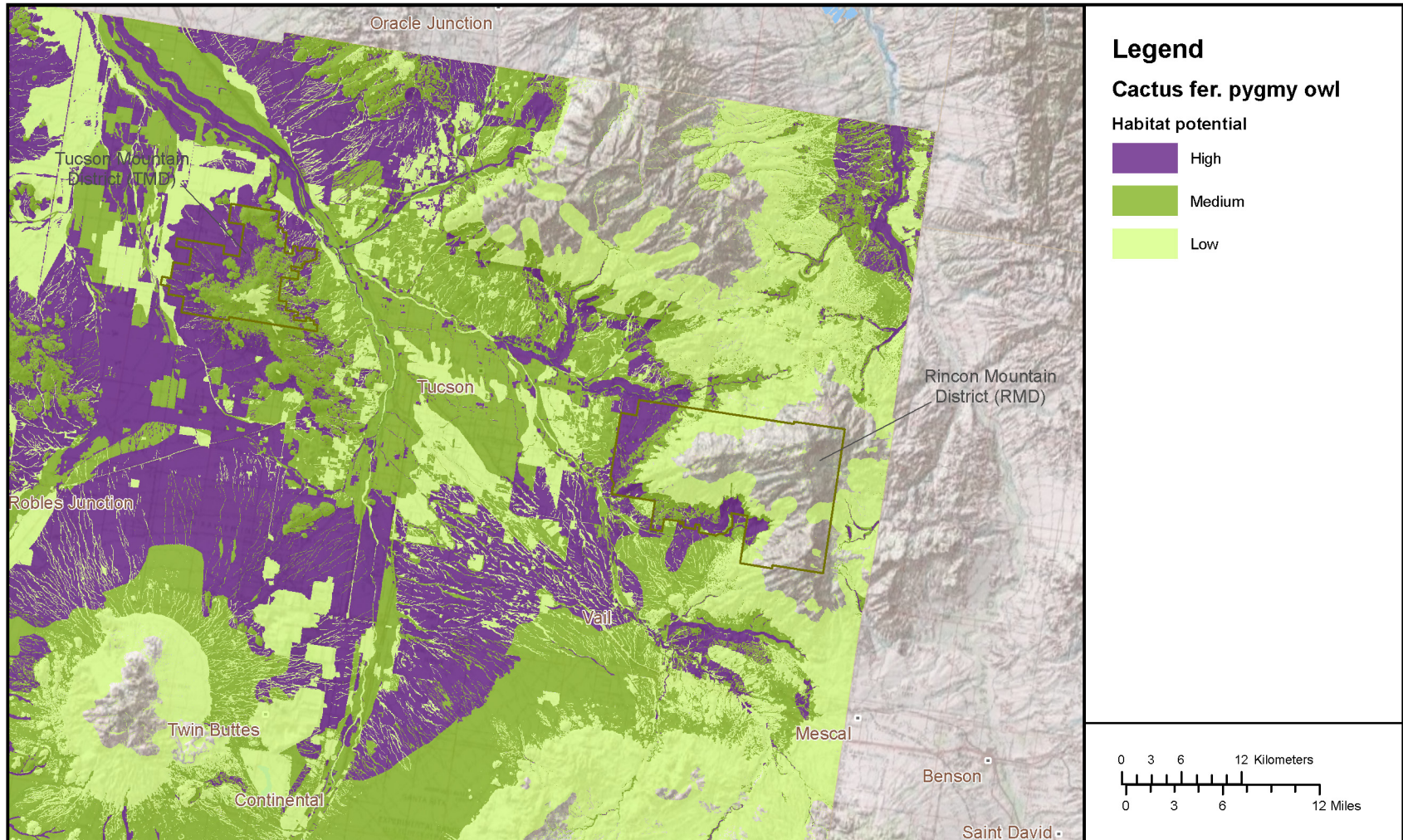
Map 67. Habitat suitability model for the Tucson shovelnose snake, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



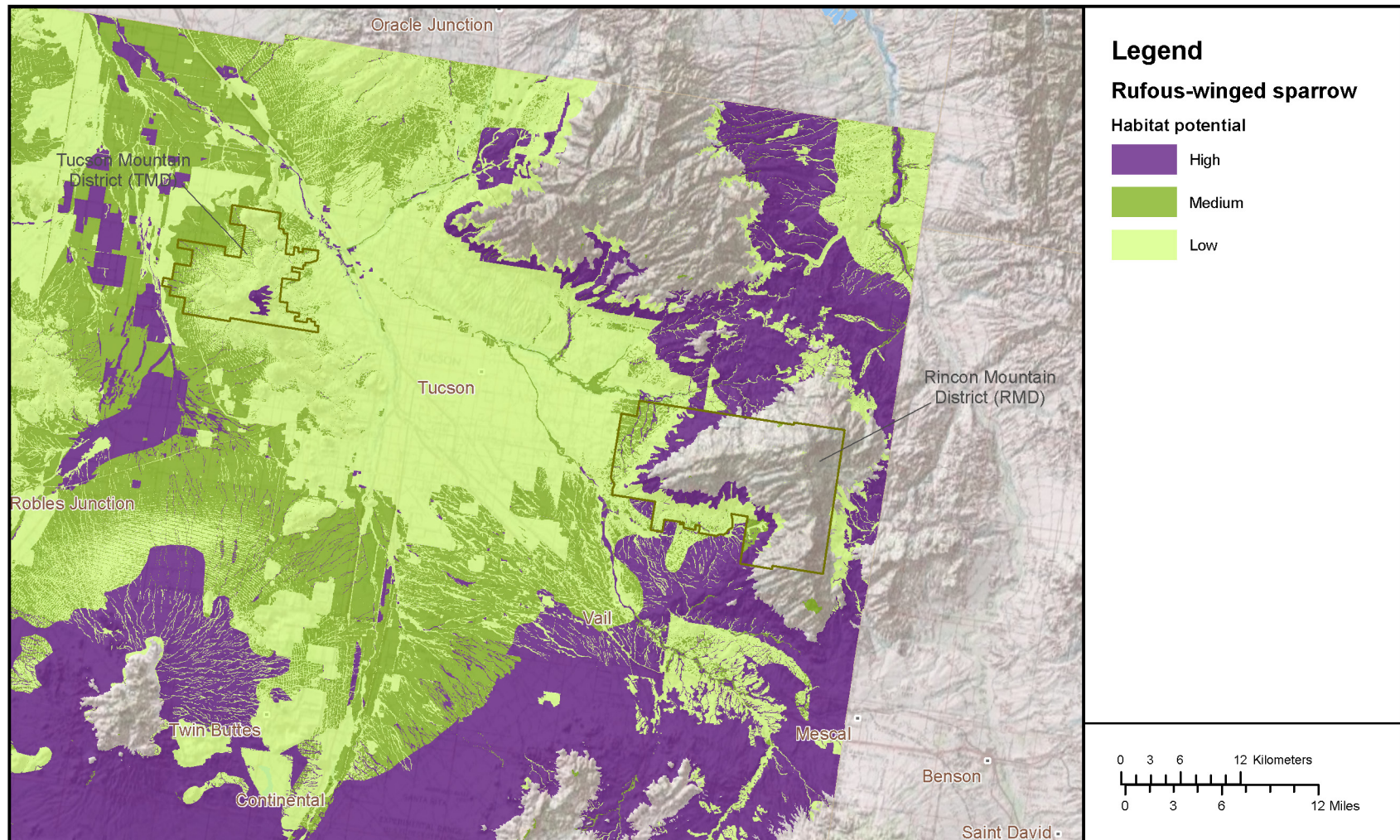
Map 68. Habitat suitability model for Abert's towhee, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



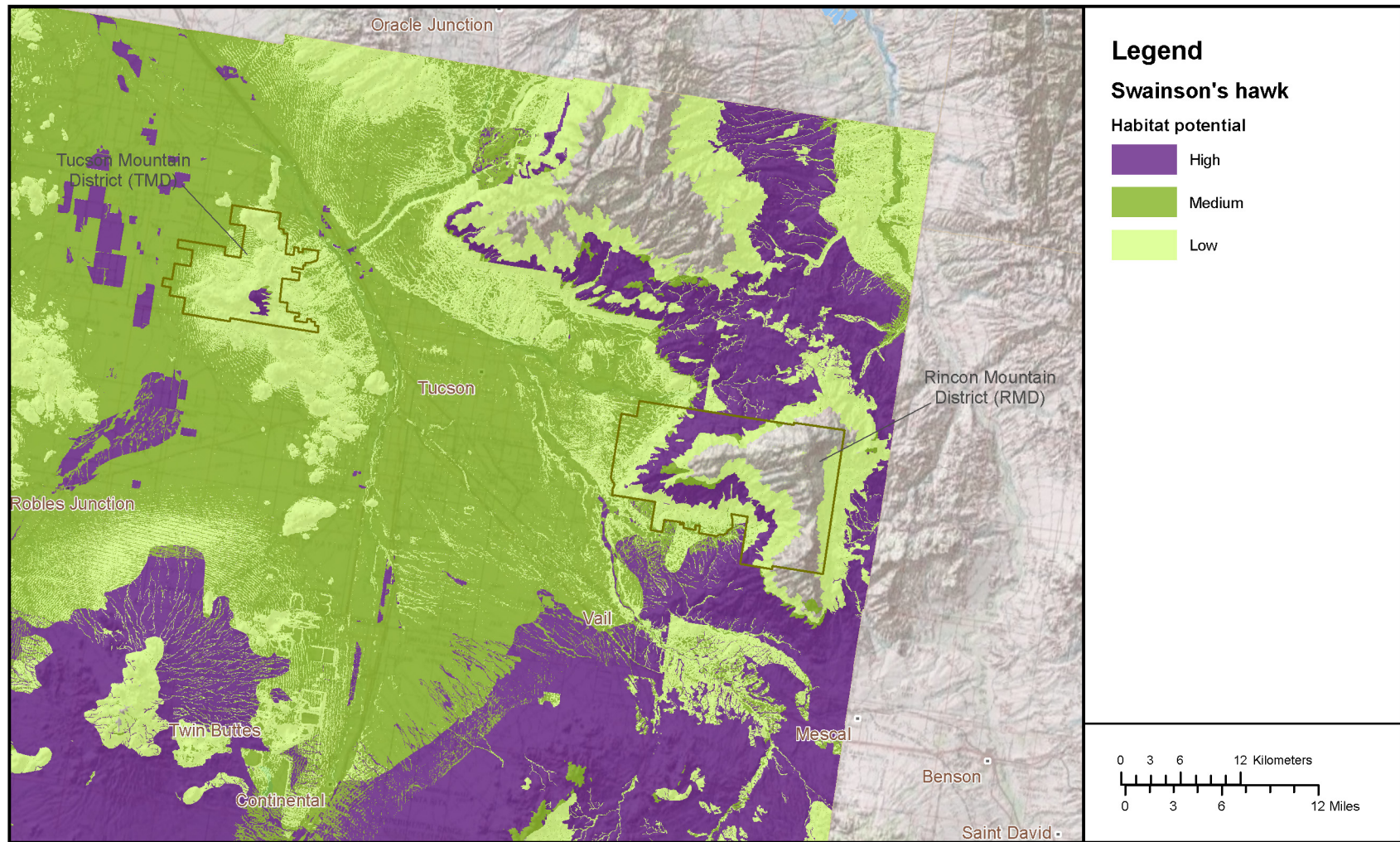
Map 69. Habitat suitability model for Bell's vireo, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



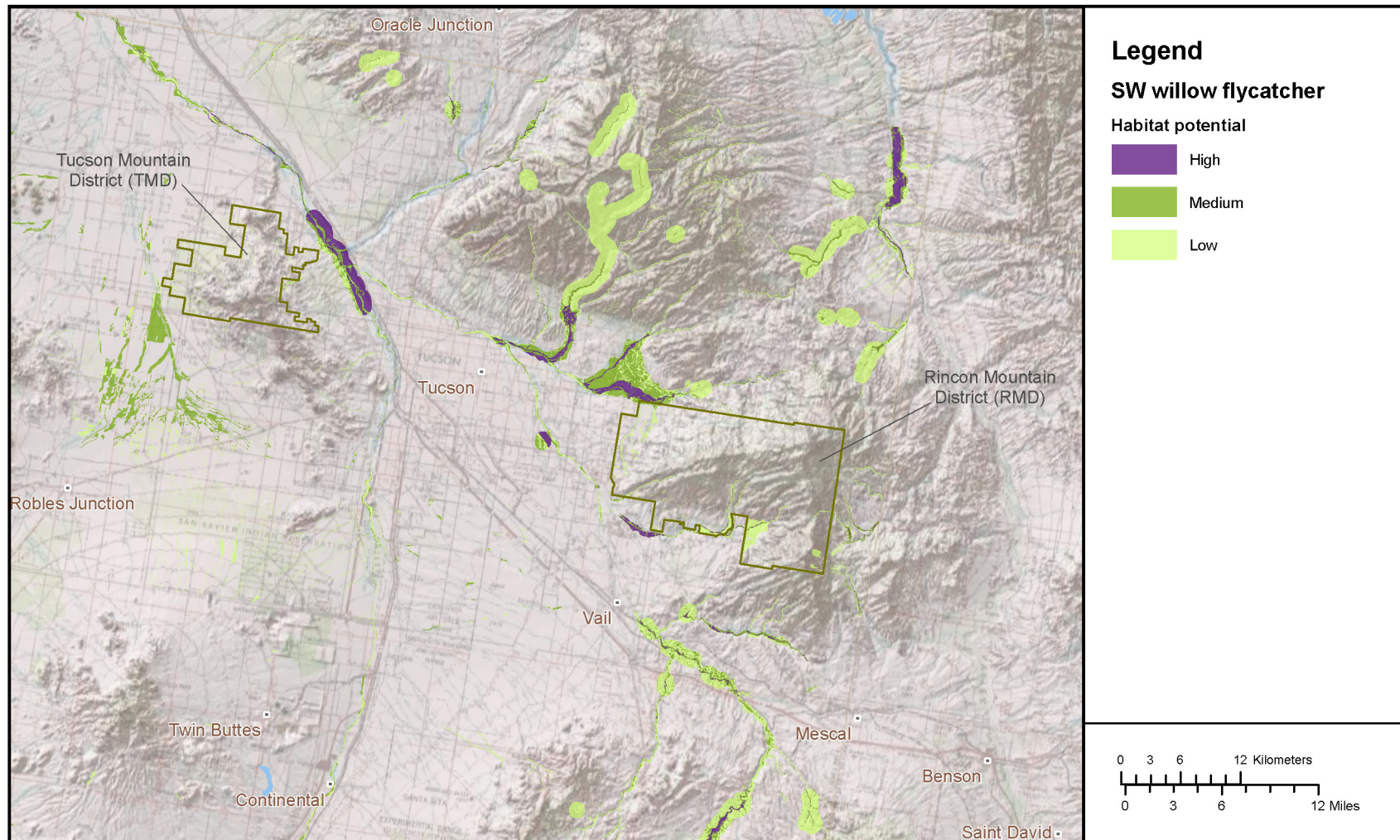
Map 70. Habitat suitability model for cactus ferruginous pygmy owl, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



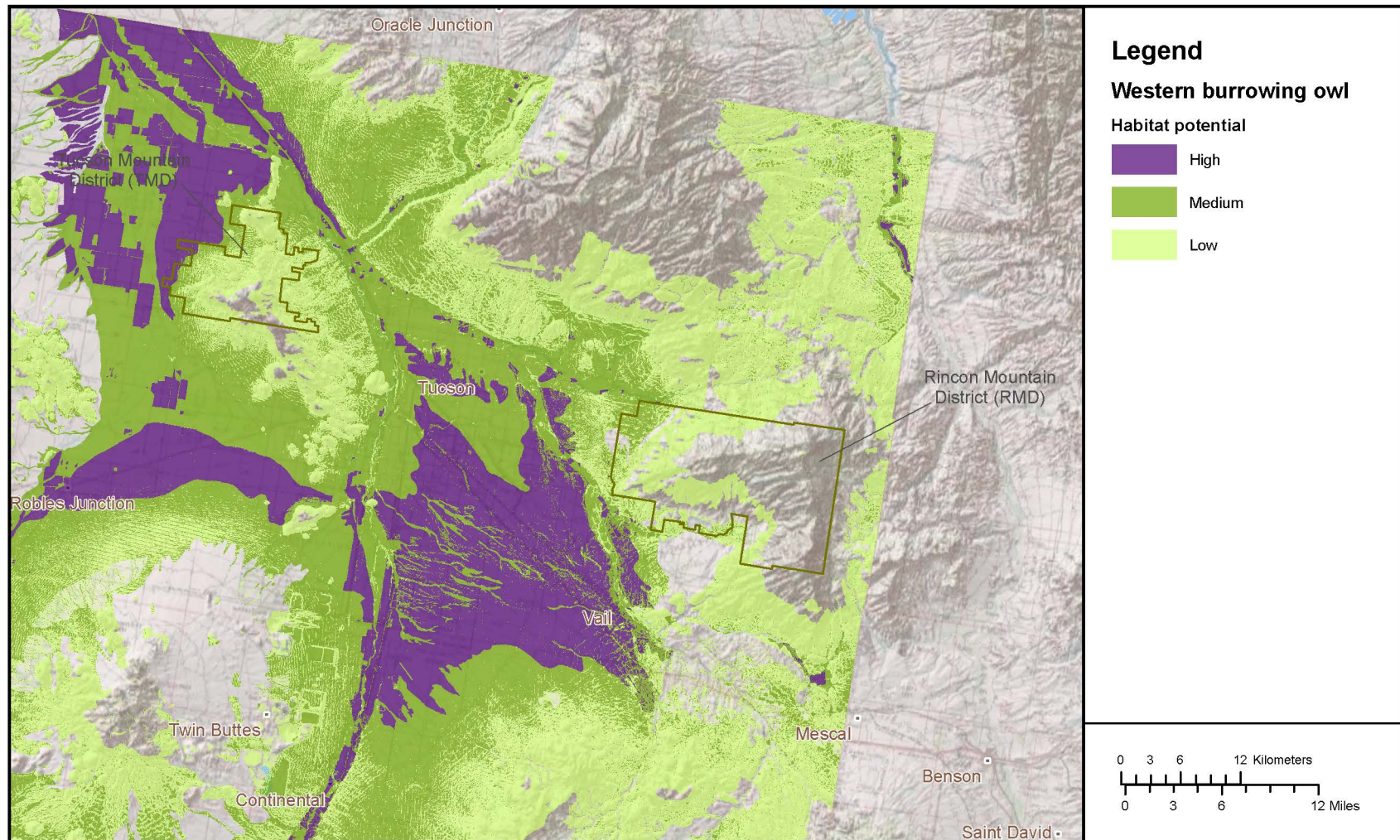
Map 71. Habitat suitability model for the rufous-winged sparrow, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



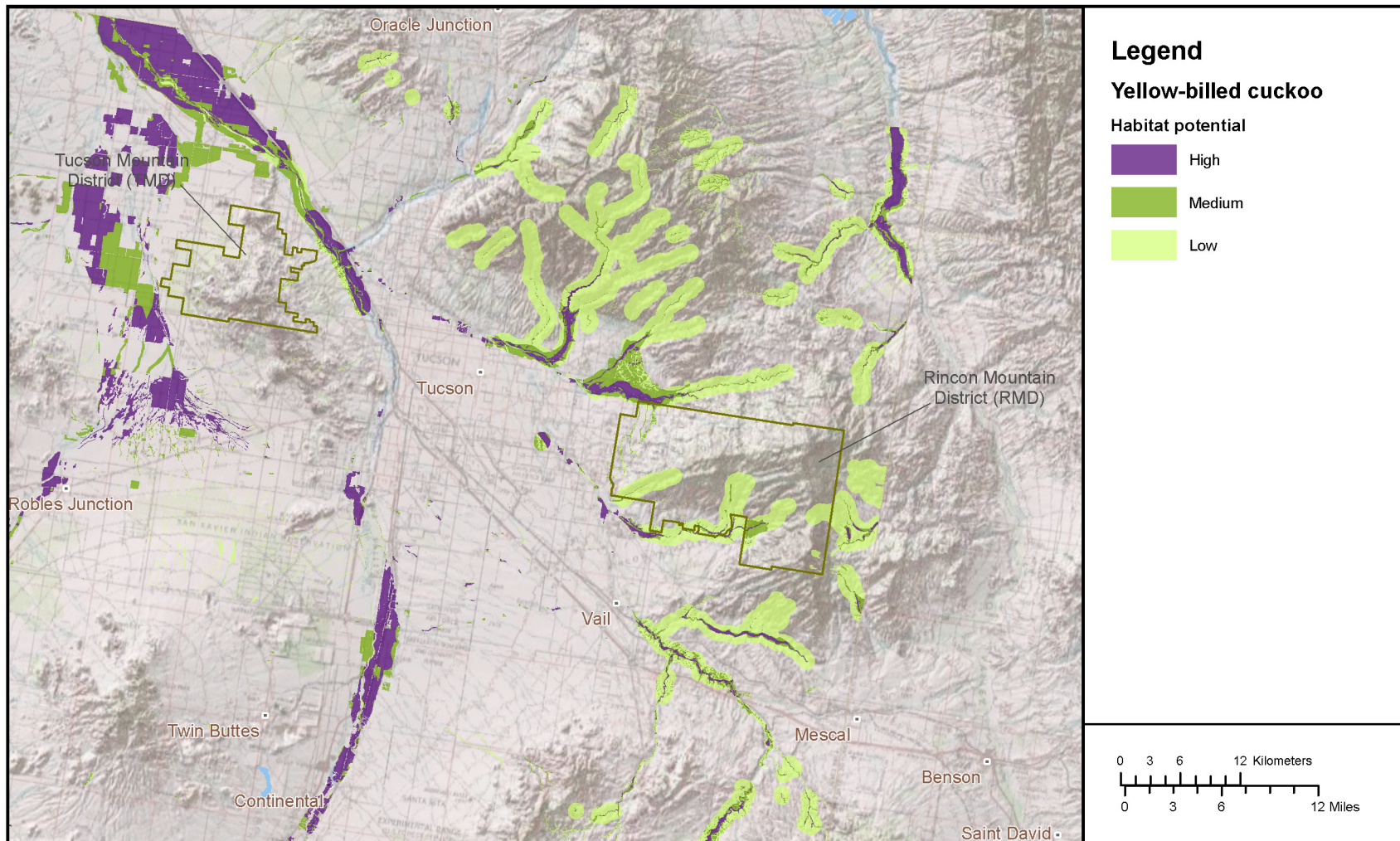
Map 72. Habitat suitability model Swainson's hawk, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



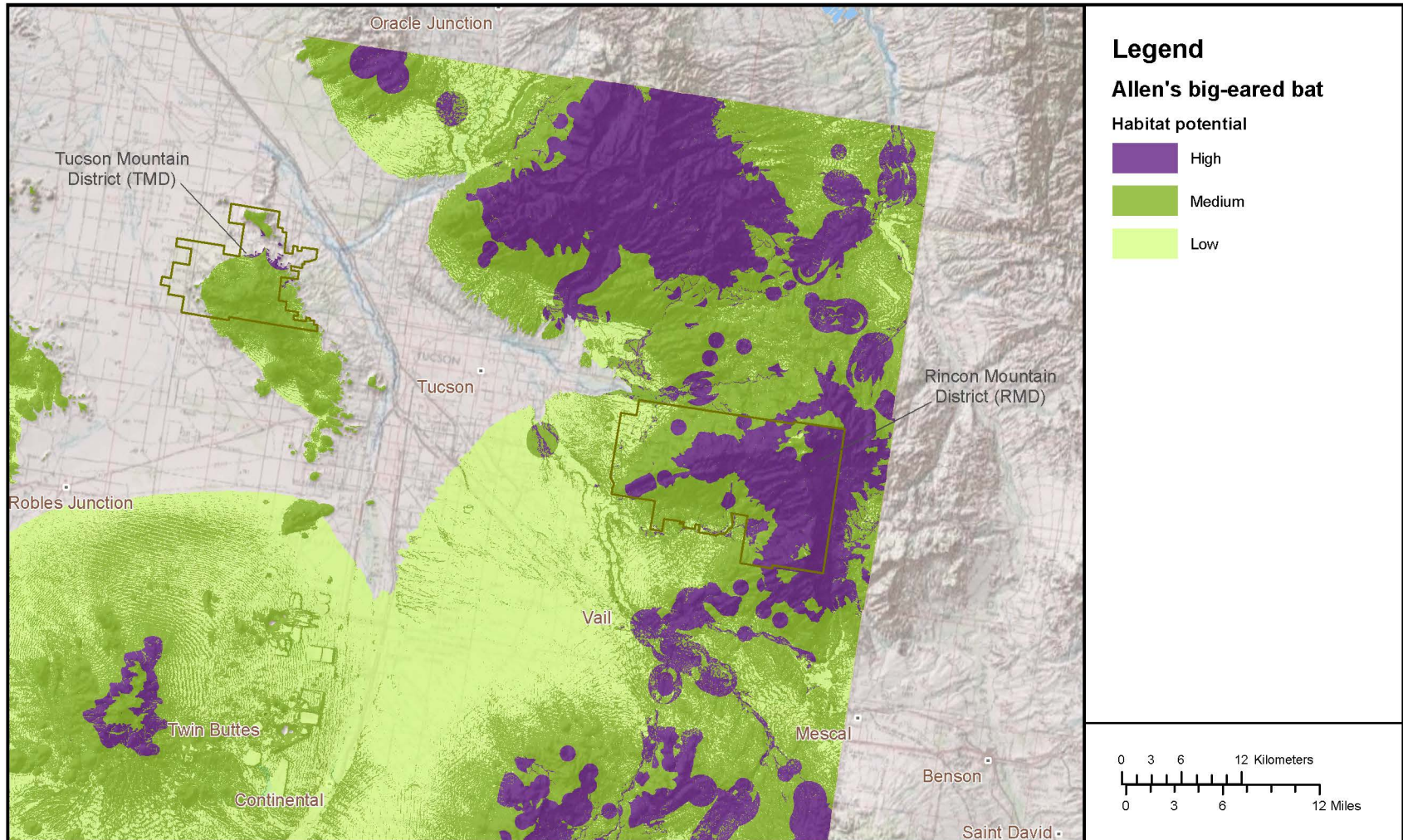
Map 73. Habitat suitability model for the southwestern willow flycatcher, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



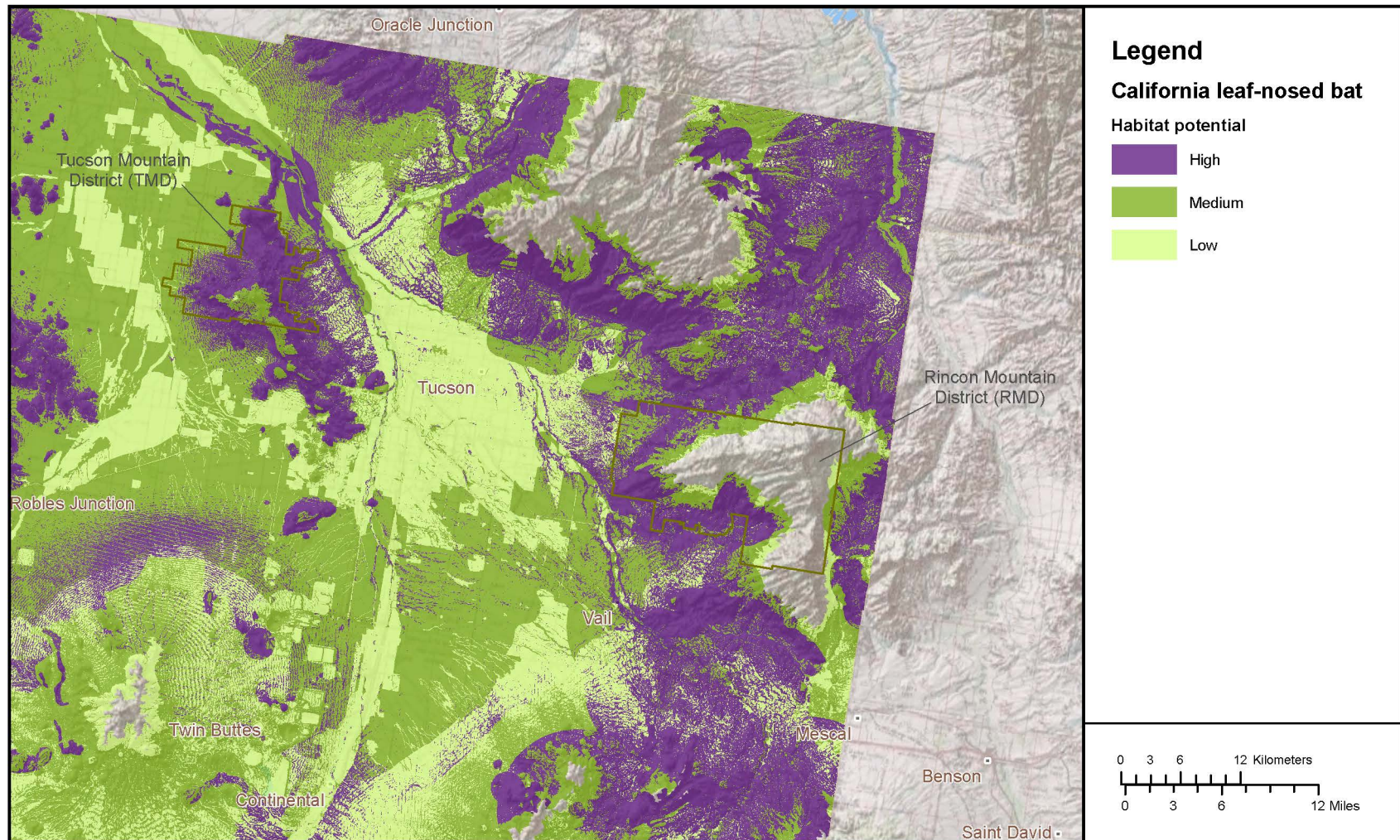
Map 74. Habitat suitability model for the western burrowing owl, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



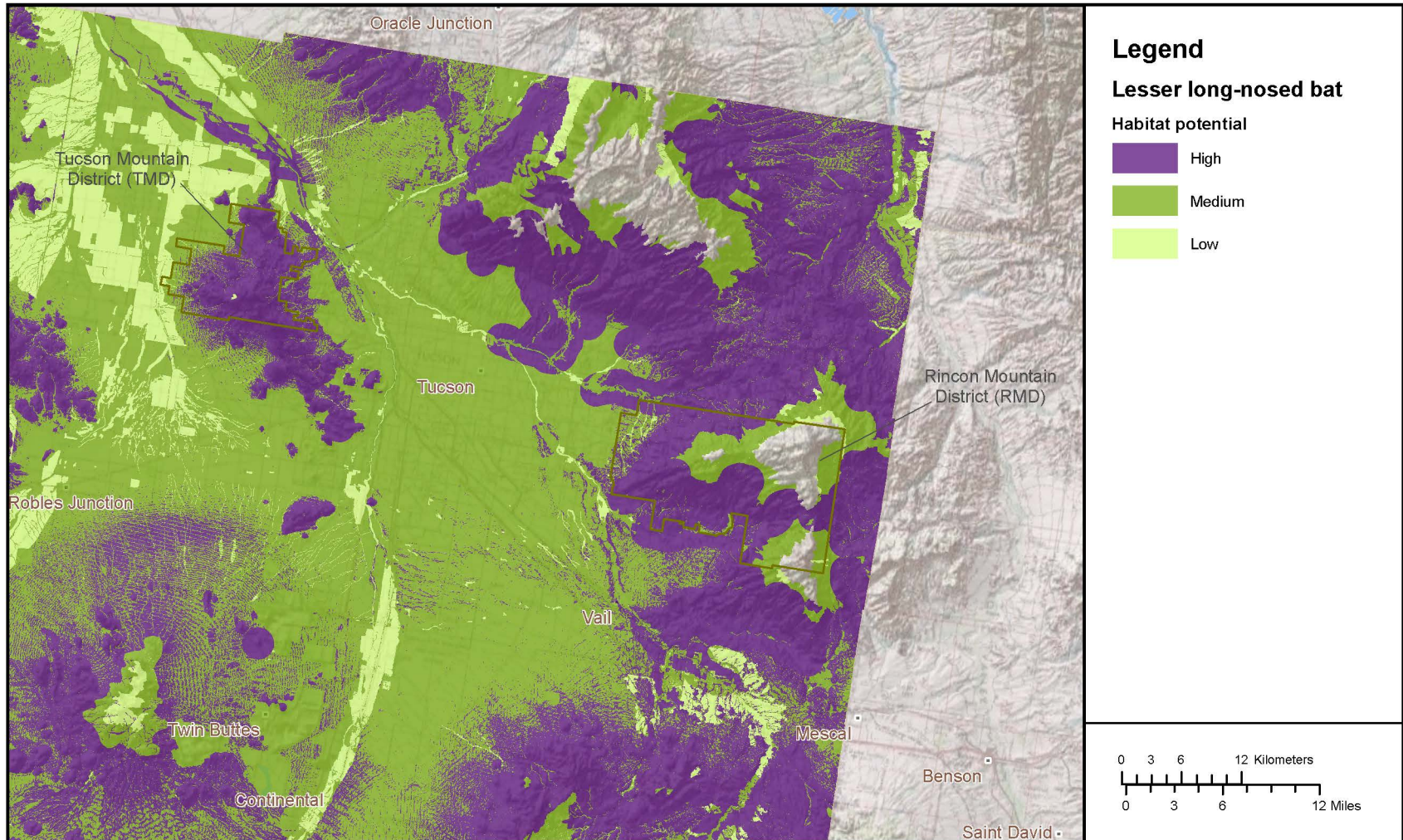
Map 75. Habitat suitability model for the yellow-billed cuckoo, a vulnerable bird species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



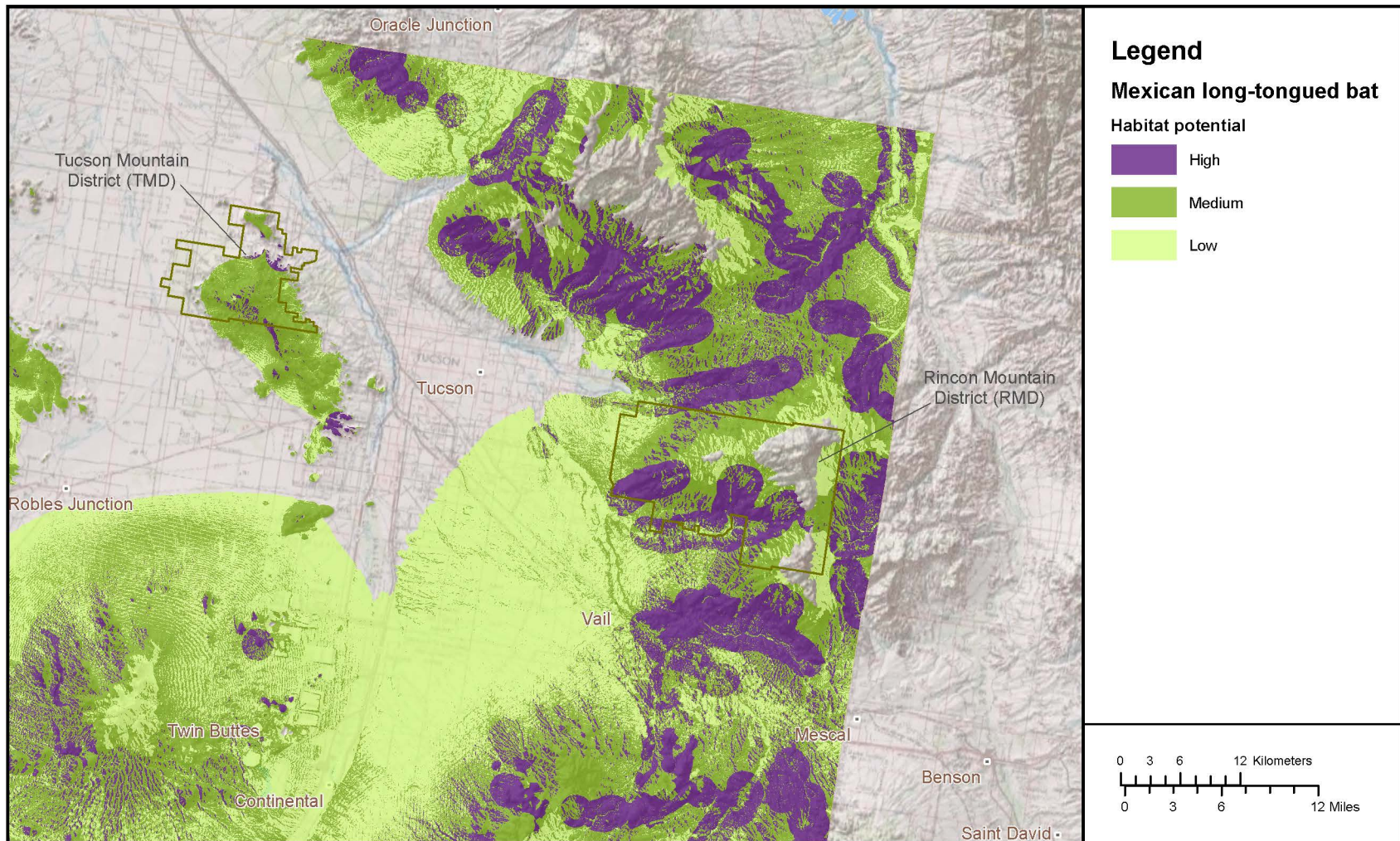
Map 76. Habitat suitability model for Allen's big-eared bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



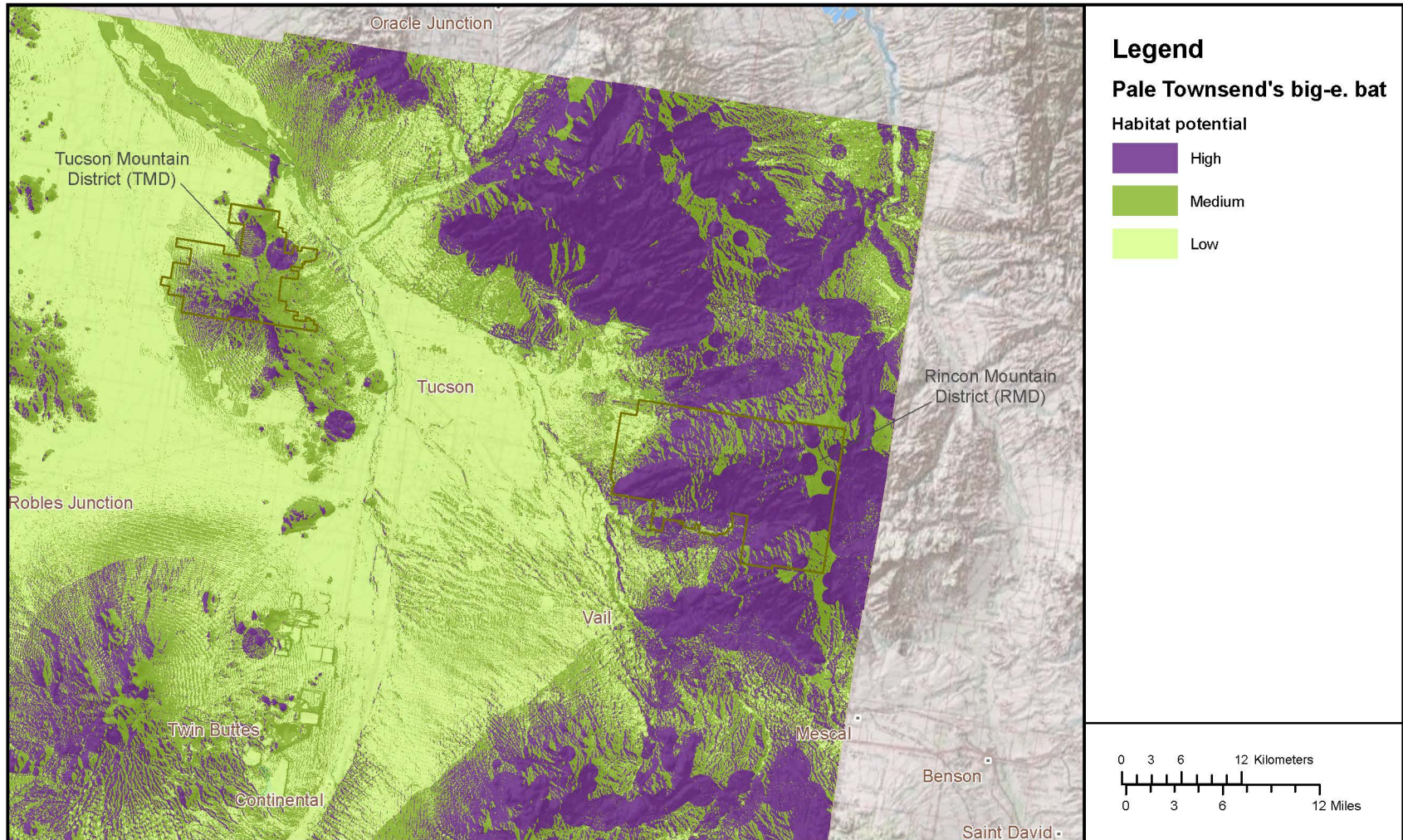
Map 77. Habitat suitability model for the California leaf-nose bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



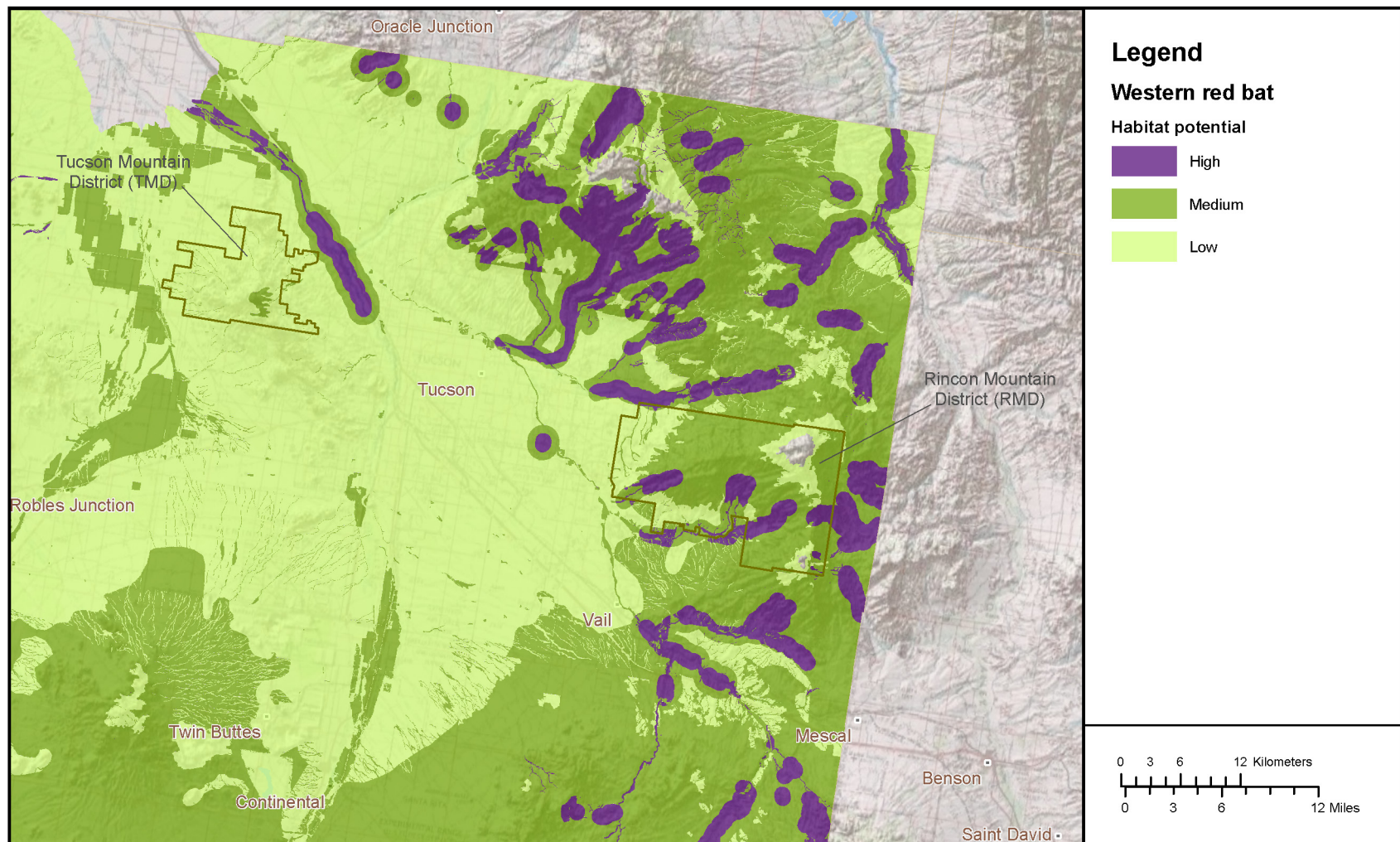
Map 78. Habitat suitability model for the lesser long-nosed bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



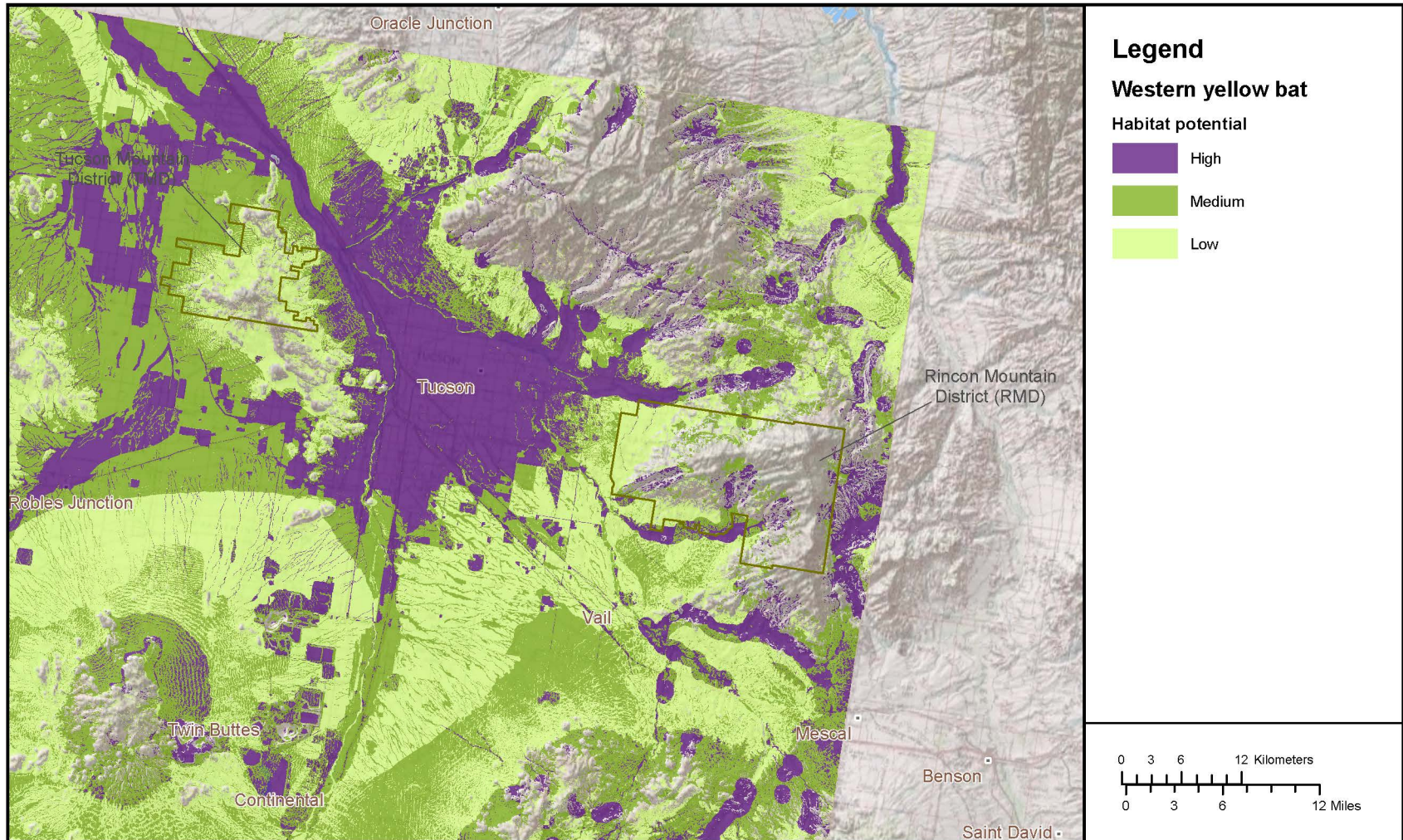
Map 79. Habitat suitability model for the Mexican long-tongued bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



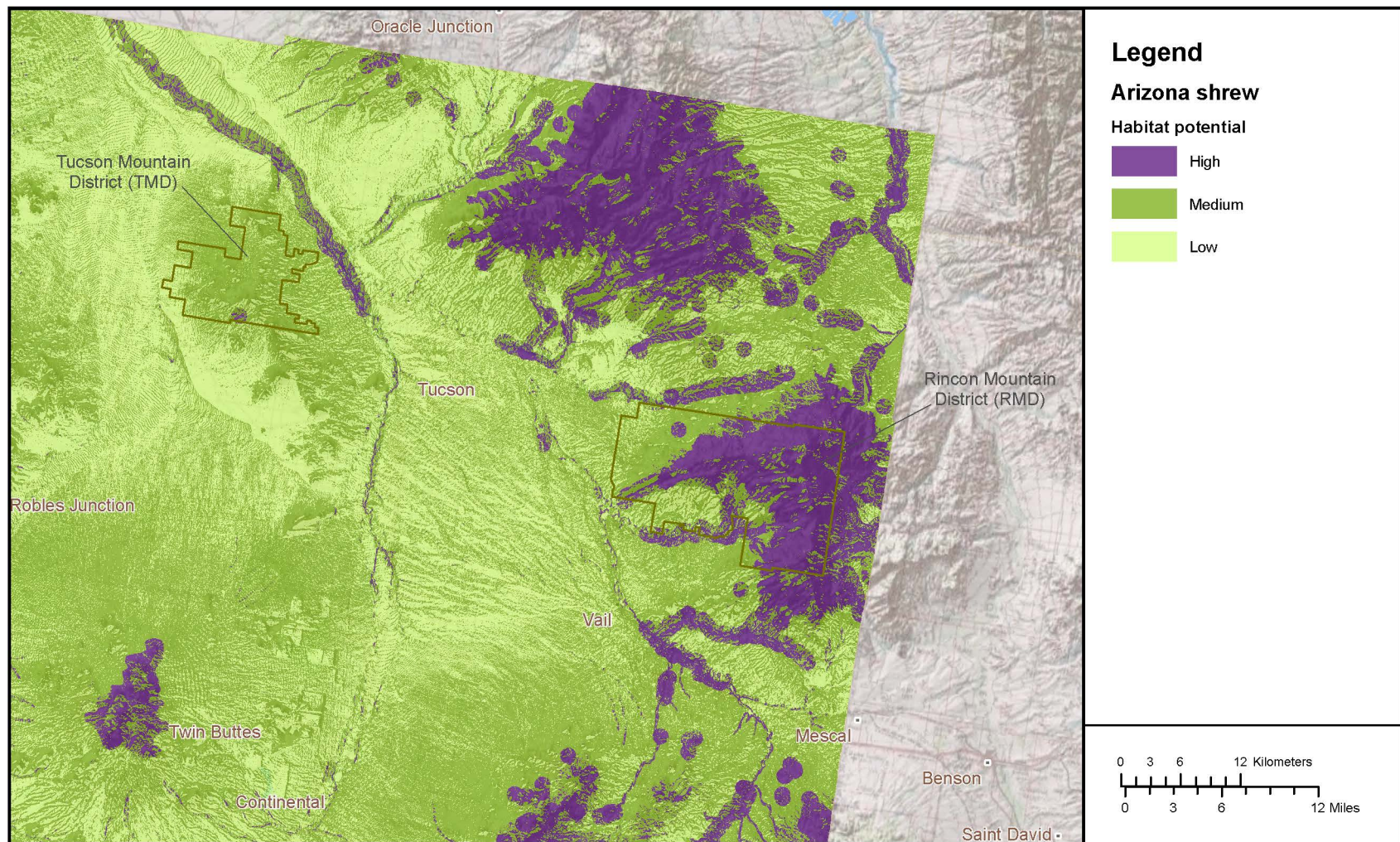
Map 80. Habitat suitability model for Pale Townsend' big-eared bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.



Map 81. Habitat suitability model for the western red bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.

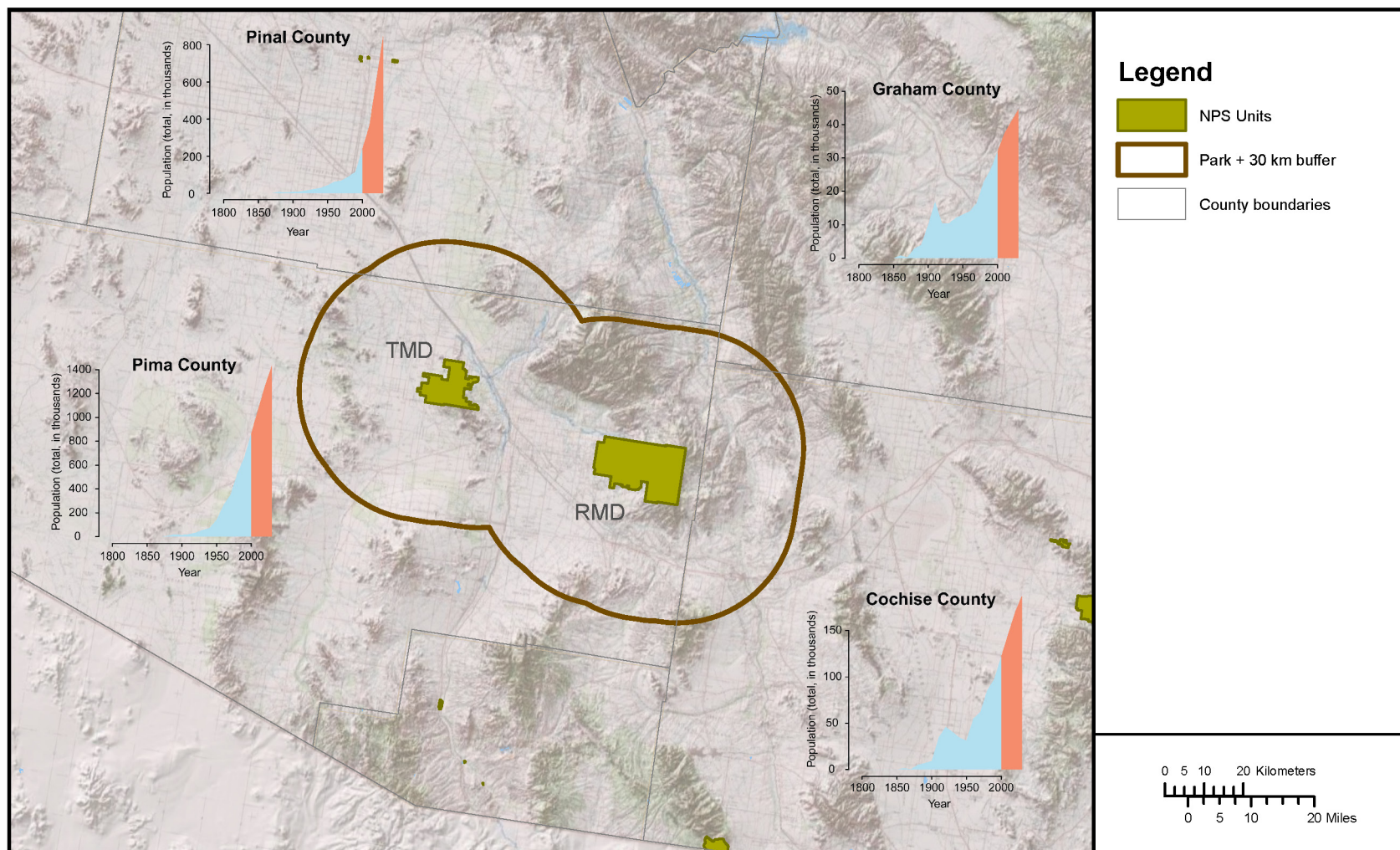


Map 82. Habitat suitability model for the western yellow bat, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.

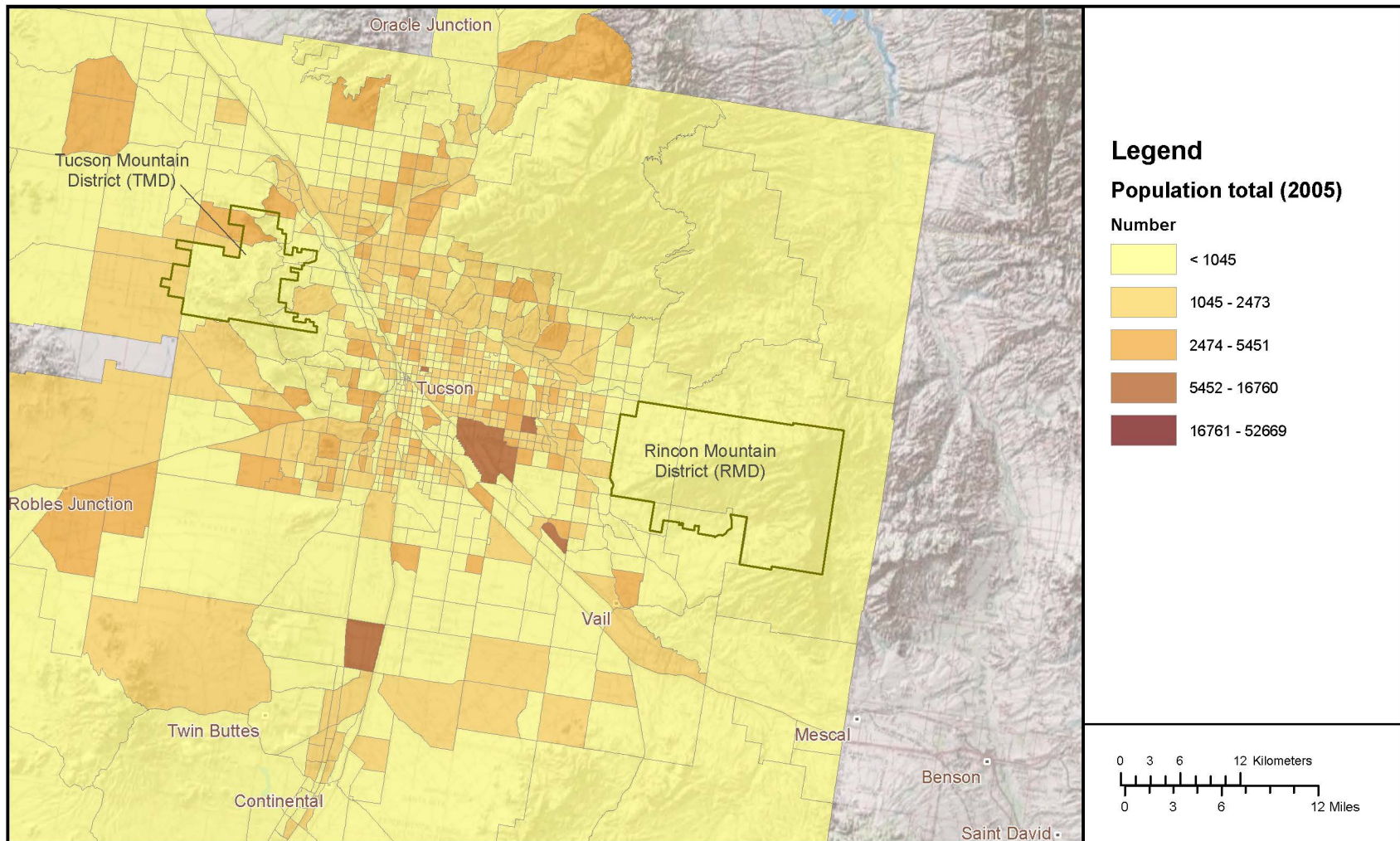


Map 83. Habitat suitability model for the Arizona shrew, a vulnerable species in Pima County, ranked according to high, medium, and low habitat potential. Data (dated 2003) obtained from the Pima County Information Technology Department.

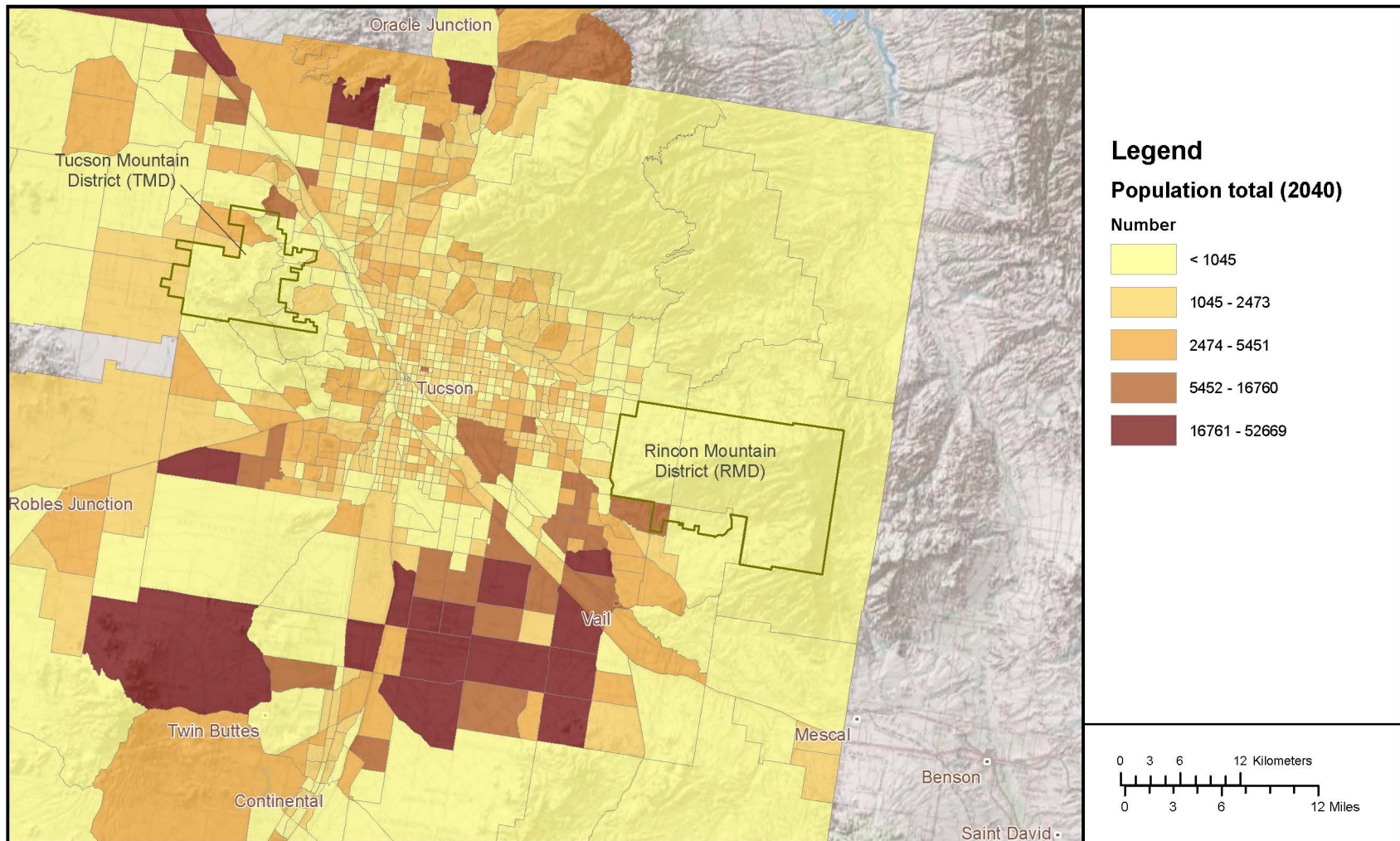
Human Population



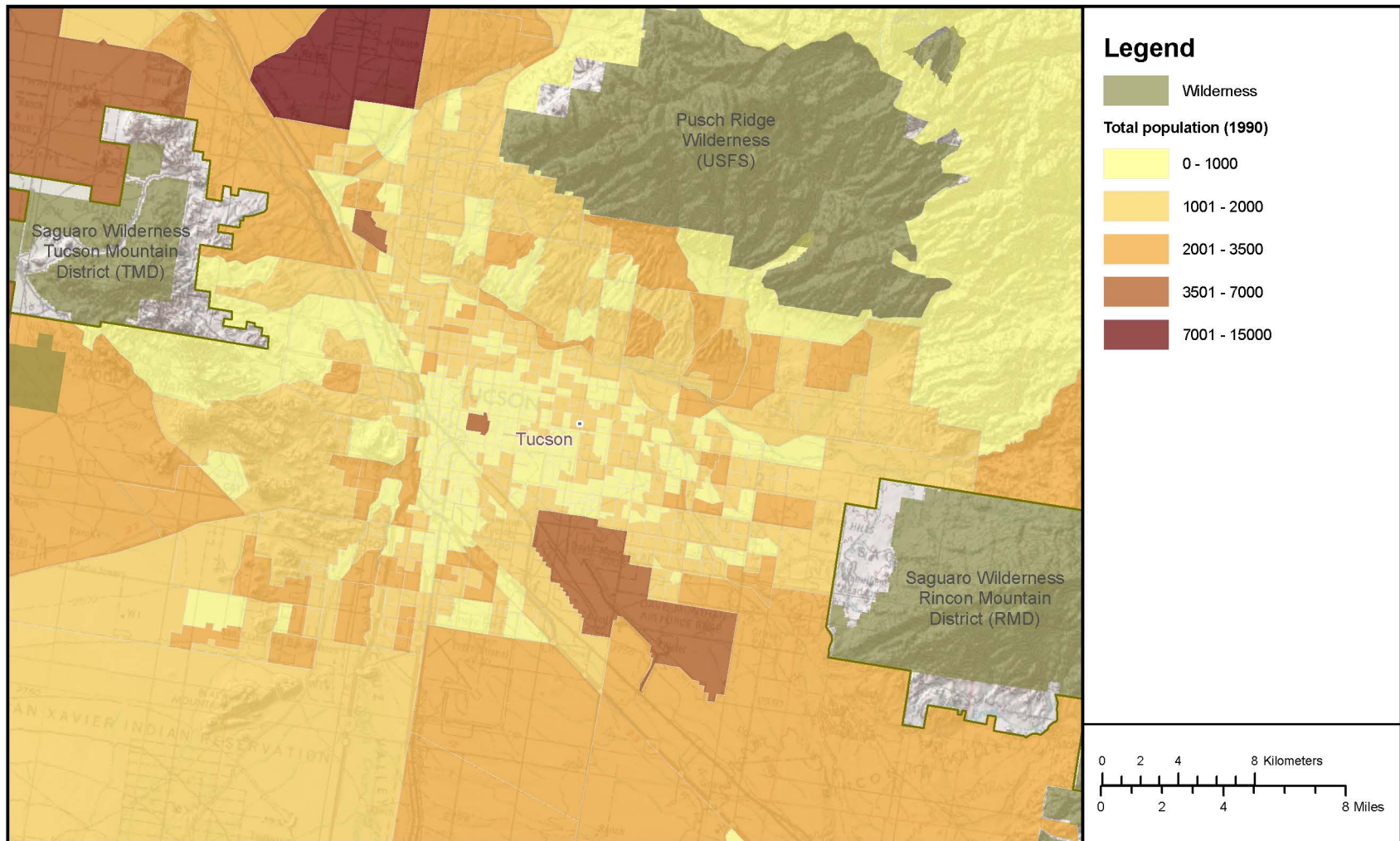
Map 84. Historic and projected future trends in total population in the local area surrounding Saguaro National Park. Population data processed by NPScape.



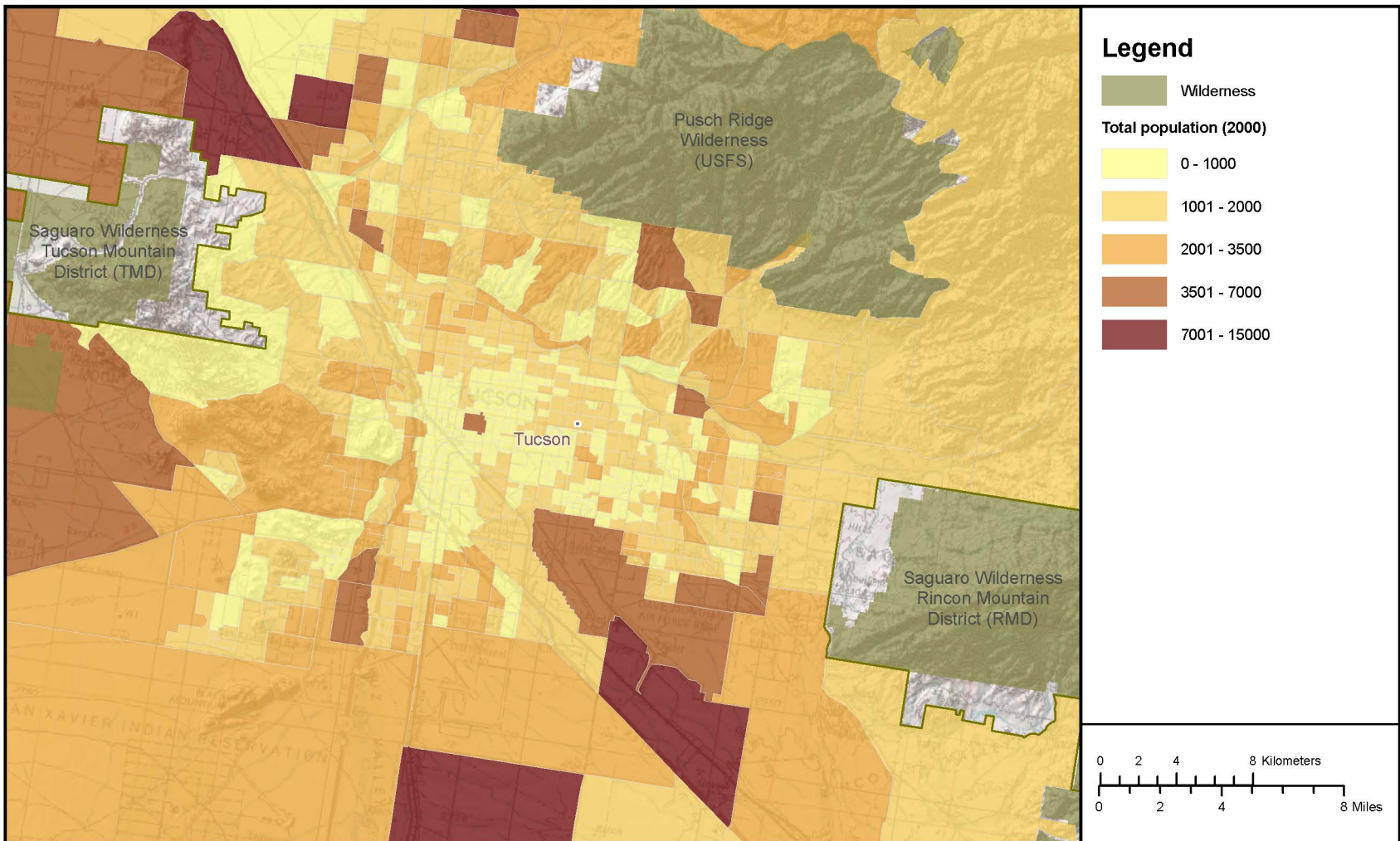
Map 85. Current (2005) estimates of total population in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



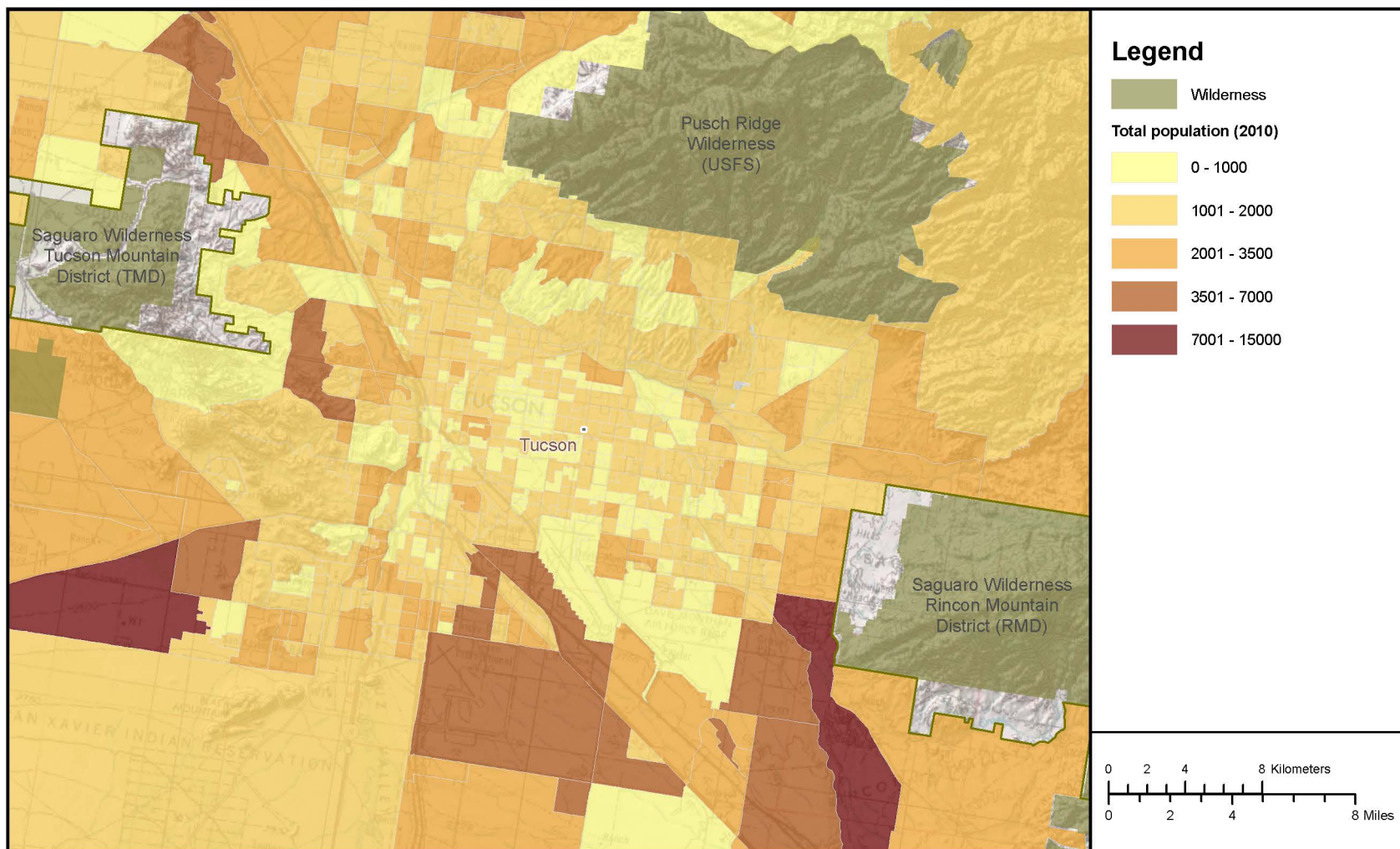
Map 86. Projected future (2040) estimates of total population in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



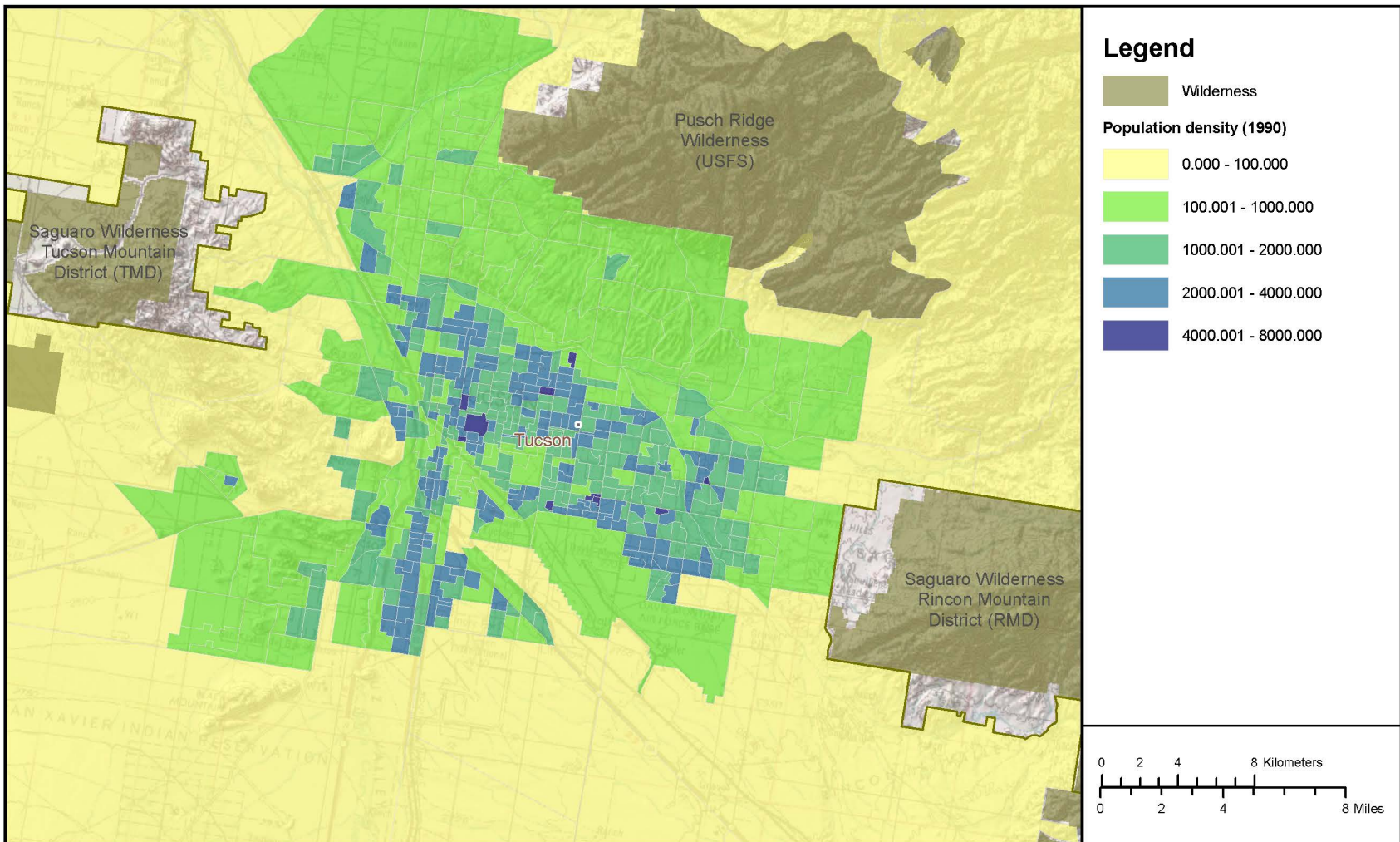
Map 87. Number of people according to the US Census Bureau (1990) in the local area surrounding Saguaro National Park. Population data processed by NPSScape. Wilderness areas obtained from the Pima County Information Technology Department.



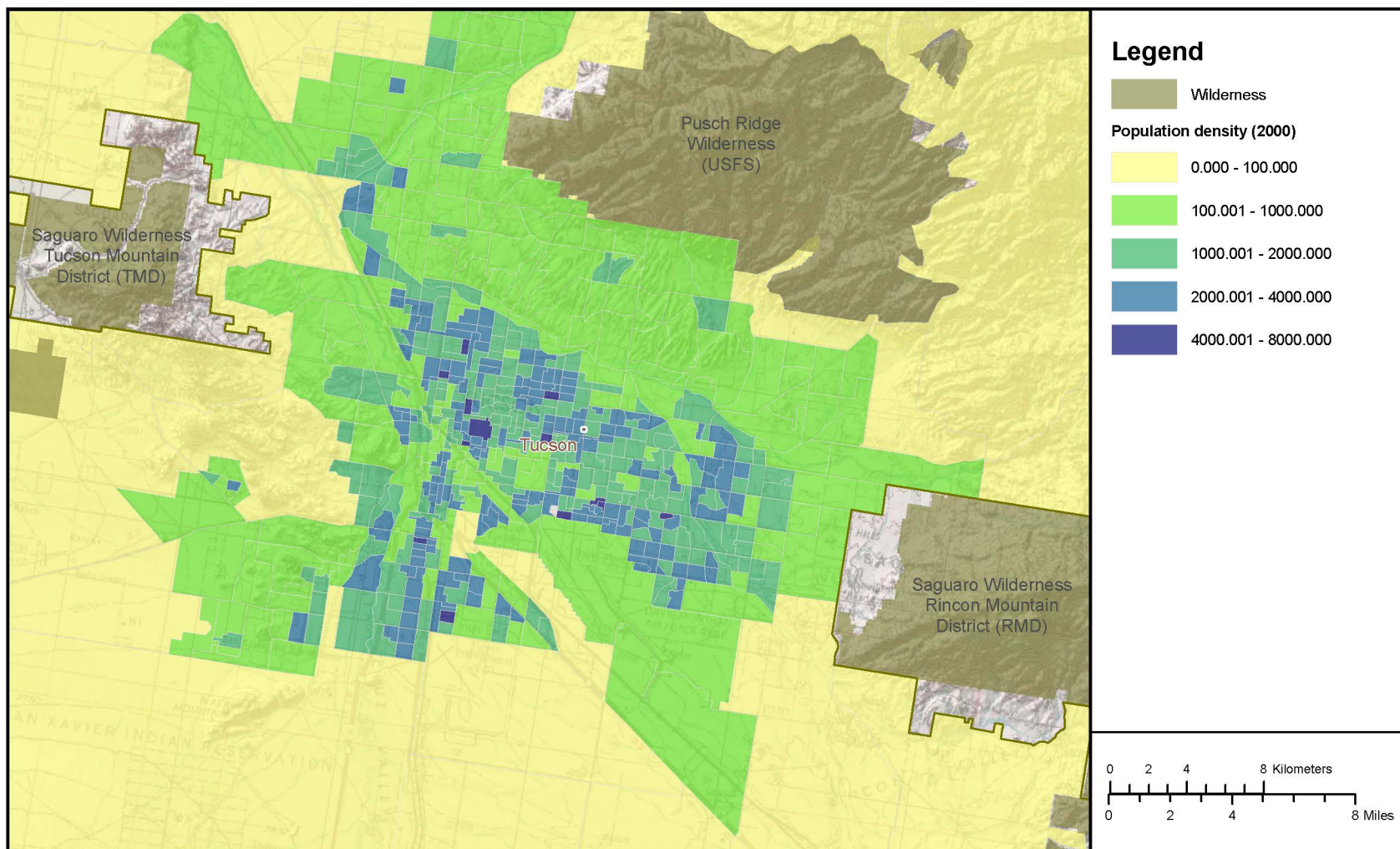
Map 88. Number of people according to the US Census Bureau (2000) in the local area surrounding Saguaro National Park. Population data processed by NPScape. Wilderness areas obtained from the Pima County Information Technology Department.



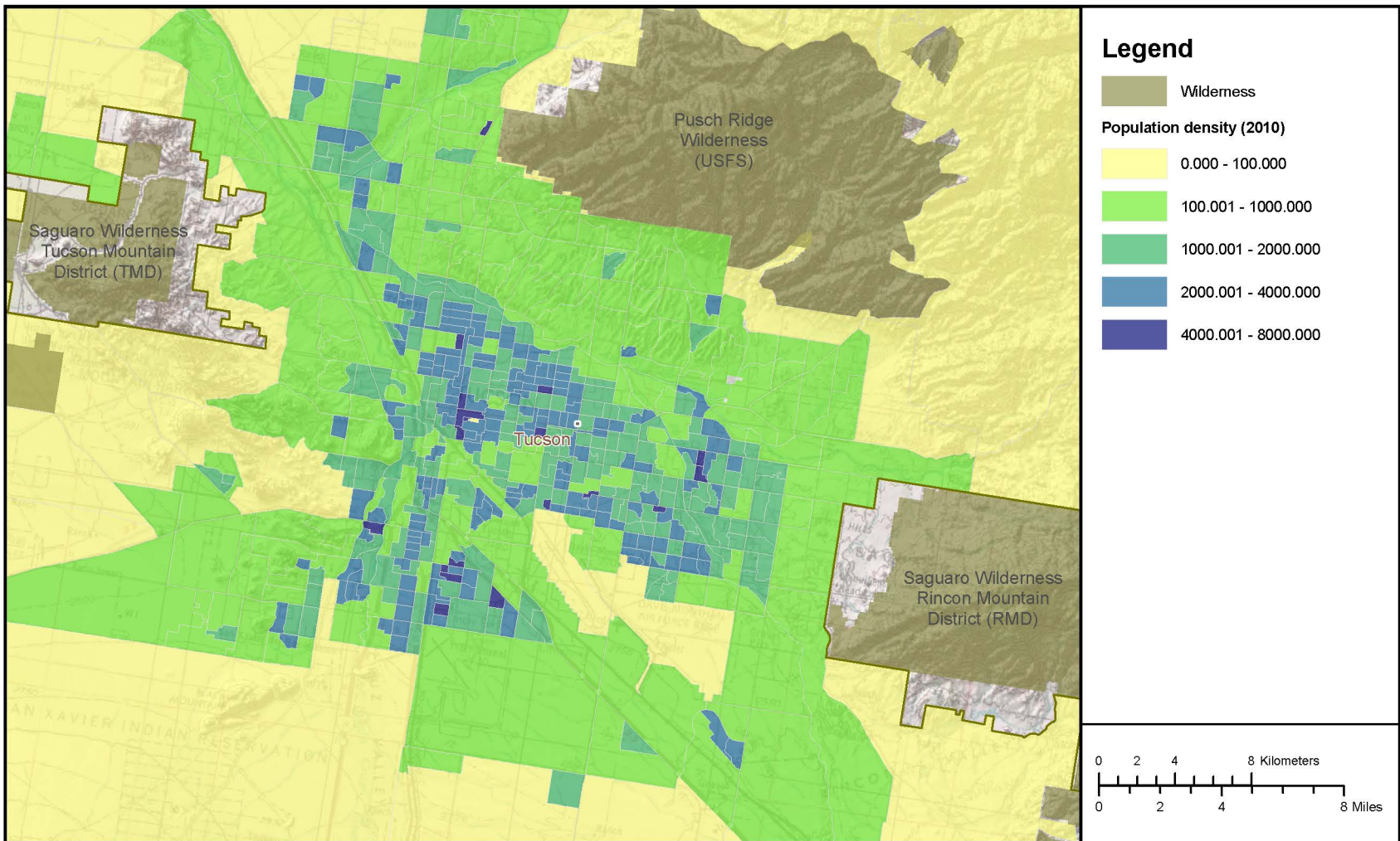
Map 89. Number of people according to the US Census Bureau (2010) in the local area surrounding Saguaro National Park. Population data processed by NPScape. Wilderness areas obtained from the Pima County Information Technology Department.



Map 90. Population density according to the US Census Bureau (1990) in the local area surrounding Saguaro National Park. Population data processed by NPSScape. Wilderness areas obtained from the Pima County Information Technology Department.

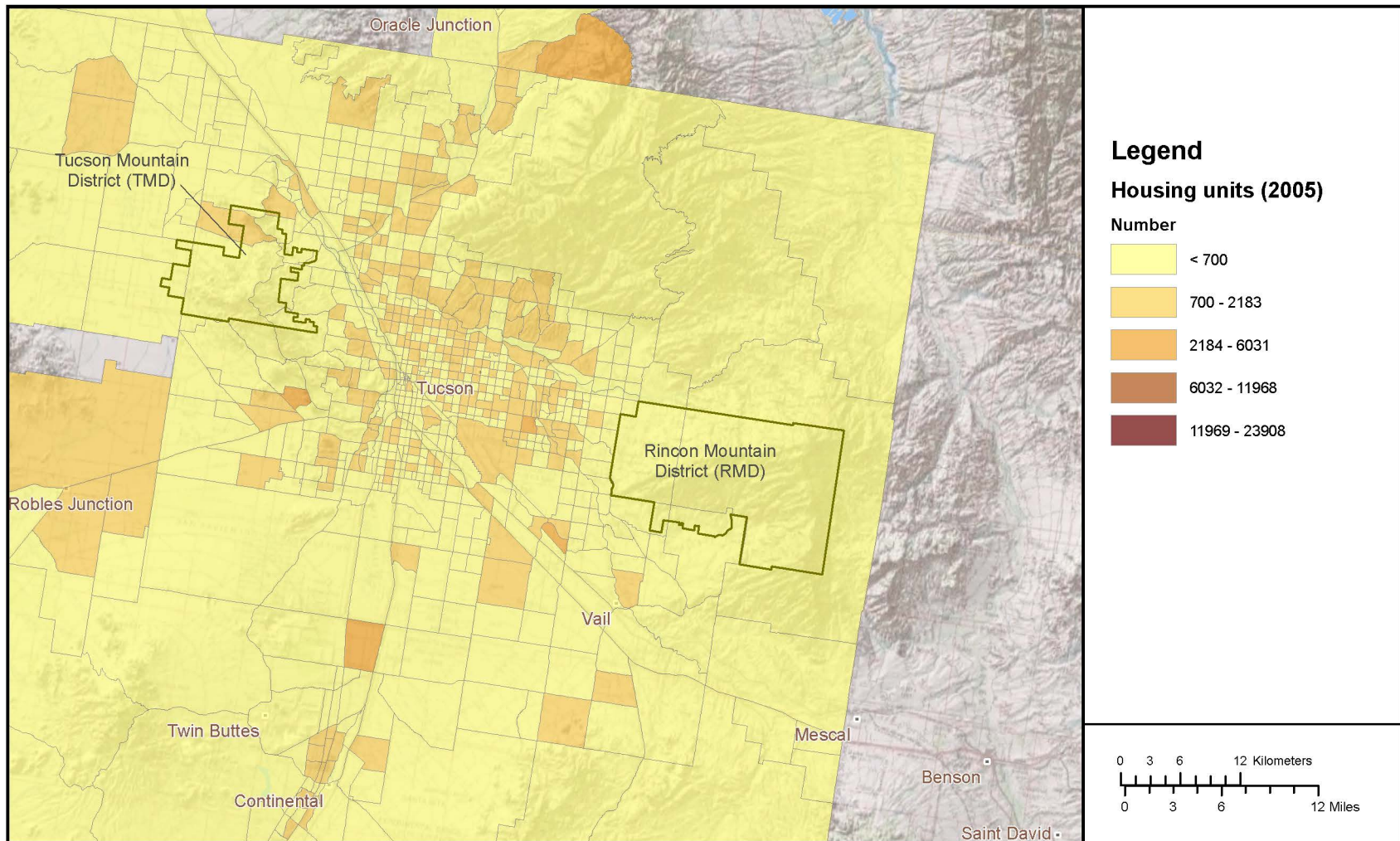


Map 91. Population density according to the US Census Bureau (2000) in the local area surrounding Saguaro National Park. Population data processed by NPSScape. Wilderness areas obtained from the Pima County Information Technology Department.

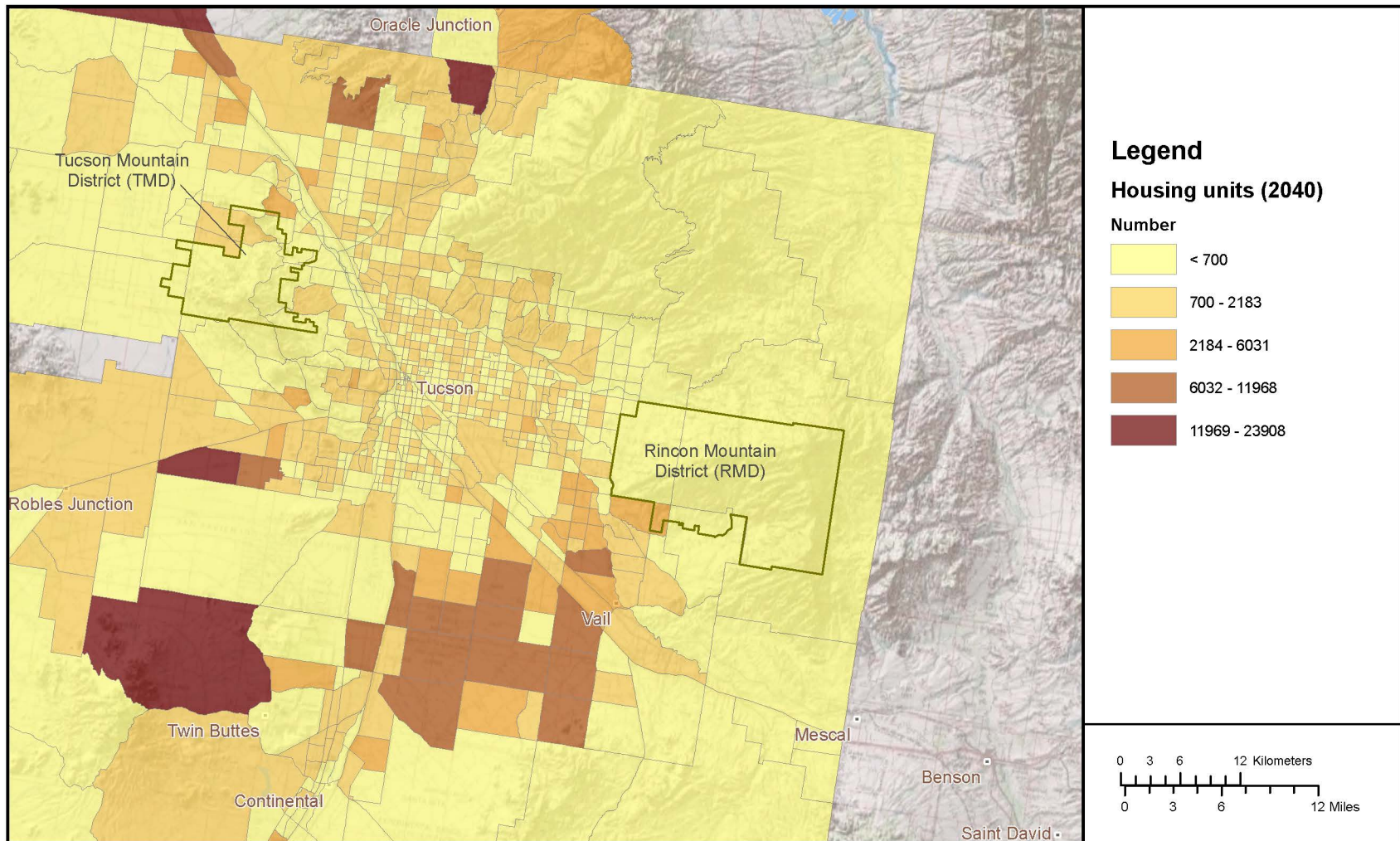


Map 92. Population density according to the US Census Bureau (2010) in the local area surrounding Saguaro National Park. Population data processed by NPSScape. Wilderness areas obtained from the Pima County Information Technology Department.

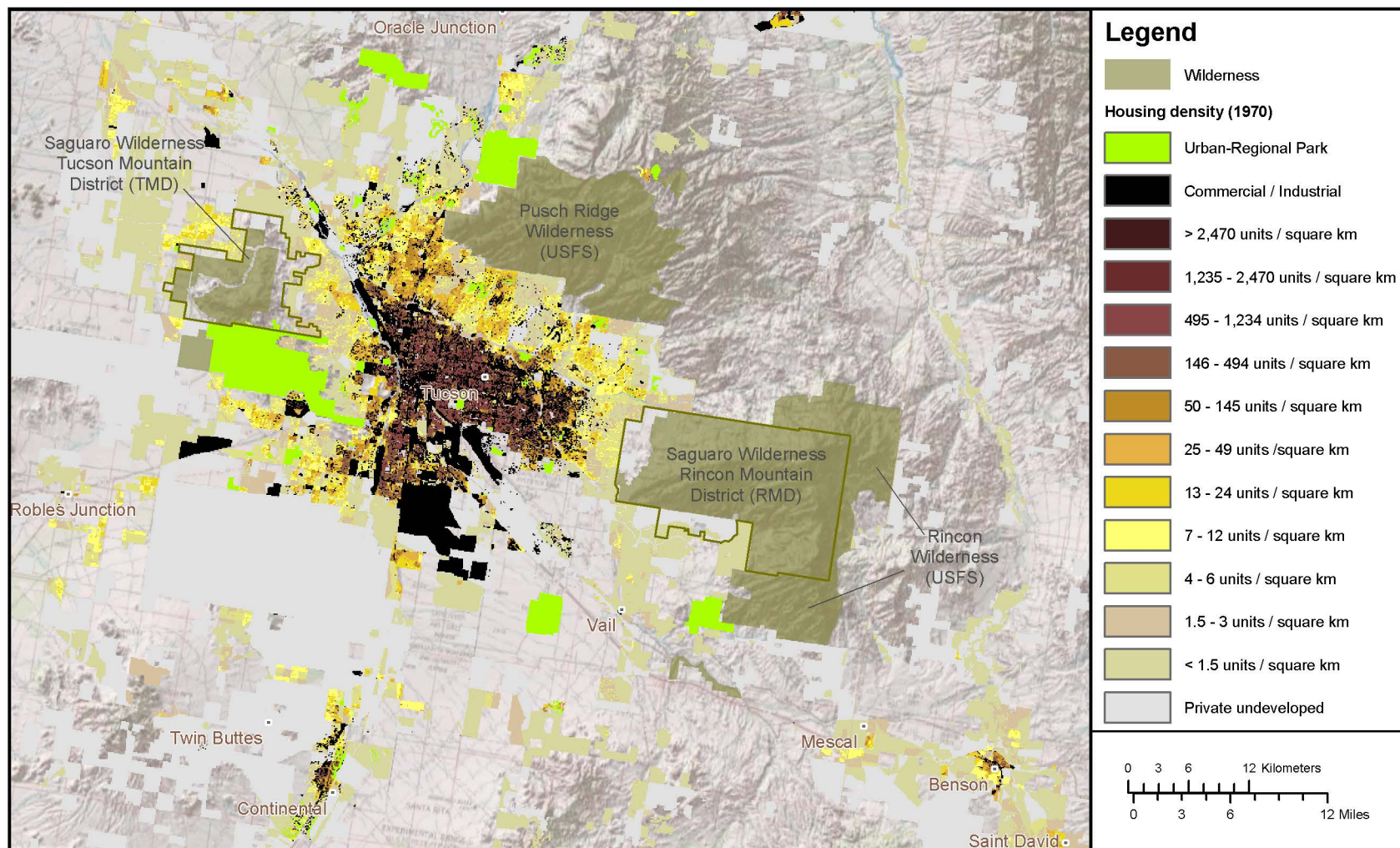
Housing



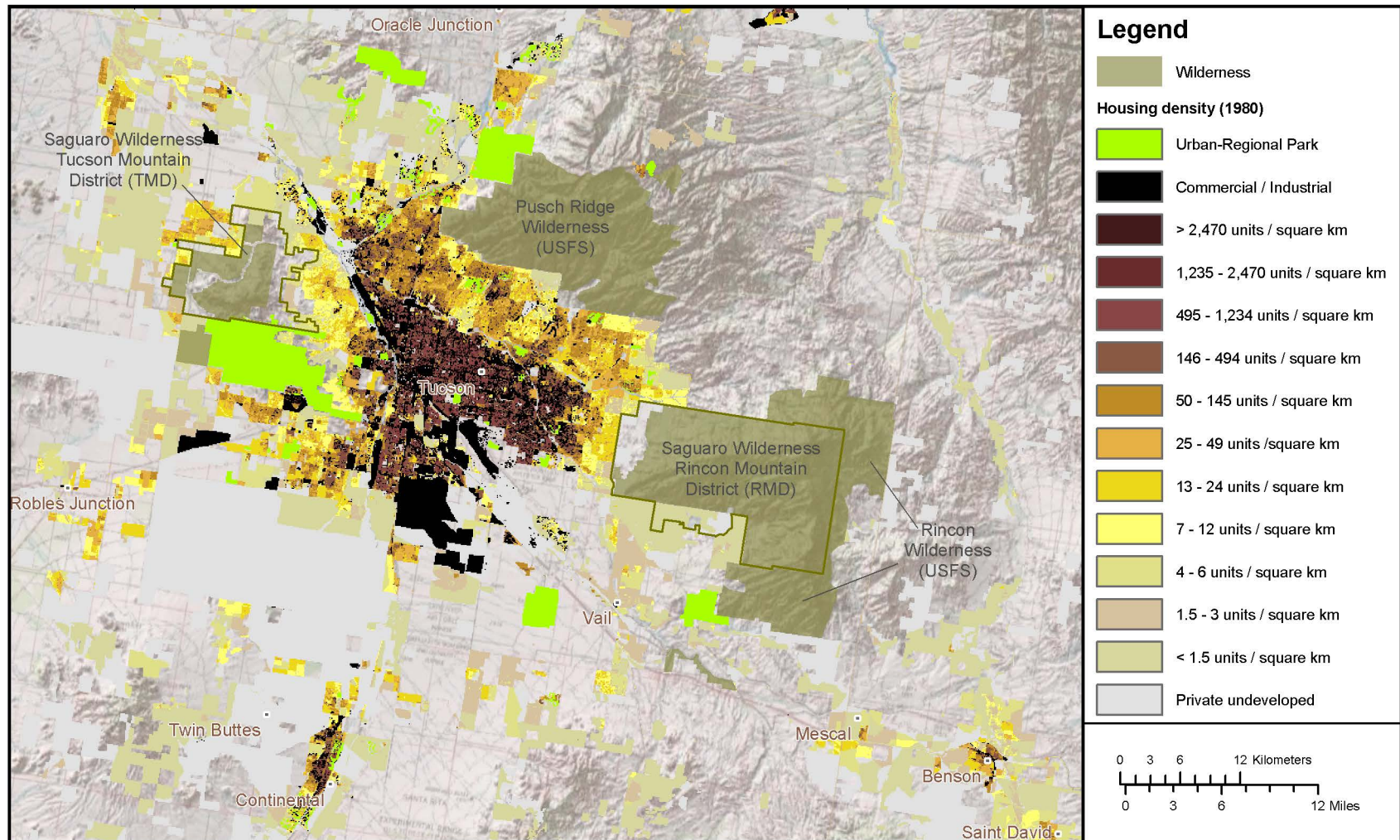
Map 93. Number of housing units (year 2005) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



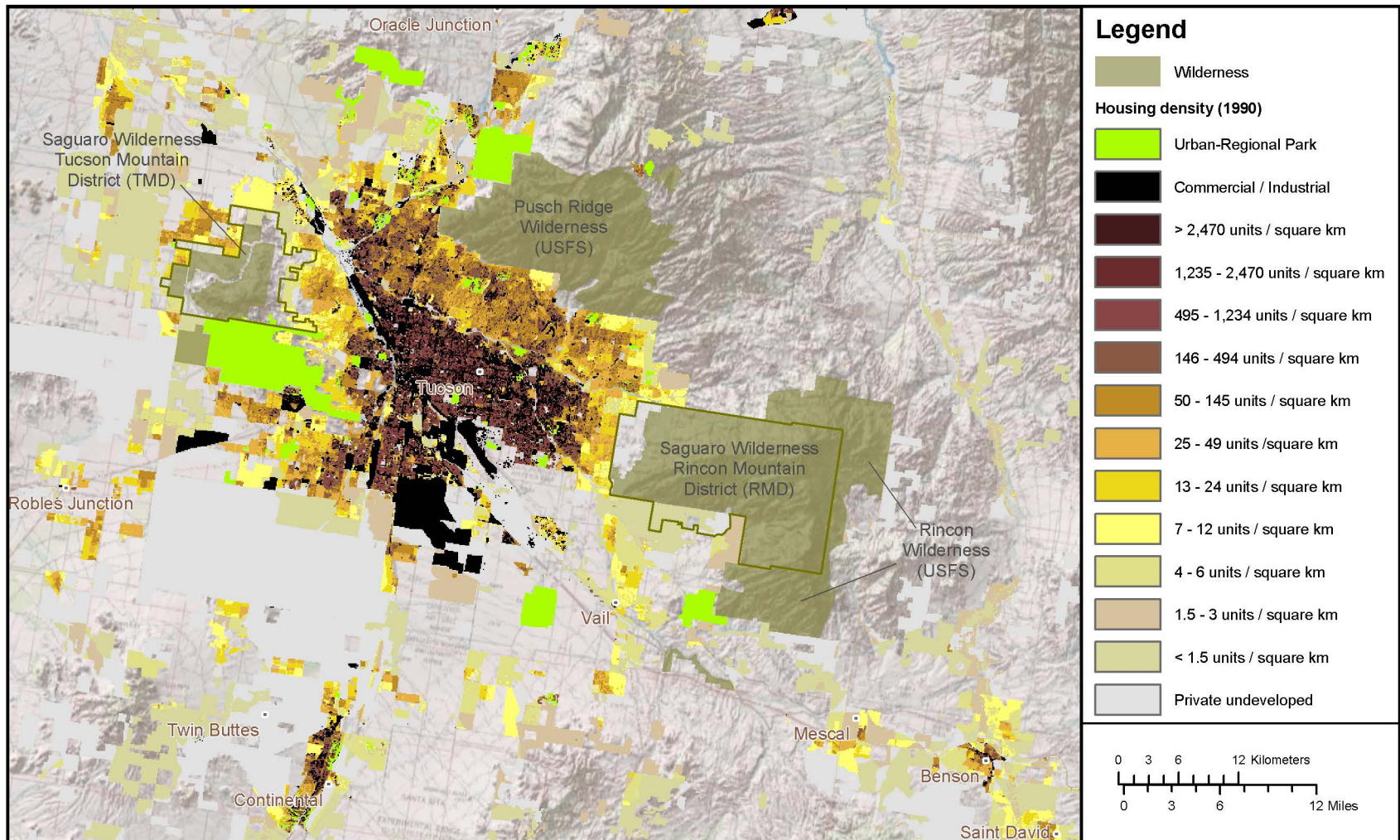
Map 94. Number of housing units (projected to the year 2040) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>)



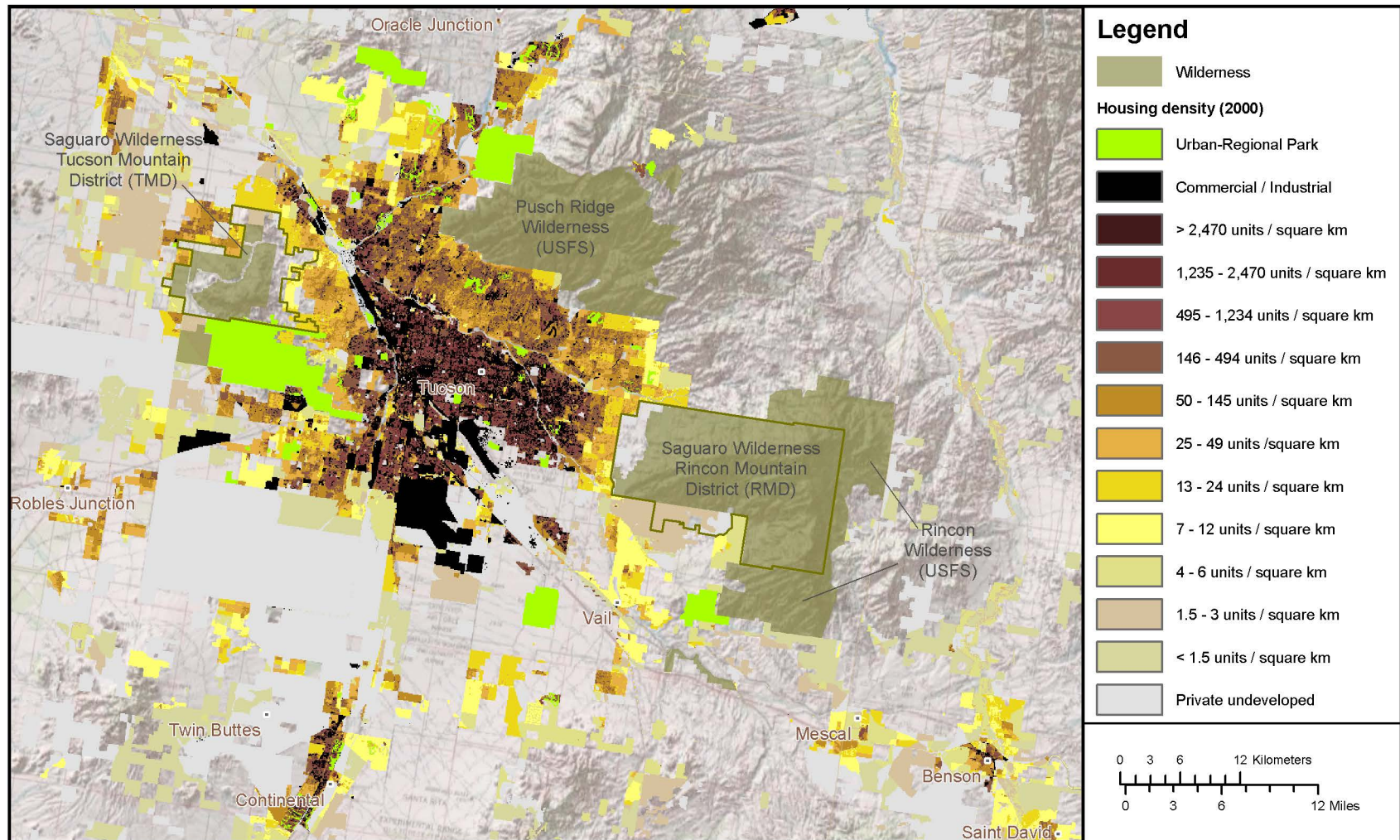
Map 95. Housing density according to the Spatially Explicit Regional Growth Model (1970) in the local area surrounding Saguaro National Park. Data processed by NPScape.



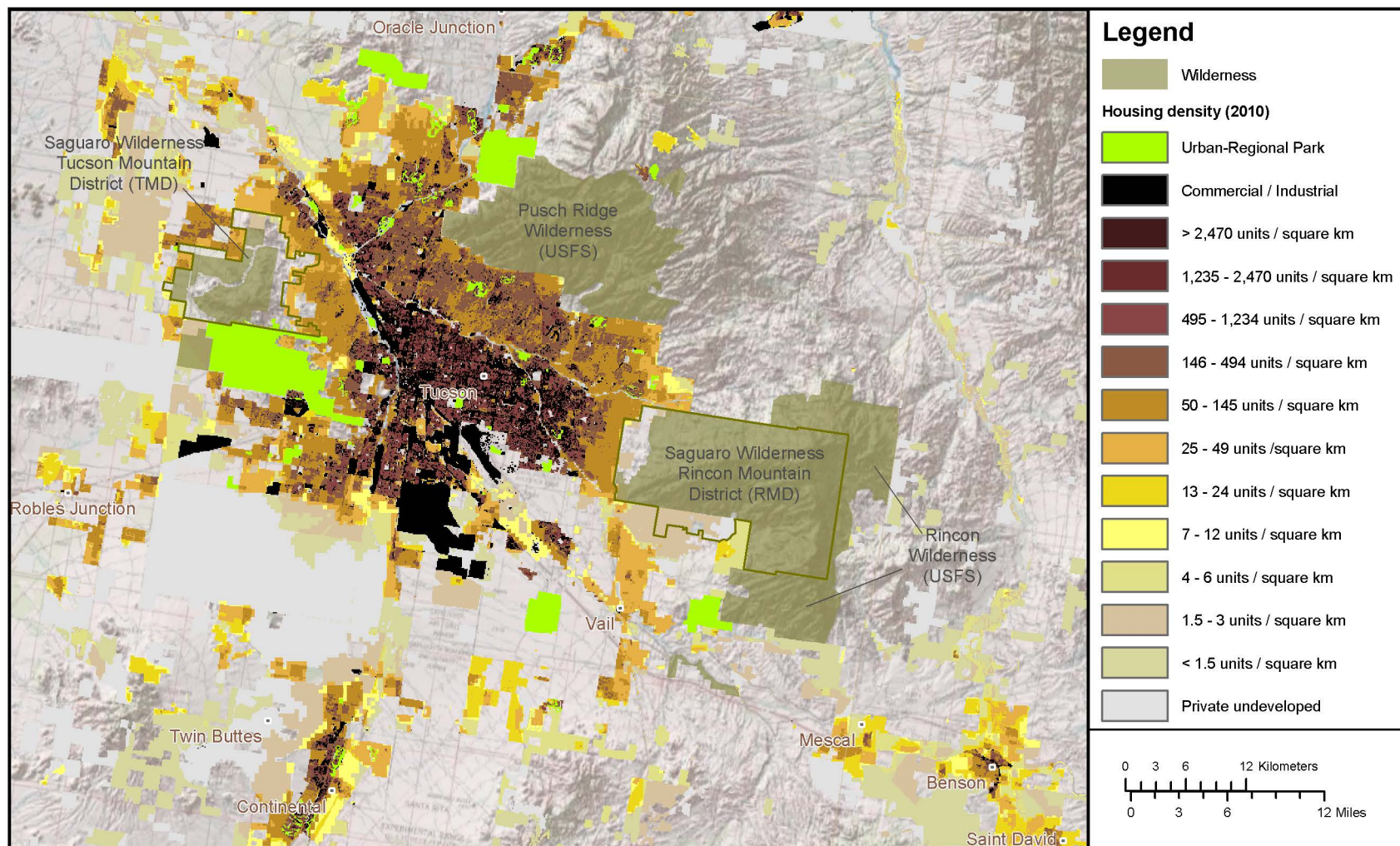
Map 96. Housing density according to the Spatially Explicit Regional Growth Model (1980) in the local area surrounding Saguaro National Park. Data processed by NPScape.



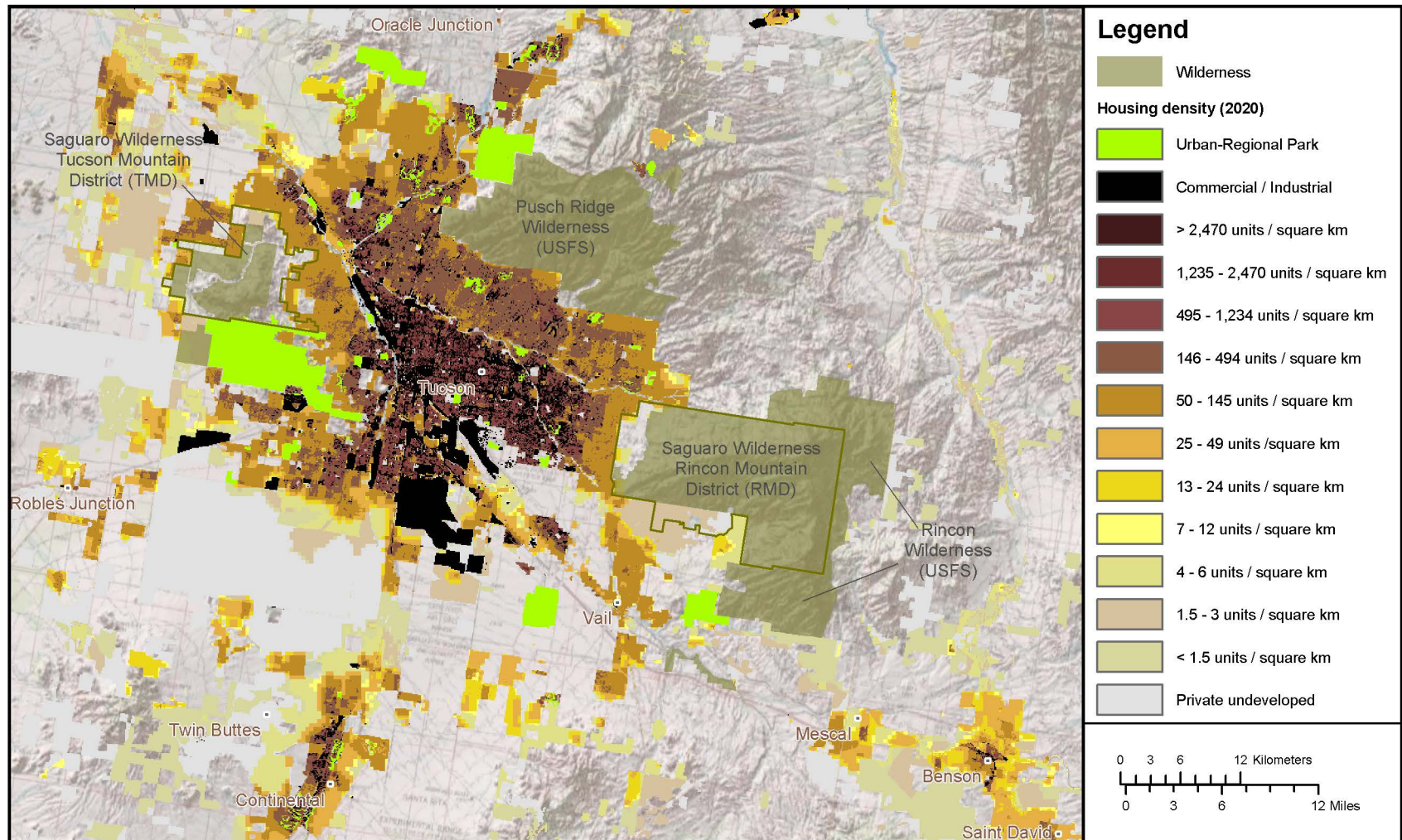
Map 97. Housing density according to the Spatially Explicit Regional Growth Model (1990) in the local area surrounding Saguaro National Park. Data processed by NPScape.



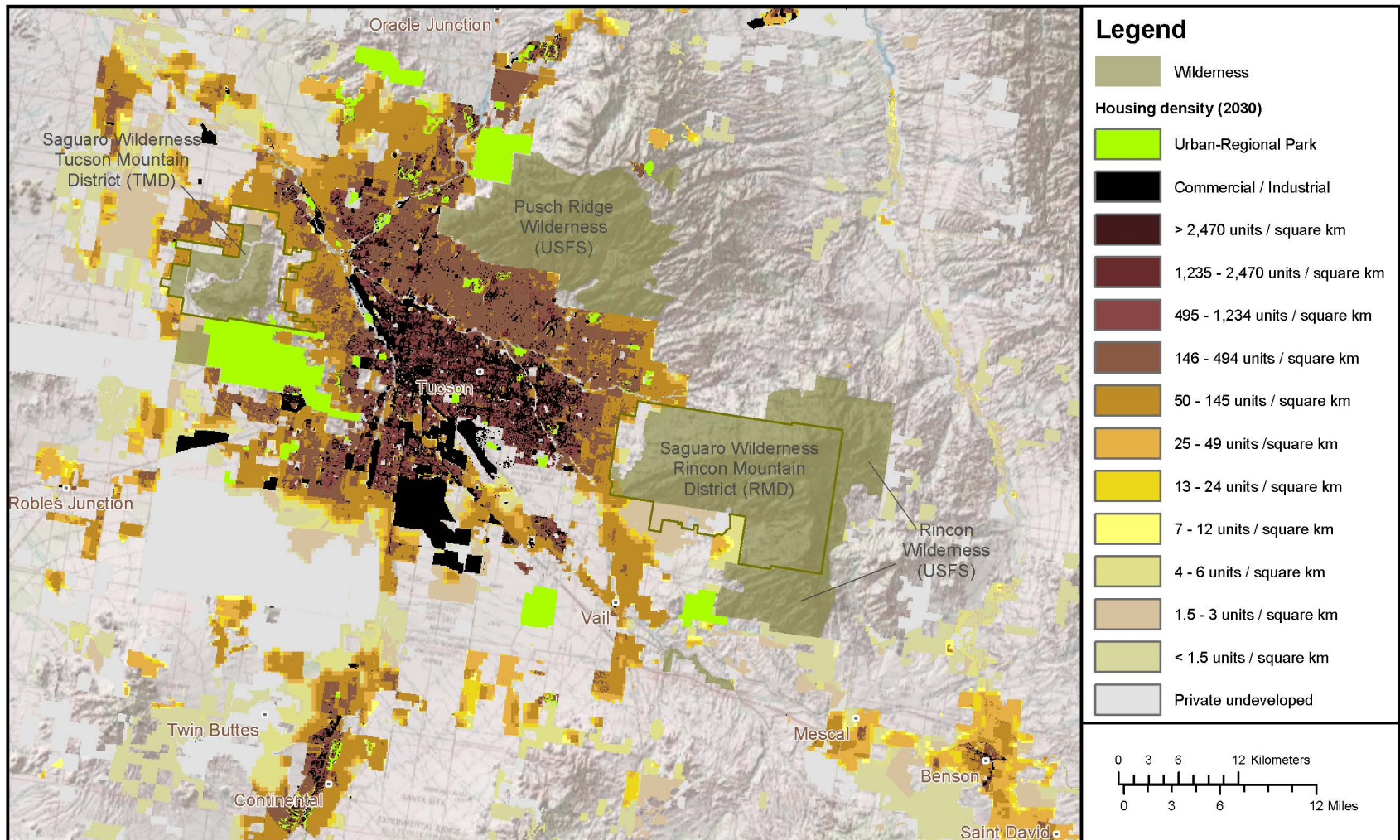
Map 98. Housing density according to the Spatially Explicit Regional Growth Model (2000) in the local area surrounding Saguaro National Park. Data processed by NPScene.



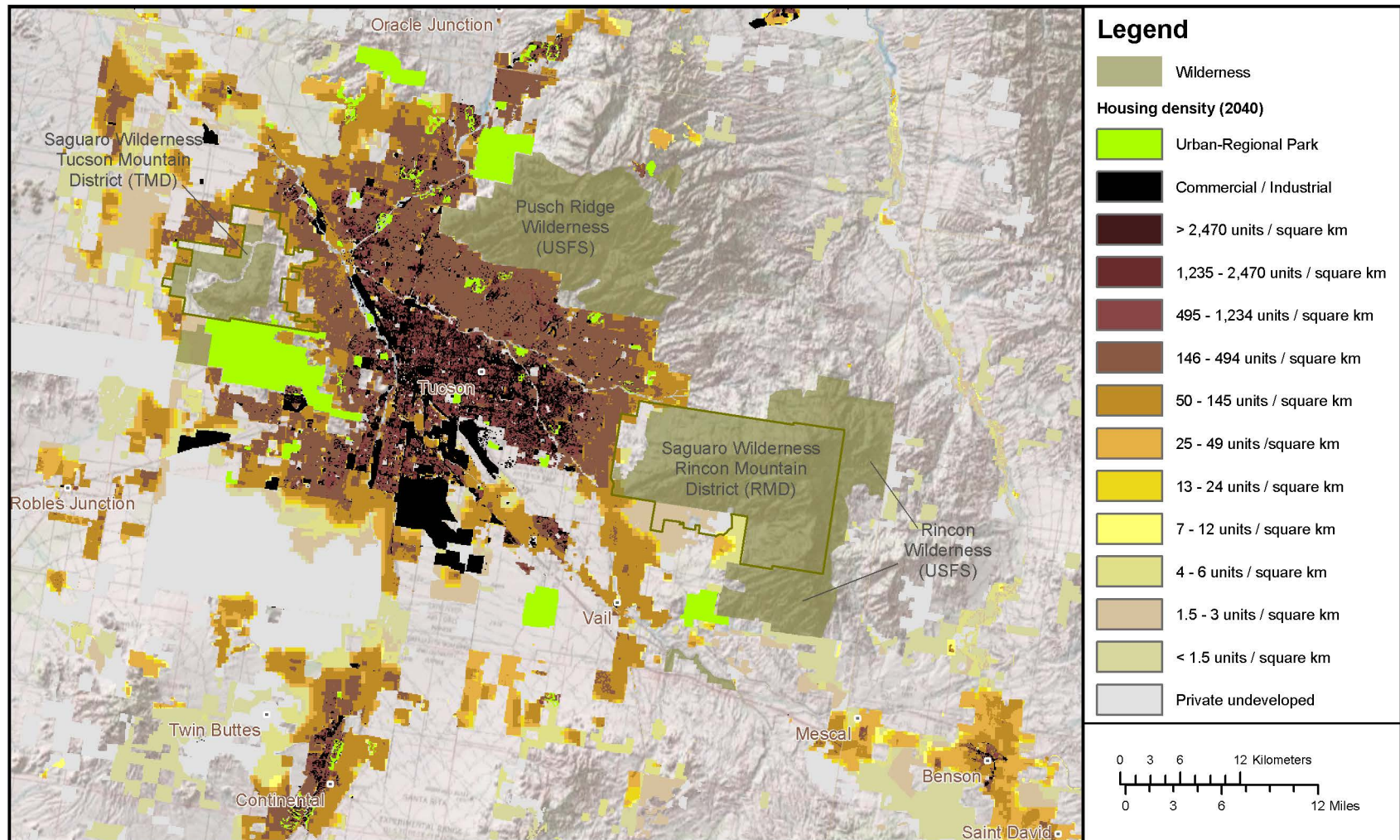
Map 99. Housing density according to the Spatially Explicit Regional Growth Model (2010) in the local area surrounding Saguaro National Park. Data processed by NPScape.



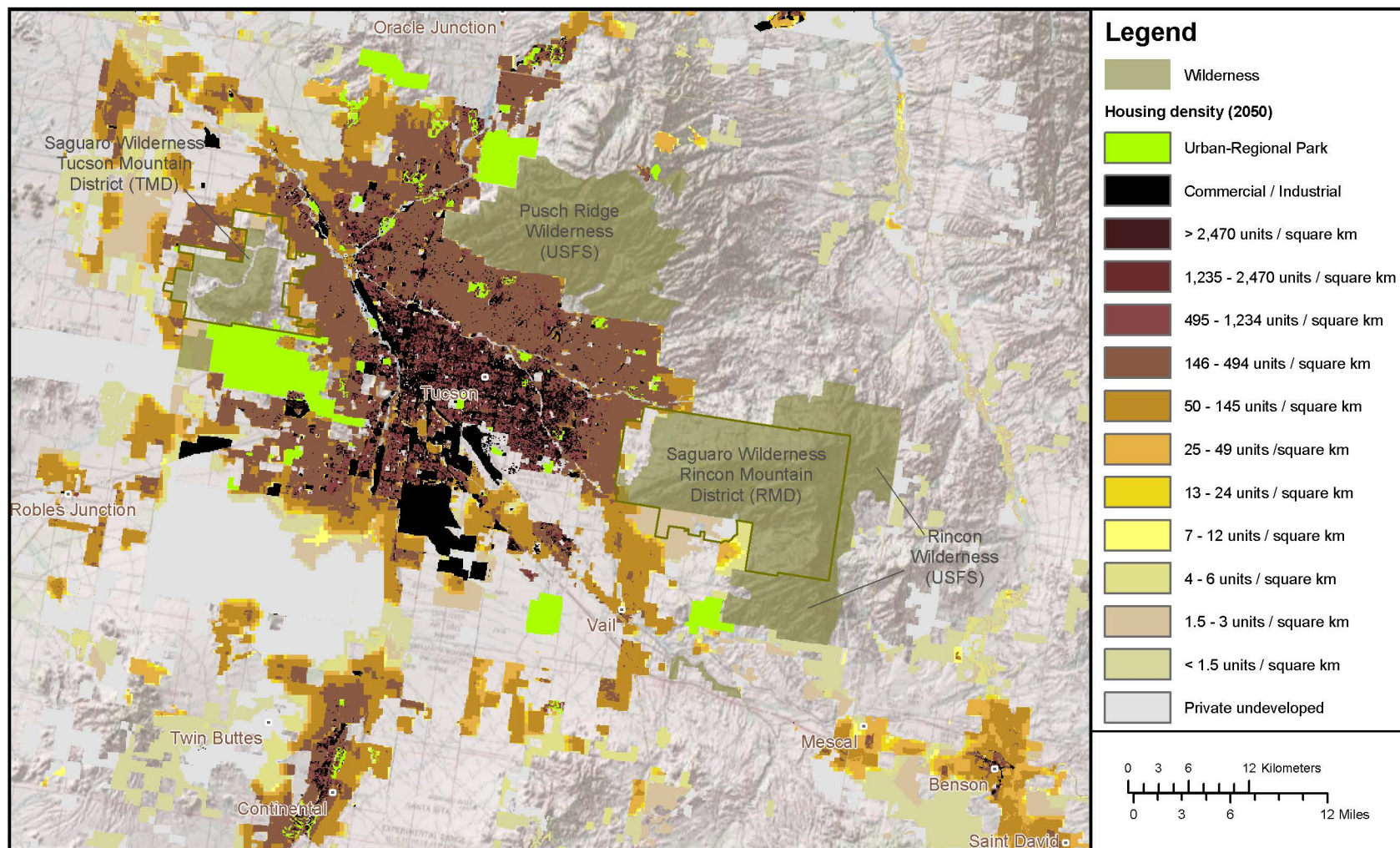
Map 100. Housing density according to the Spatially Explicit Regional Growth Model (2020) in the local area surrounding Saguaro National Park. Data processed by NPScape.



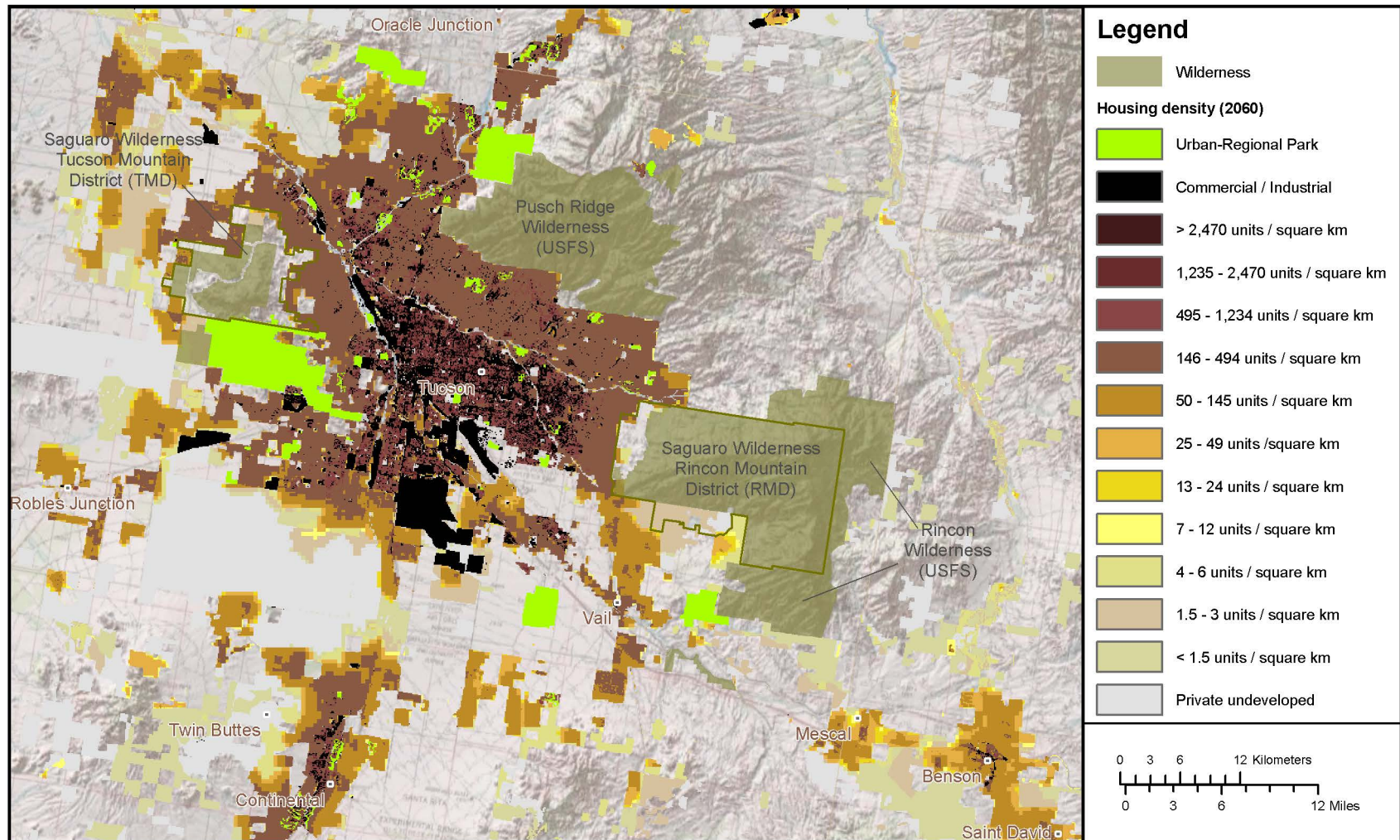
Map 101. Housing density according to the Spatially Explicit Regional Growth Model (2030) in the local area surrounding Saguaro National Park. Data processed by NPScene.



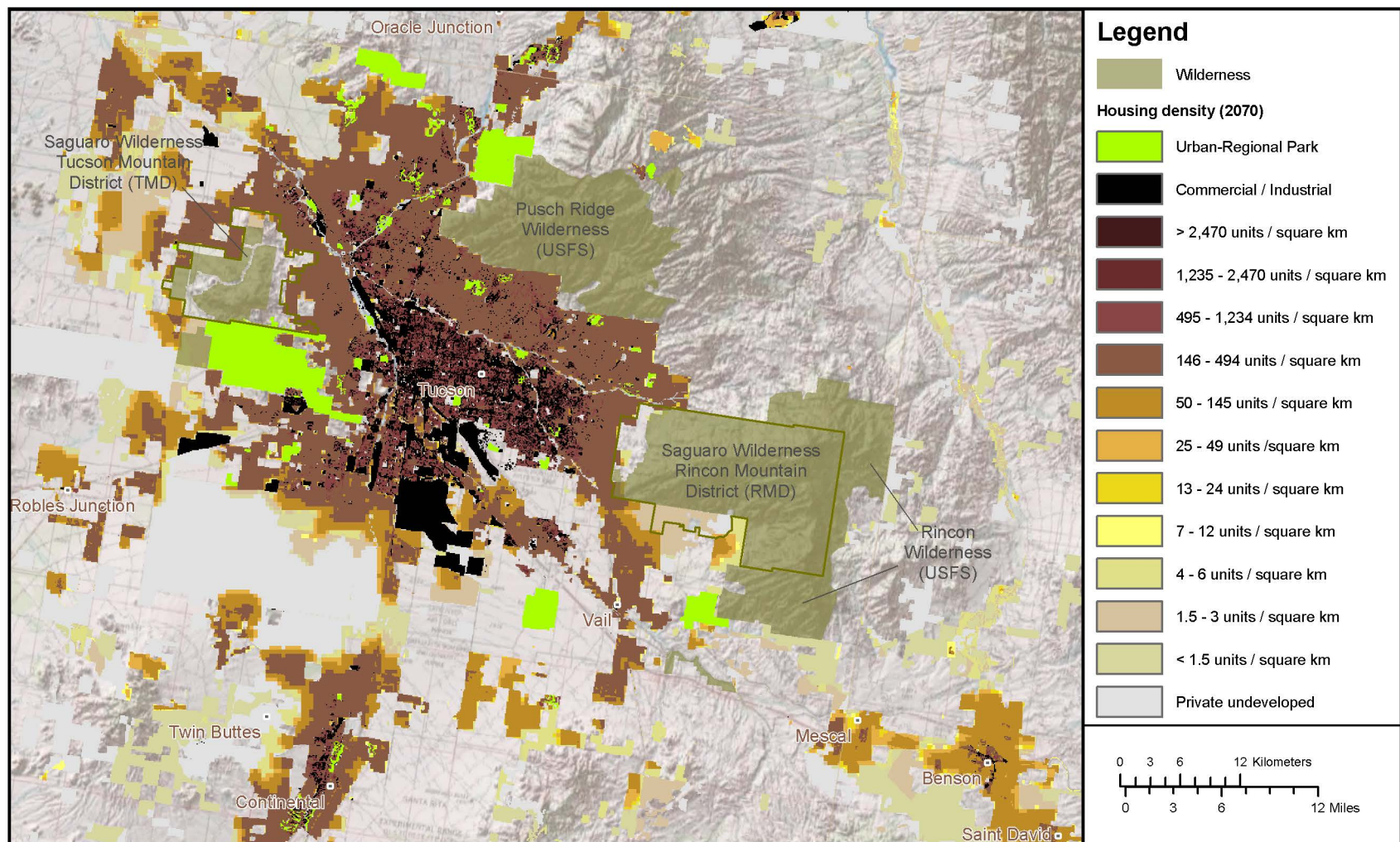
Map 102. Housing density according to the Spatially Explicit Regional Growth Model (2040) in the local area surrounding Saguaro National Park. Data processed by NPScene.



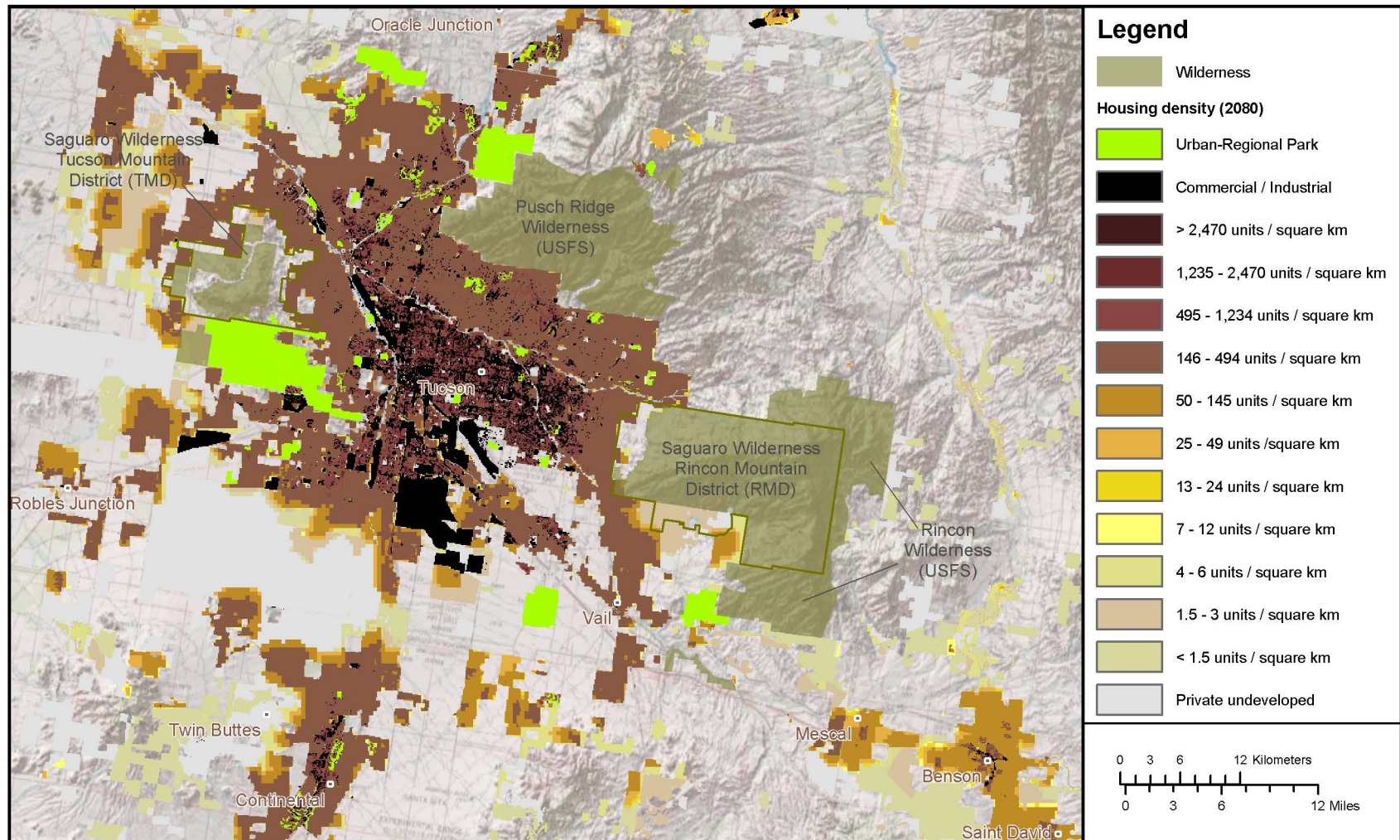
Map 103. Housing density according to the Spatially Explicit Regional Growth Model (2050) in the local area surrounding Saguaro National Park. Data processed by NPScape.



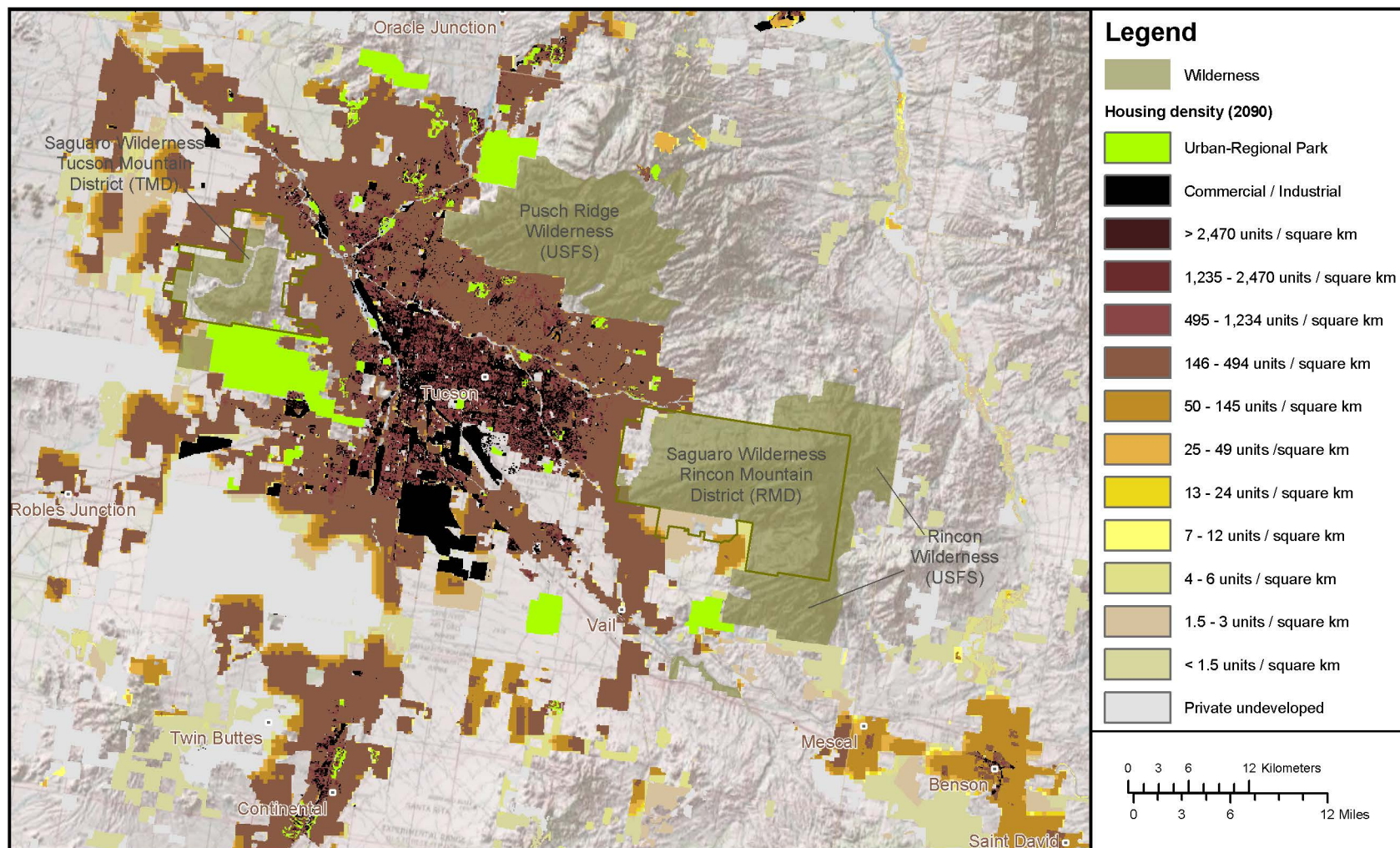
Map 104. Housing density according to the Spatially Explicit Regional Growth Model (2060) in the local area surrounding Saguaro National Park. Data processed by NPScape.



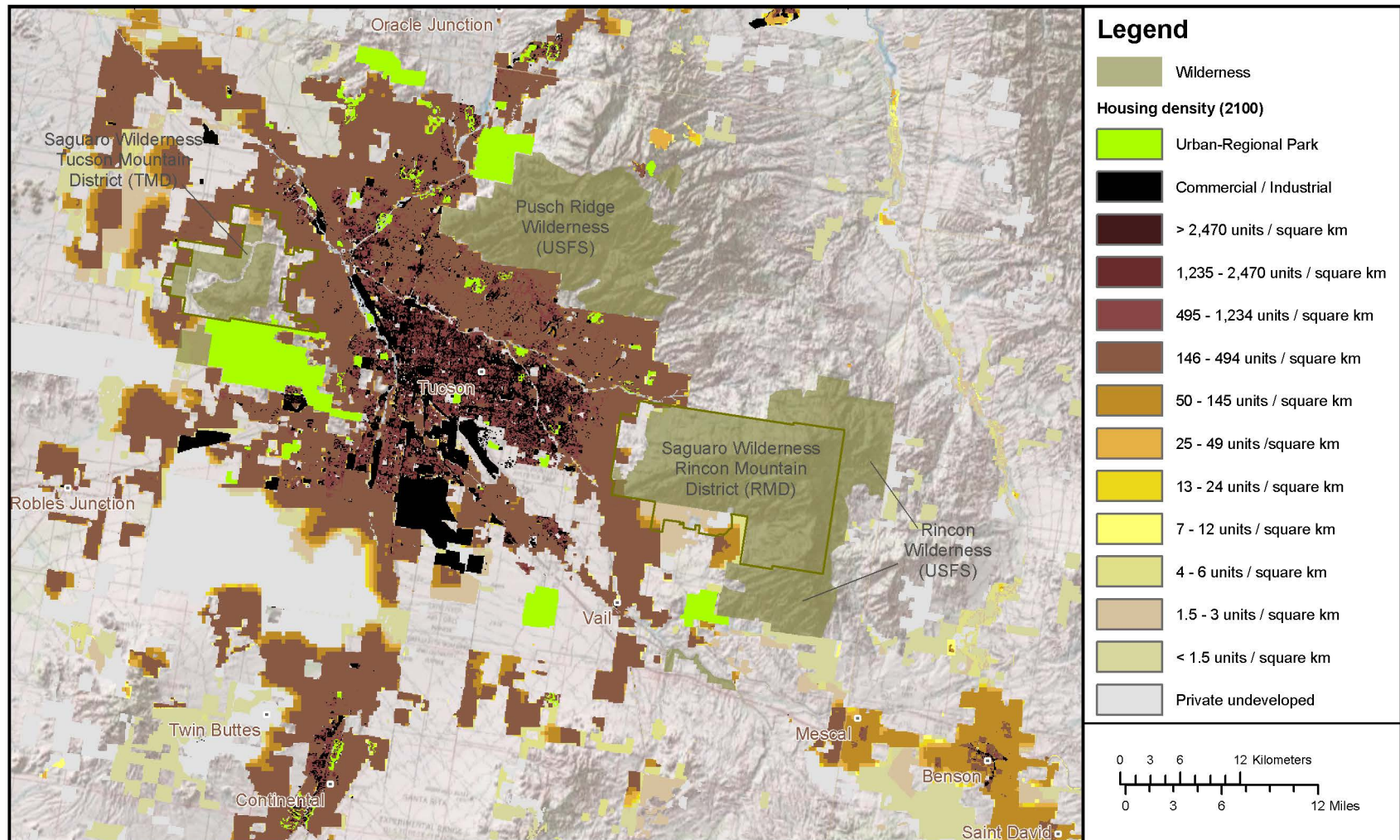
Map 105. Housing density according to the Spatially Explicit Regional Growth Model (2070) in the local area surrounding Saguaro National Park. Data processed by NPScape.



Map 106. Housing density according to the Spatially Explicit Regional Growth Model (2080) in the local area surrounding Saguaro National Park. Data processed by NPScape.

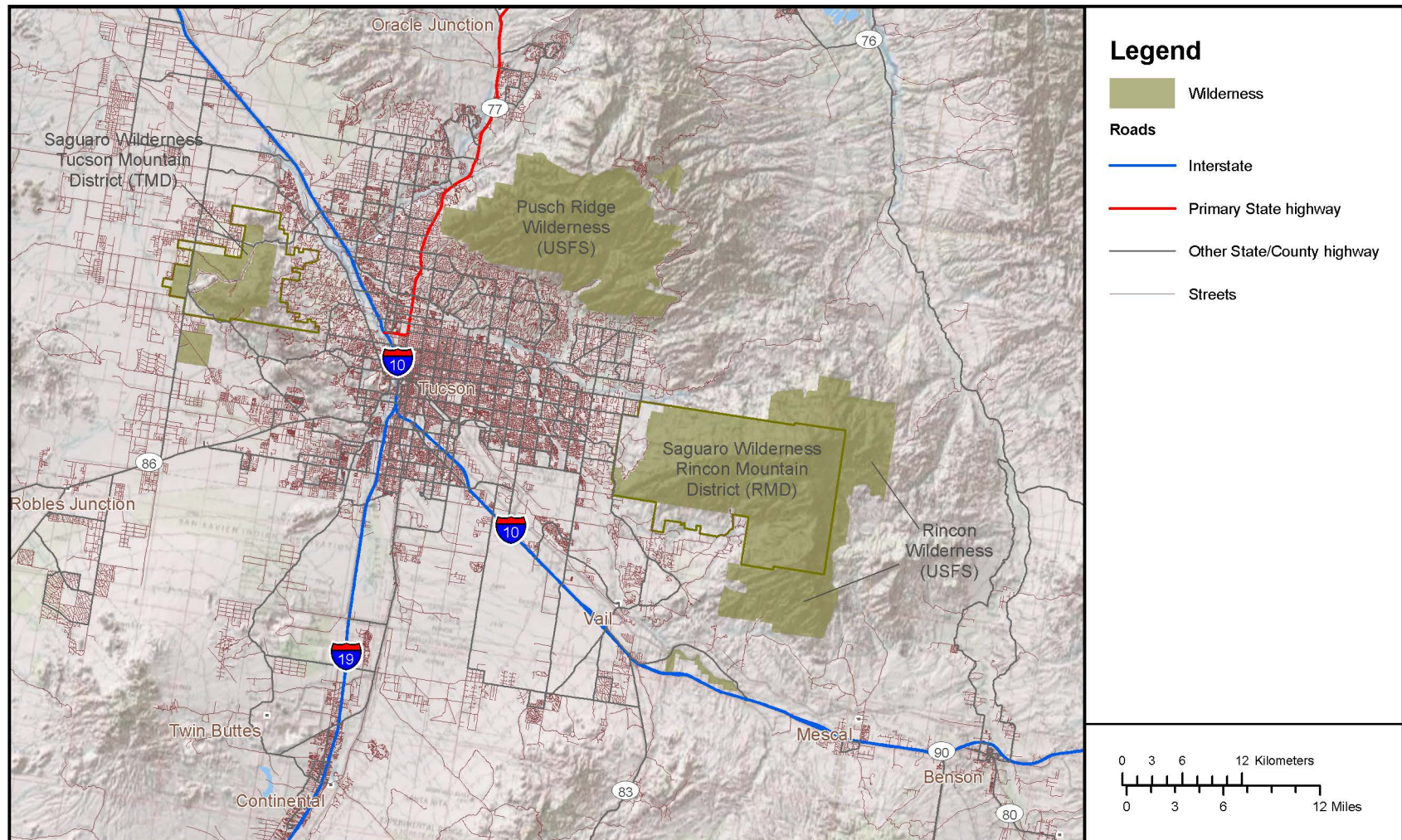


Map 107. Housing density according to the Spatially Explicit Regional Growth Model (2090) in the local area surrounding Saguaro National Park. Data processed by NPScene.

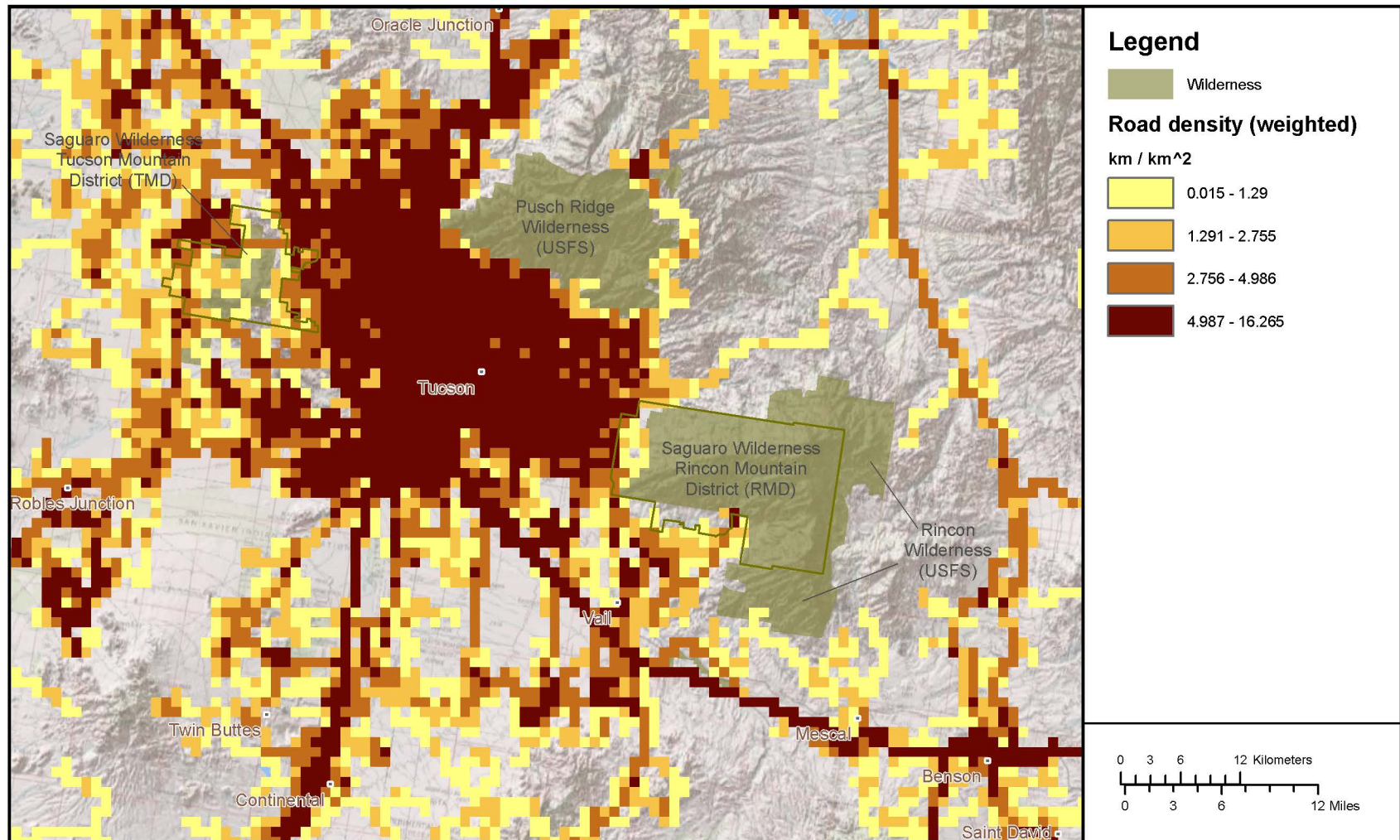


Map 108. Housing density according to the Spatially Explicit Regional Growth Model (2100) in the local area surrounding Saguaro National Park. Data processed by NPScene.

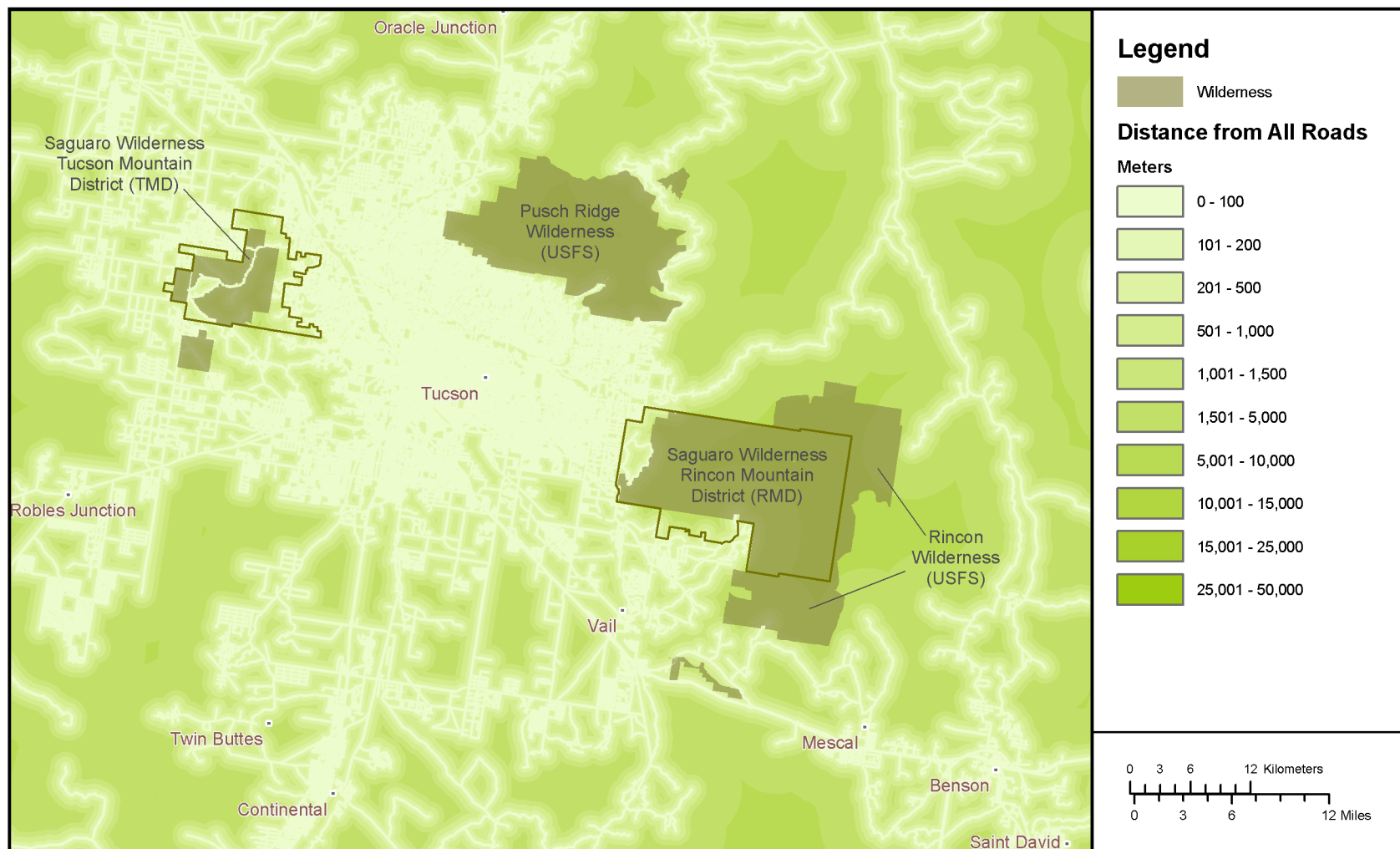
Roads & Transportation



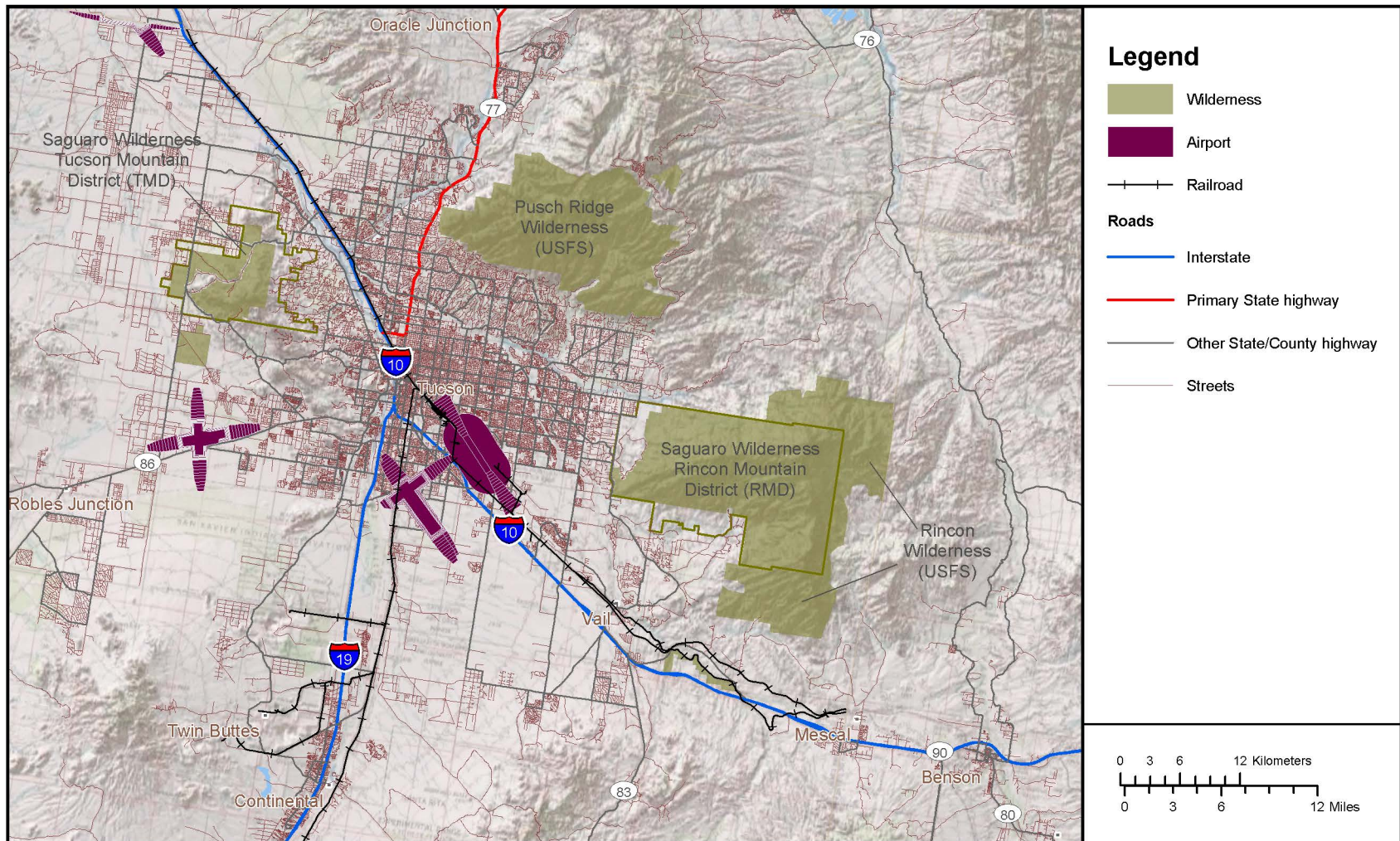
Map 109. Road network in the local area surrounding Saguaro National Park. Road data obtained from the Environmental Systems Research Institute (ESRI); used by NPScape in computing road indicators. Wilderness areas obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



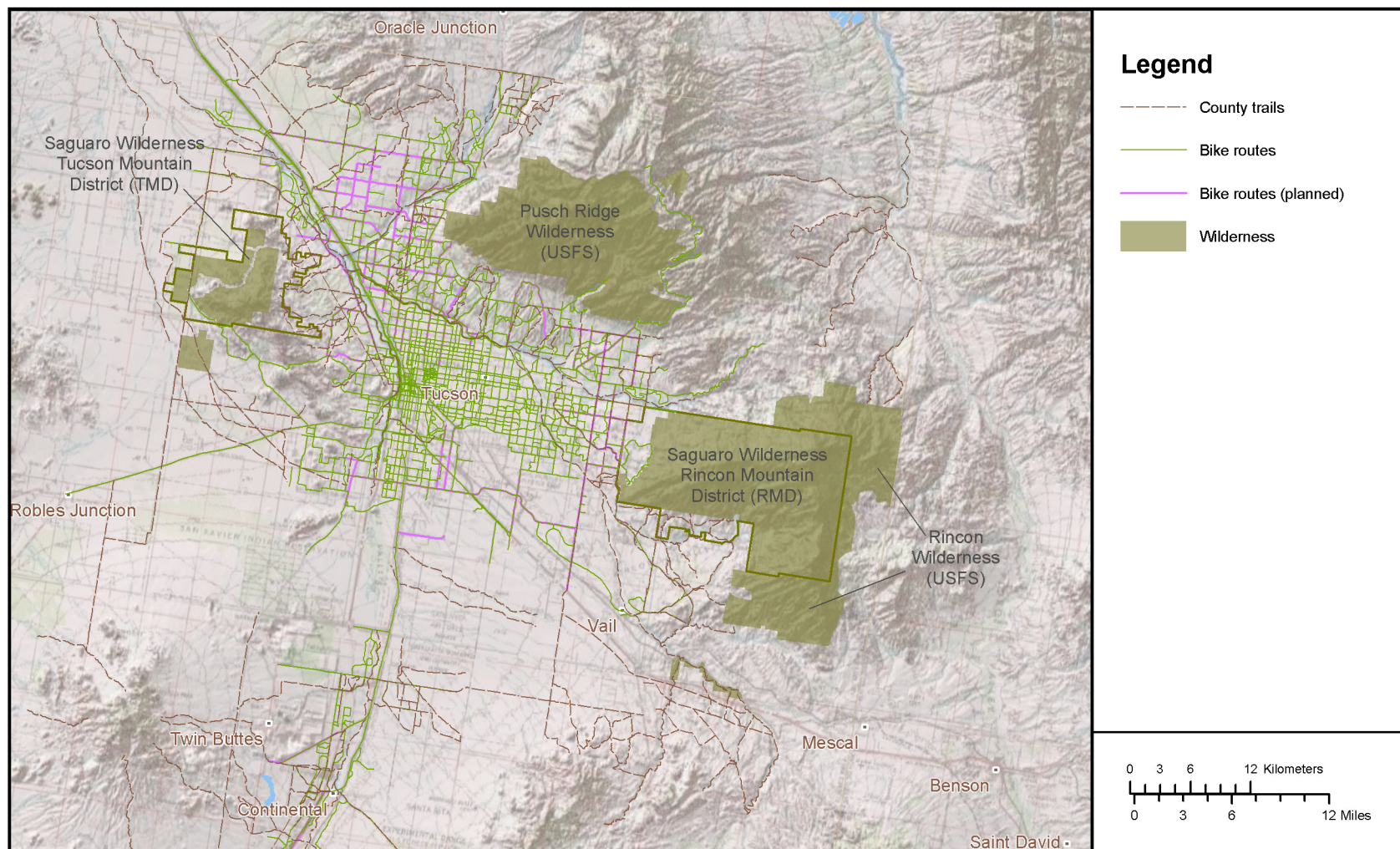
Map 110. Weighted road density in the local area surrounding Saguaro National Park. Highways are weighted by a factor of 3 and interstates by a factor of 10. Road data provided by NPScape. Wilderness areas obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



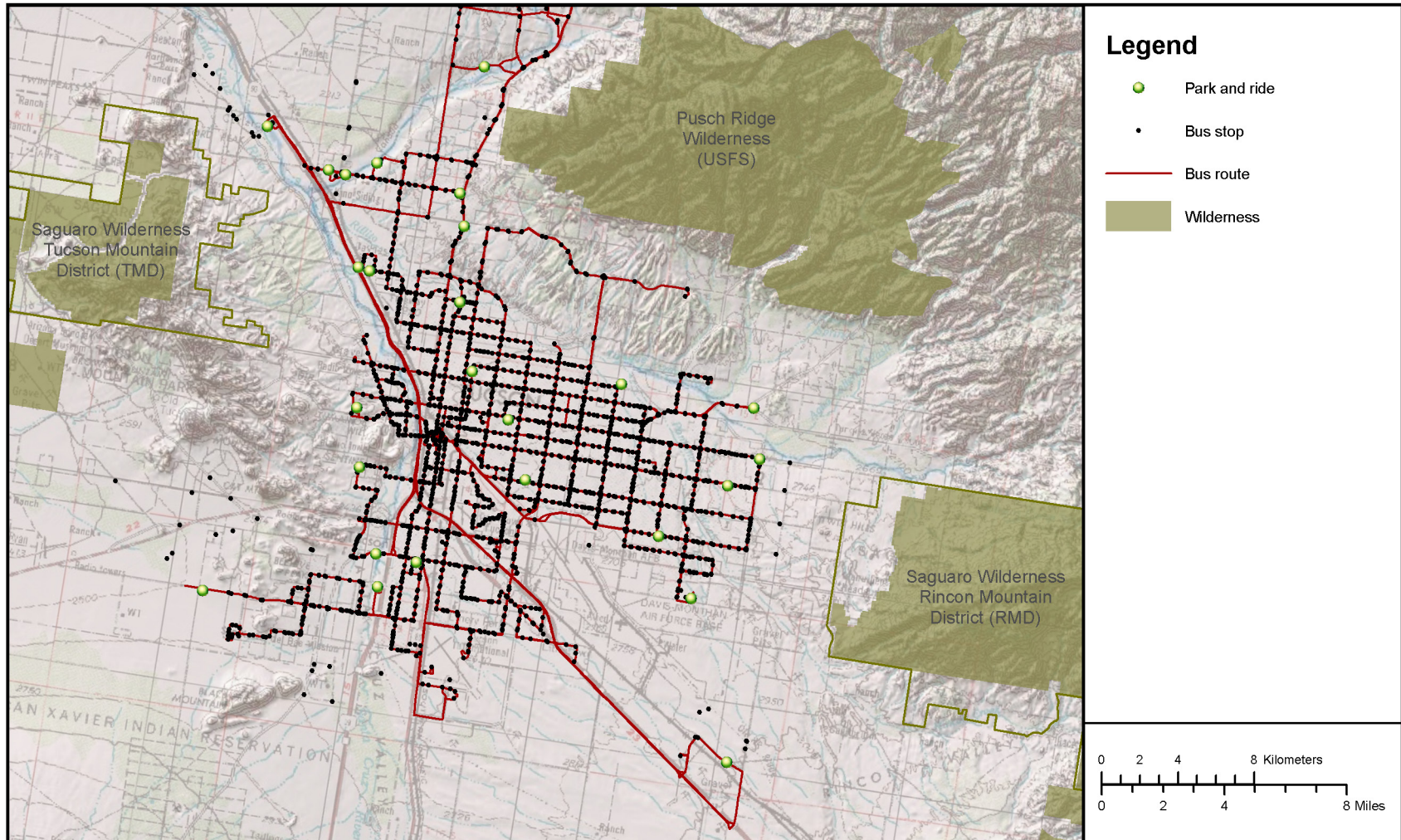
Map 111. Distance to the nearest road in the local area surrounding Saguaro National Park. Road data provided by NPScape. Wilderness areas obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



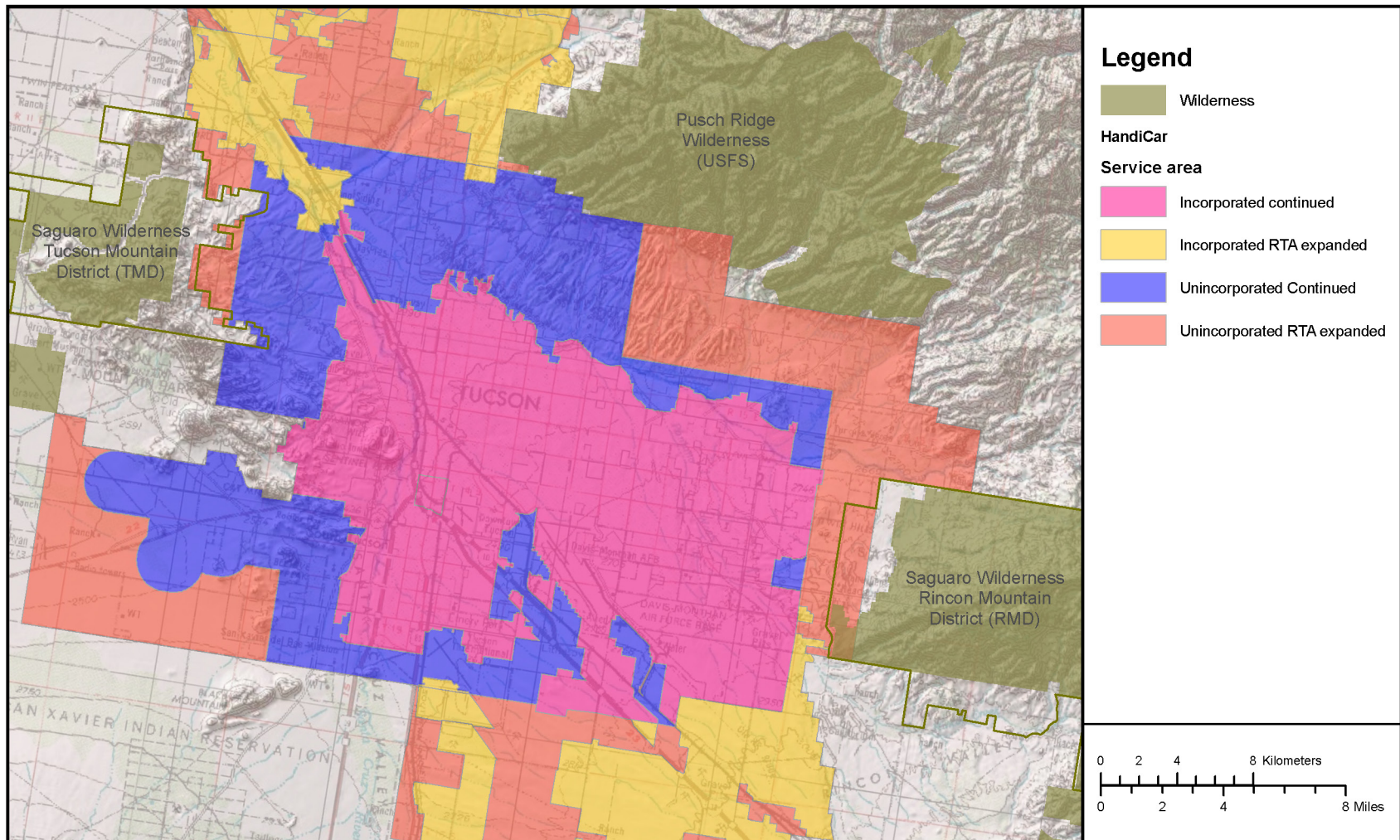
Map 112. Major air, road, and railroad transportation networks (public, private, and military) in the local area surrounding Saguaro National Park. Road network obtained from the Environmental Systems Research Institute. Other transportation data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



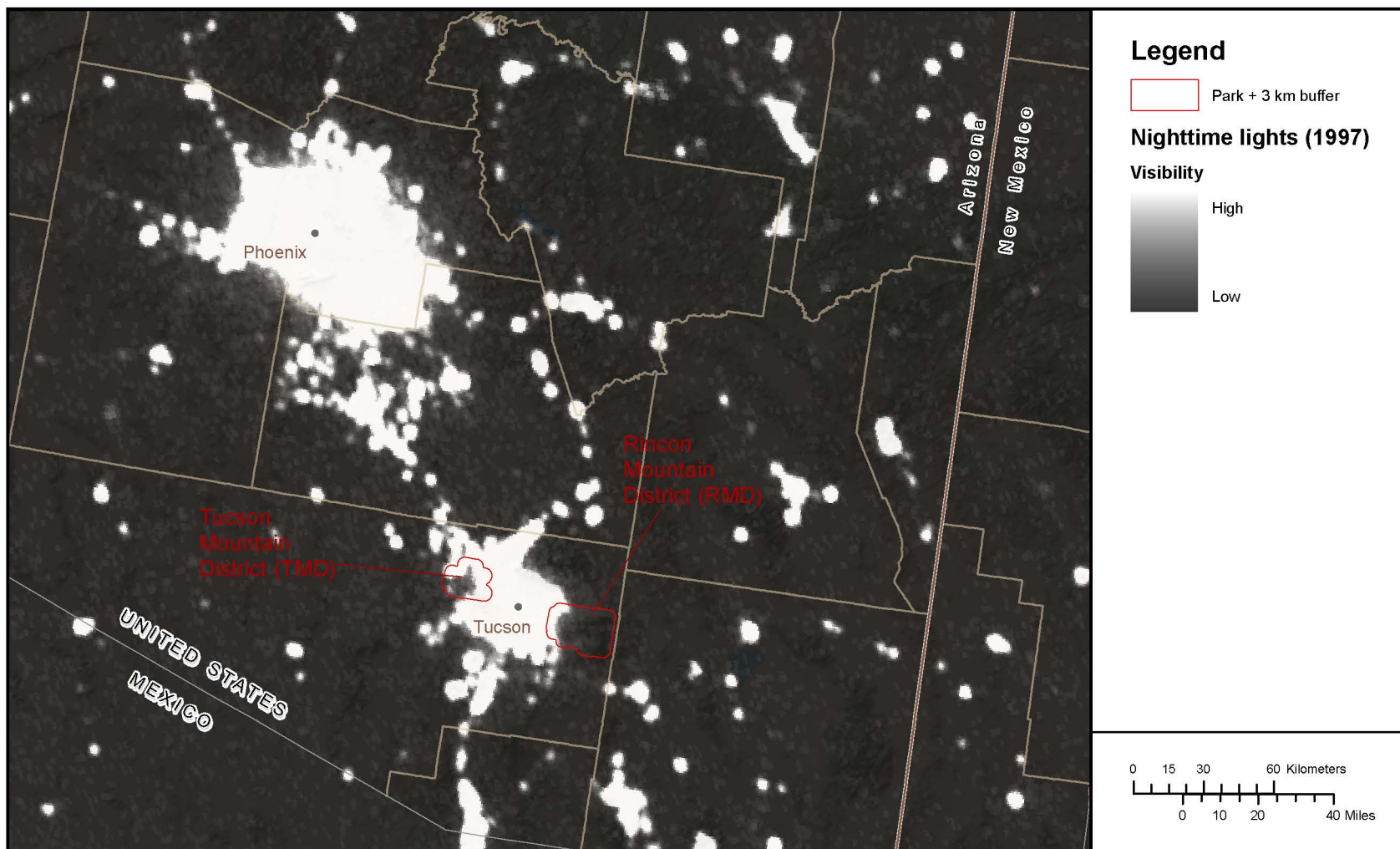
Map 113. Pima County trails and bike routes (existing, planned) in the local area surrounding Saguaro National Park. Source data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



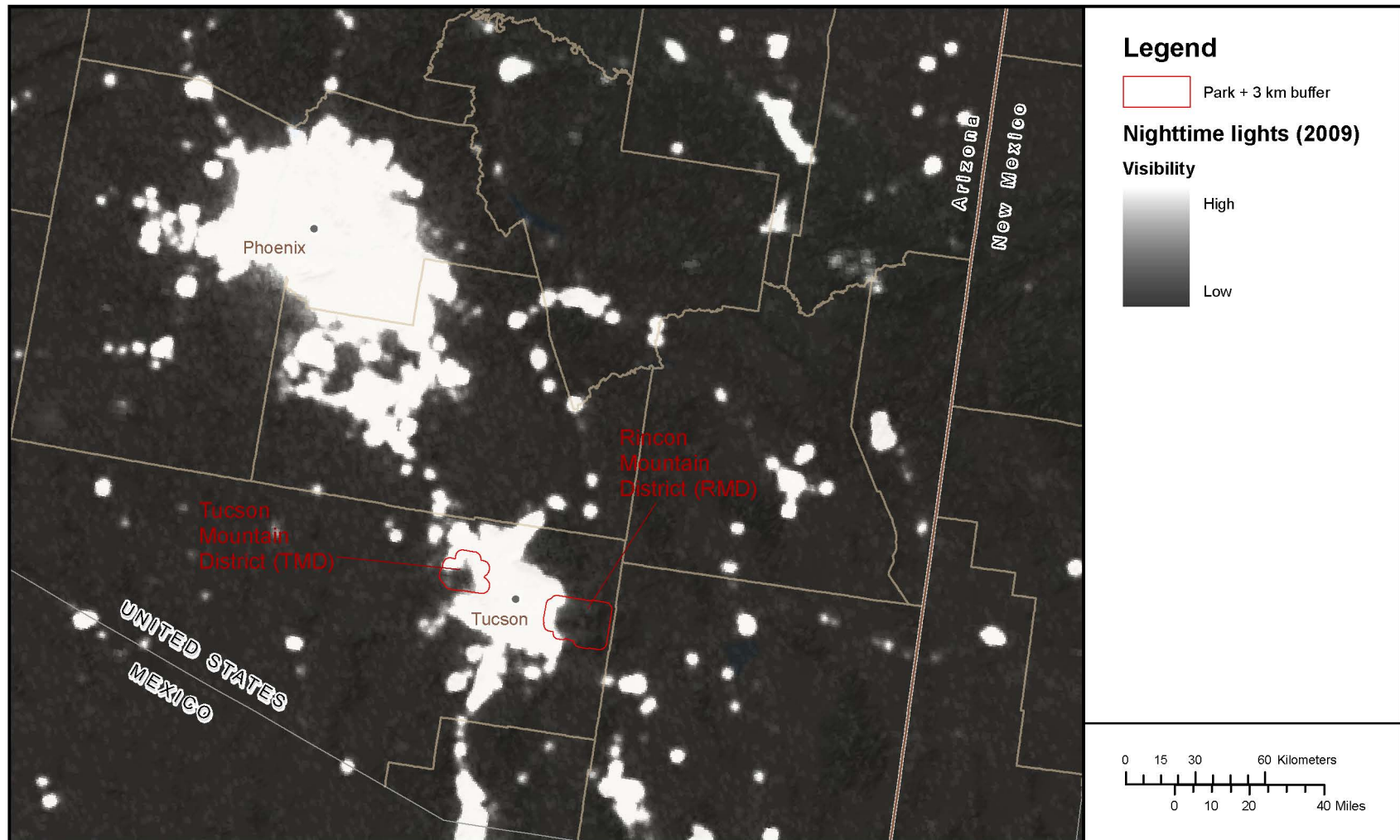
Map 114. Pima County park and ride locations, bus lines, and bus stops in the local area surrounding Saguaro National Park. Source data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



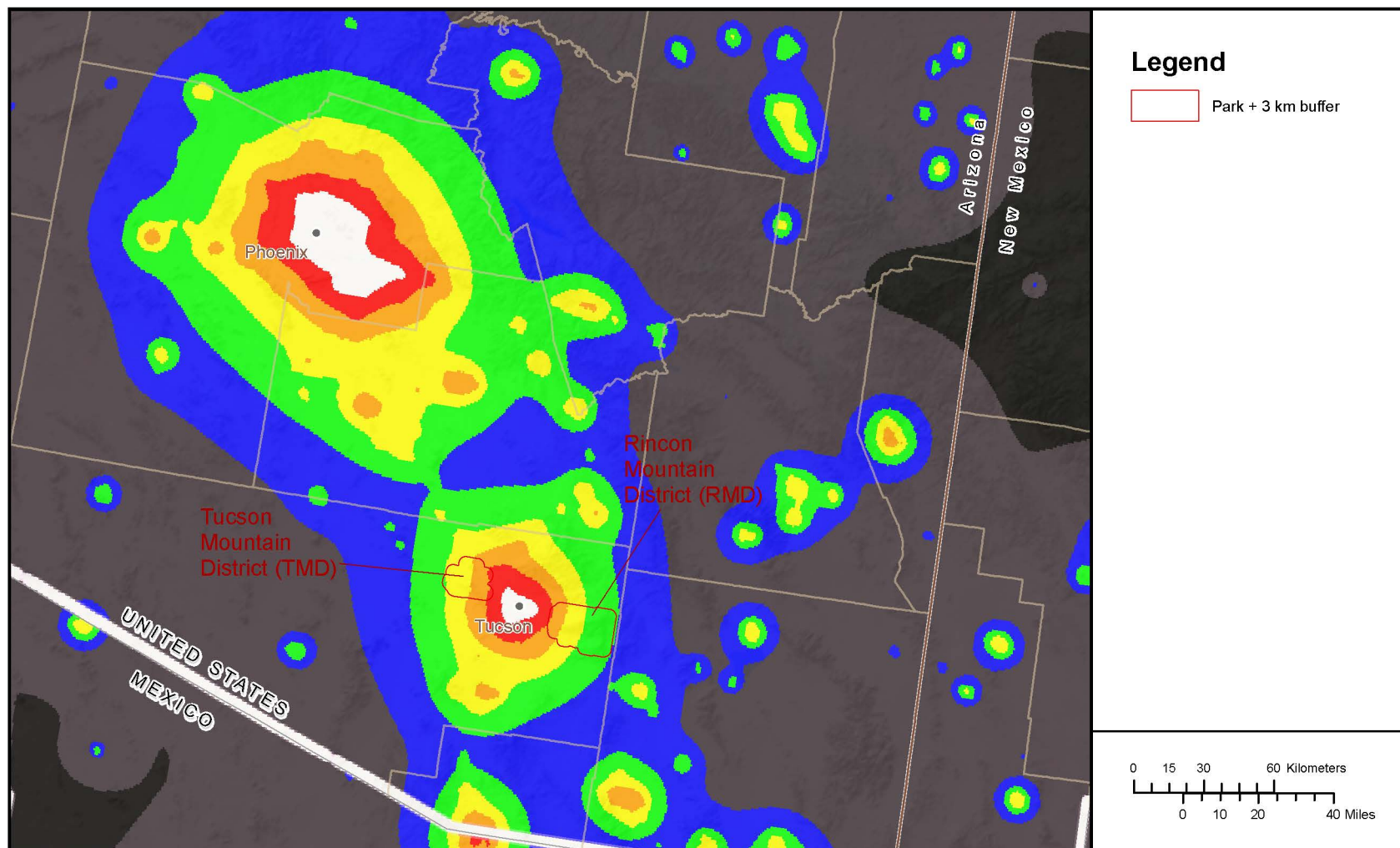
Nighttime Lights



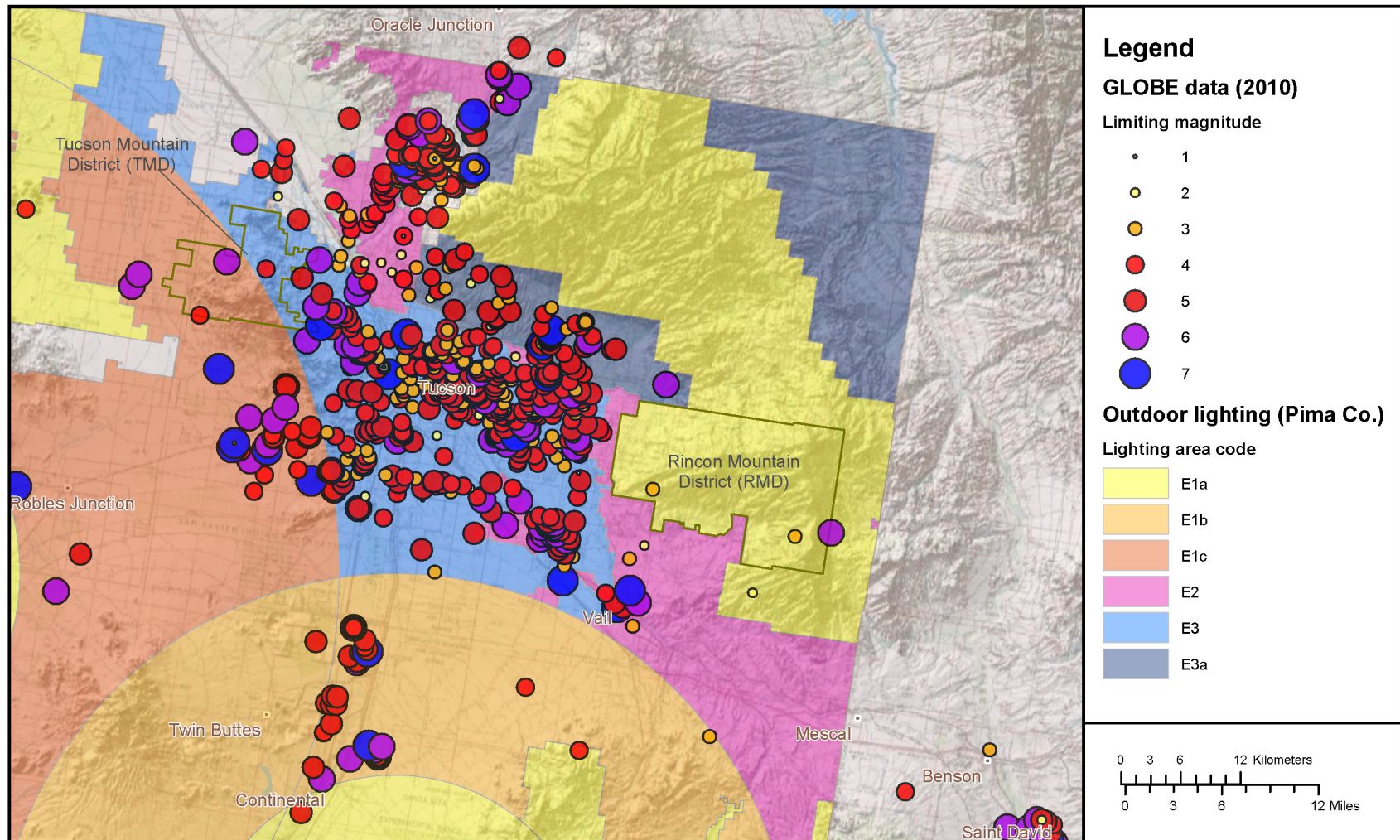
Map 116. Direct observations of average visible stable nighttime lights (Defense Meteorological Satellite Program Operational Linescan System 1997) for Saguaro National Park and ecoregional vicinity. In map extent, low nighttime light visibility is symbolized by dark/black colors while high nighttime light visibility is symbolized by light/white colors.



Map 117. Direct observations of average visible stable nighttime lights (Defense Meteorological Satellite Program Operational Linescan System 2009) for Saguaro National Park and ecoregional vicinity. The 2009 sensor is different from the one used in 1997, meaning that some differences between the two maps may reflect methodological artifacts. In map extent, low nighttime light visibility is symbolized by dark/black colors while high nighttime light visibility is symbolized by light/white colors.

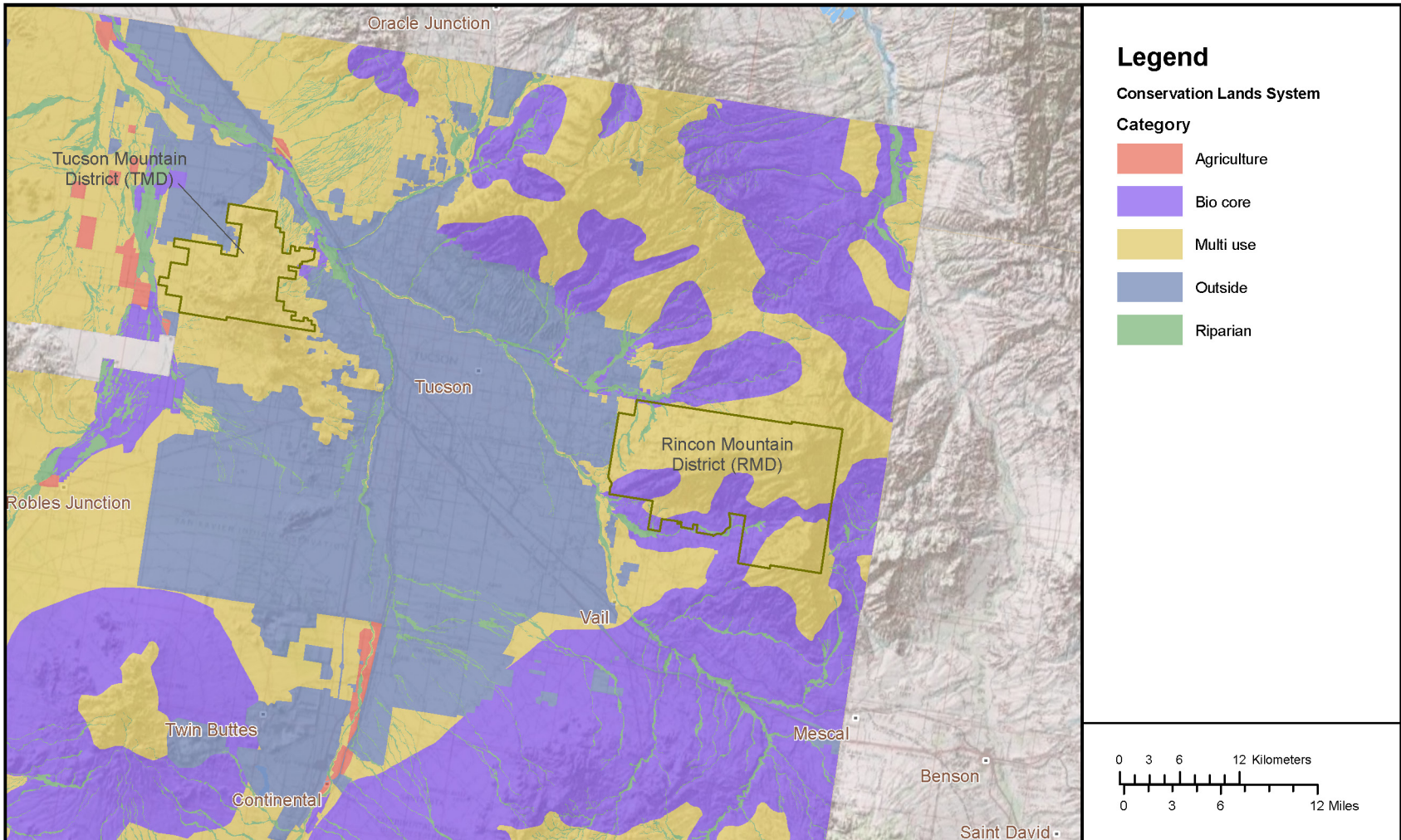


Map 118. The Cinzano model of nighttime lights that considers atmospheric scattering, or light pollution propagation. Colors range from yellow to white (increasing brightness) and green to black (increasing darkness).

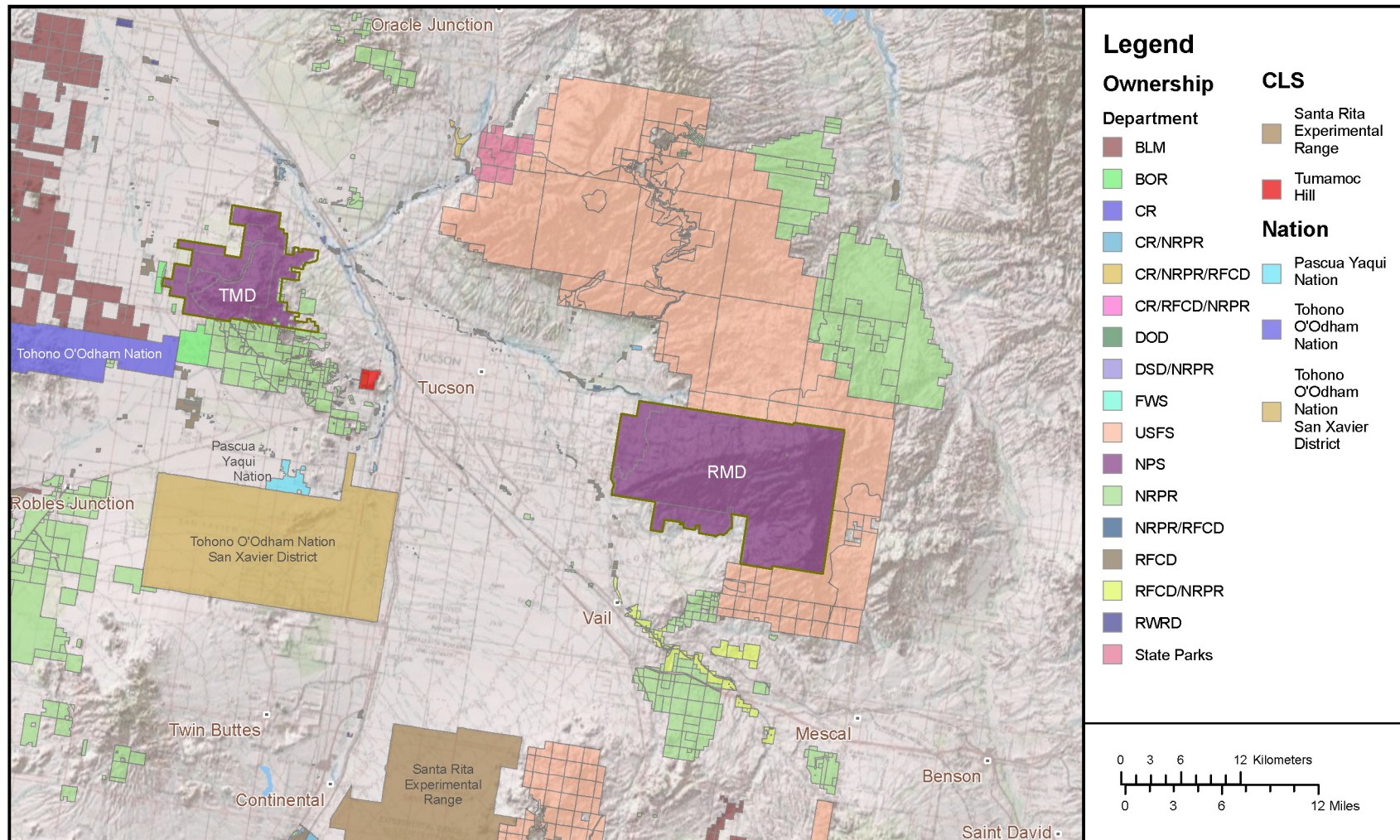


Map 119. Nighttime 'ground-up' sky observations (dated 2010) and Pima County outdoor lighting area codes (dated 2011) in the local area surrounding Saguaro National Park. Lighting area code data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>). Data on limiting magnitudes obtained from GLOBE (<http://www.globeatnight.org/analyze.html>).

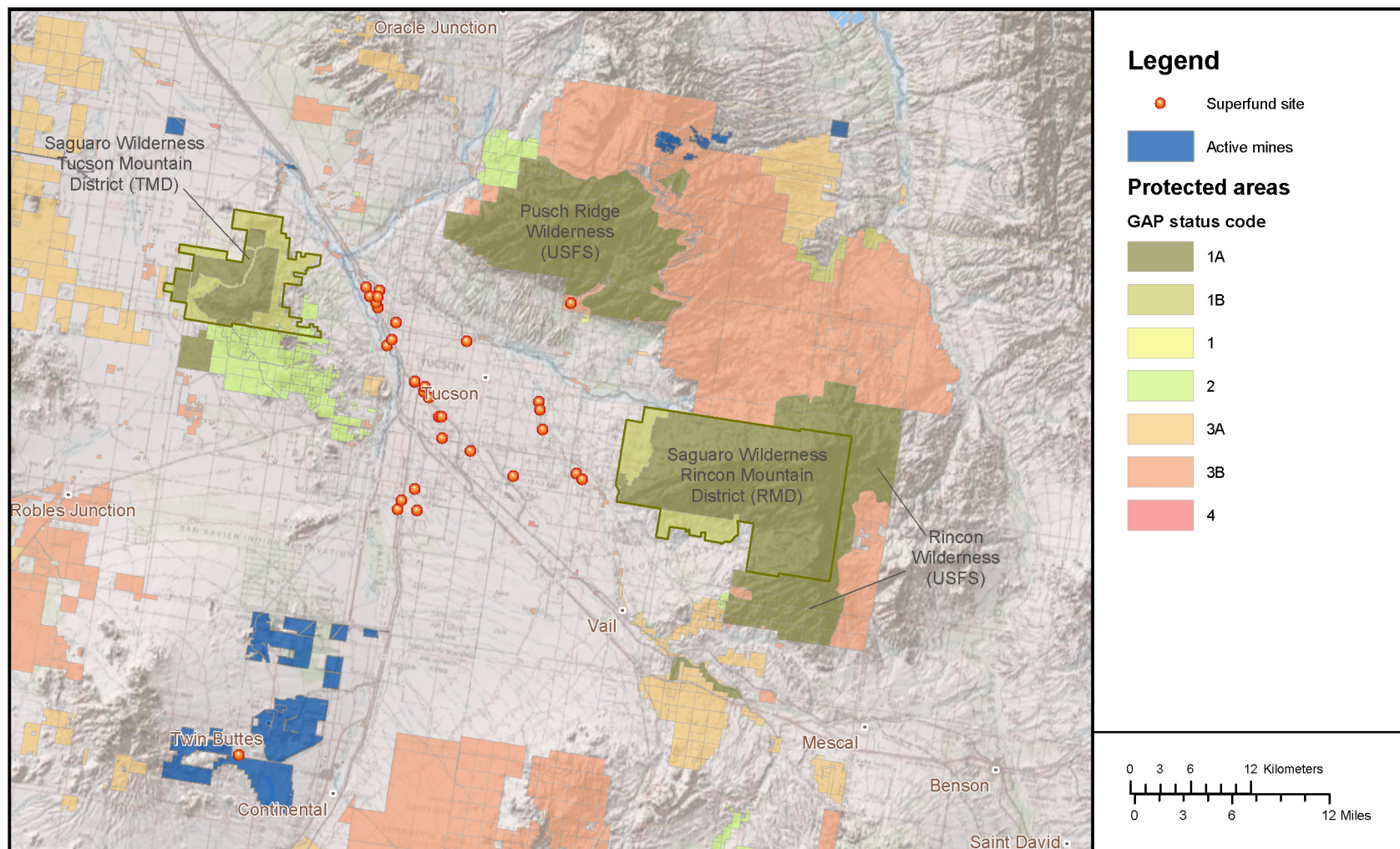
Conservation Status



Map 120. Pima County Conservation Lands System (CLS) classification in the local area surrounding Saguaro National Park. CLS data (dated 2004) obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

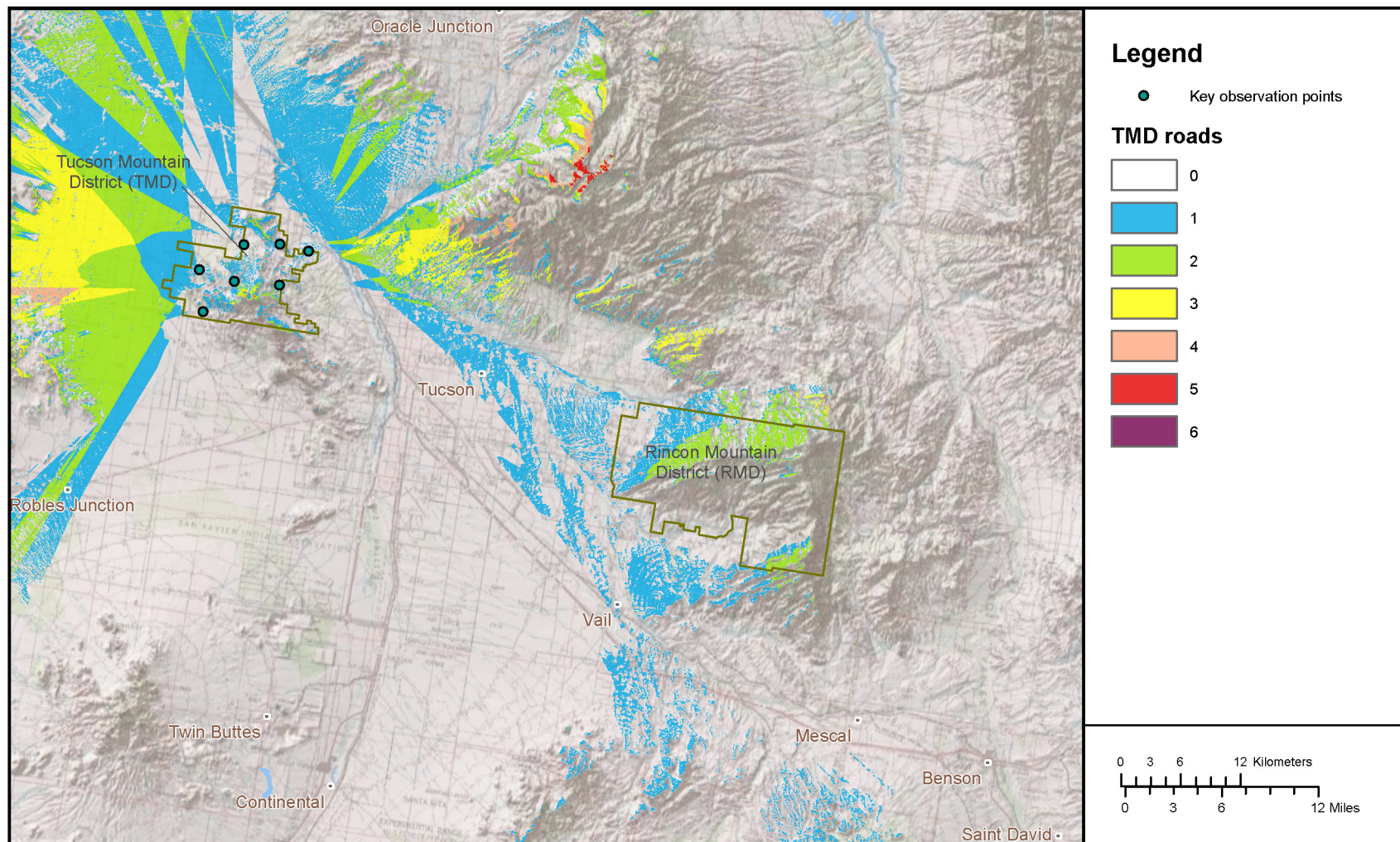


Map 121. Major landowners and land managing agencies in the local area surrounding Saguaro National Park. Ownership data (dated 2007) obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

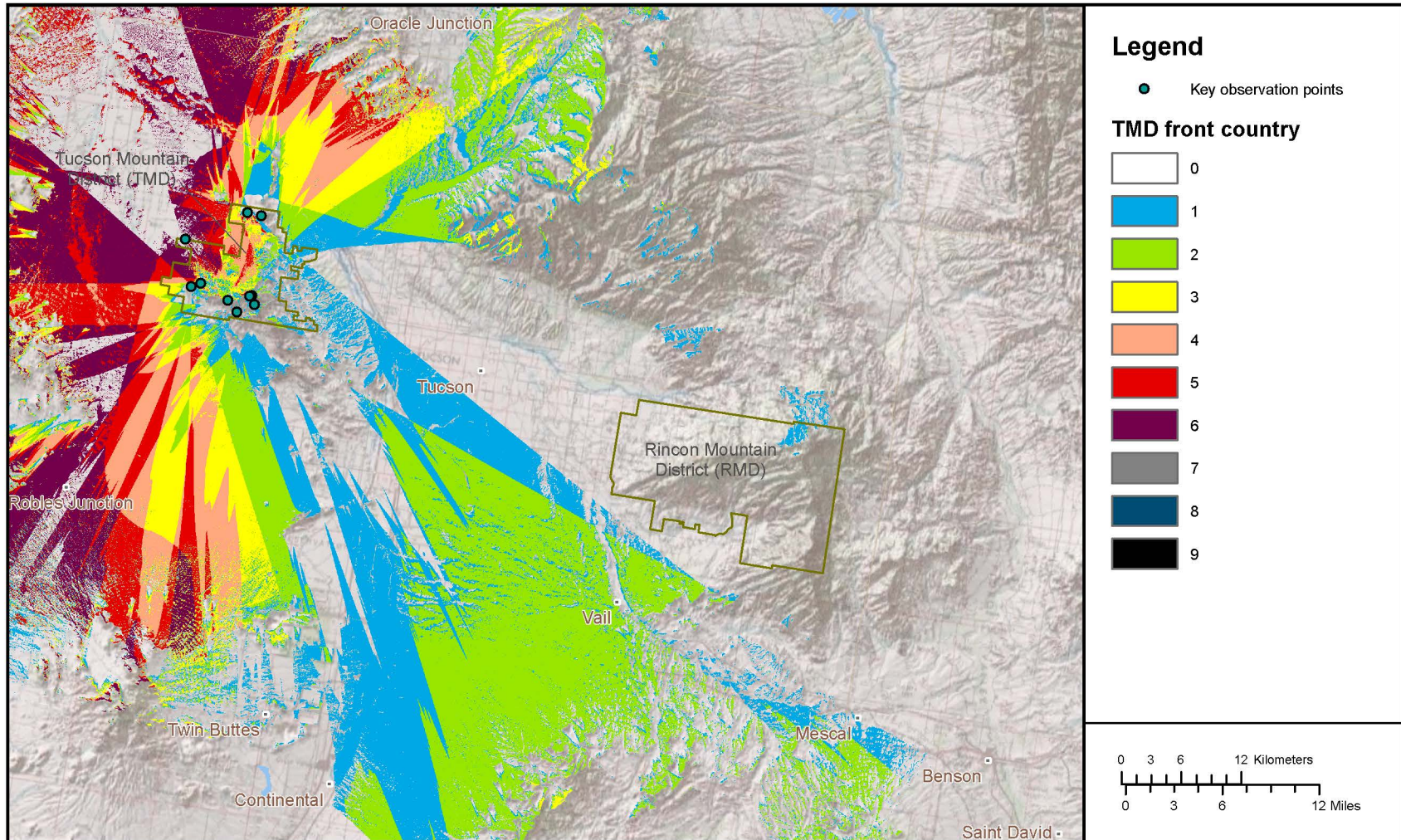


Map 122. Multiple levels of protected areas (denoted by GAP status code, see Methods – Section 2.3.1) considered in relation to potential stressors or disturbances originating from superfund sites and active mines in the local area surrounding Saguaro National Park. Protected areas (dated 2007), superfund sites (dated 2001), and active mines (dated 1996) obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

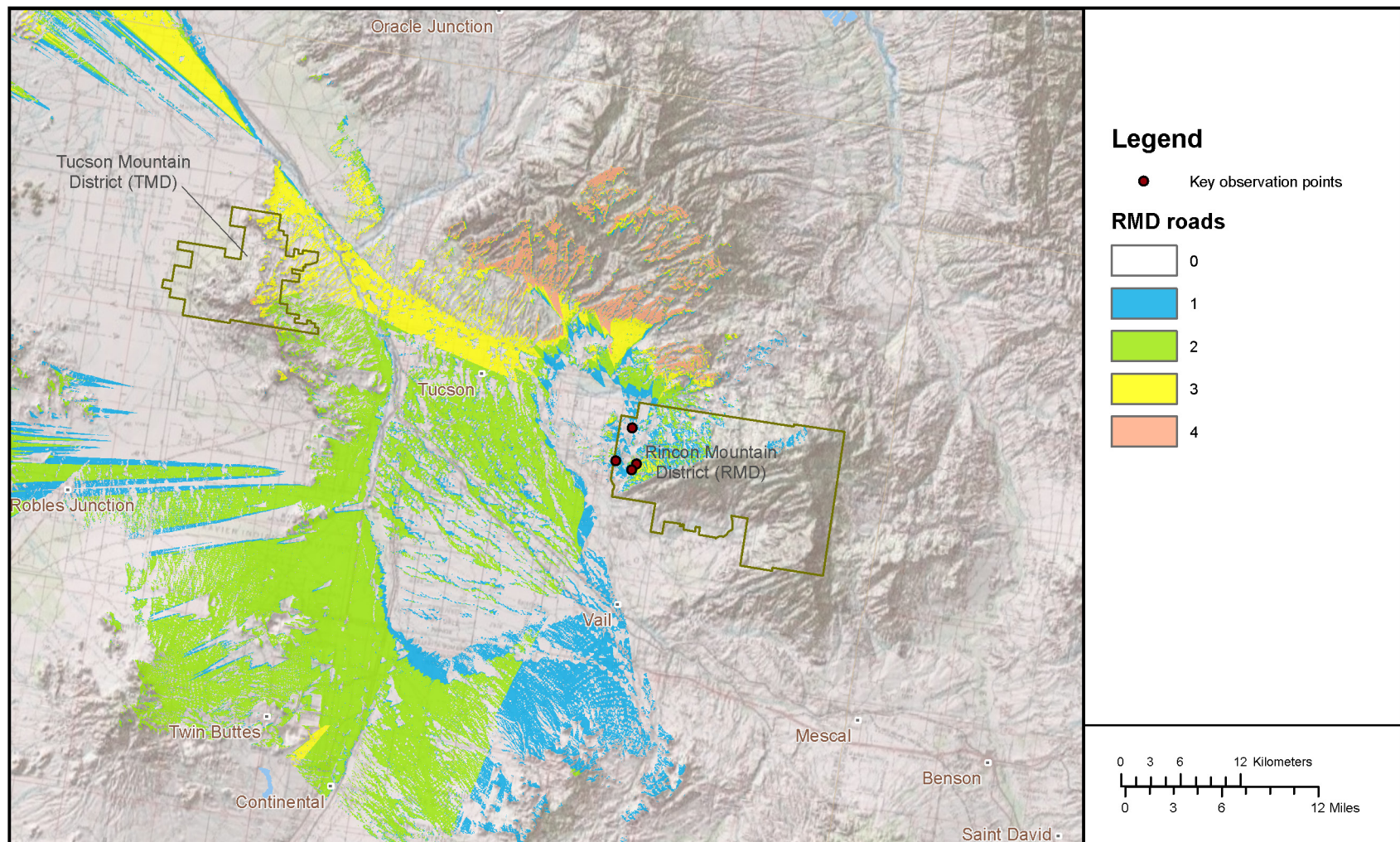
Viewsheds



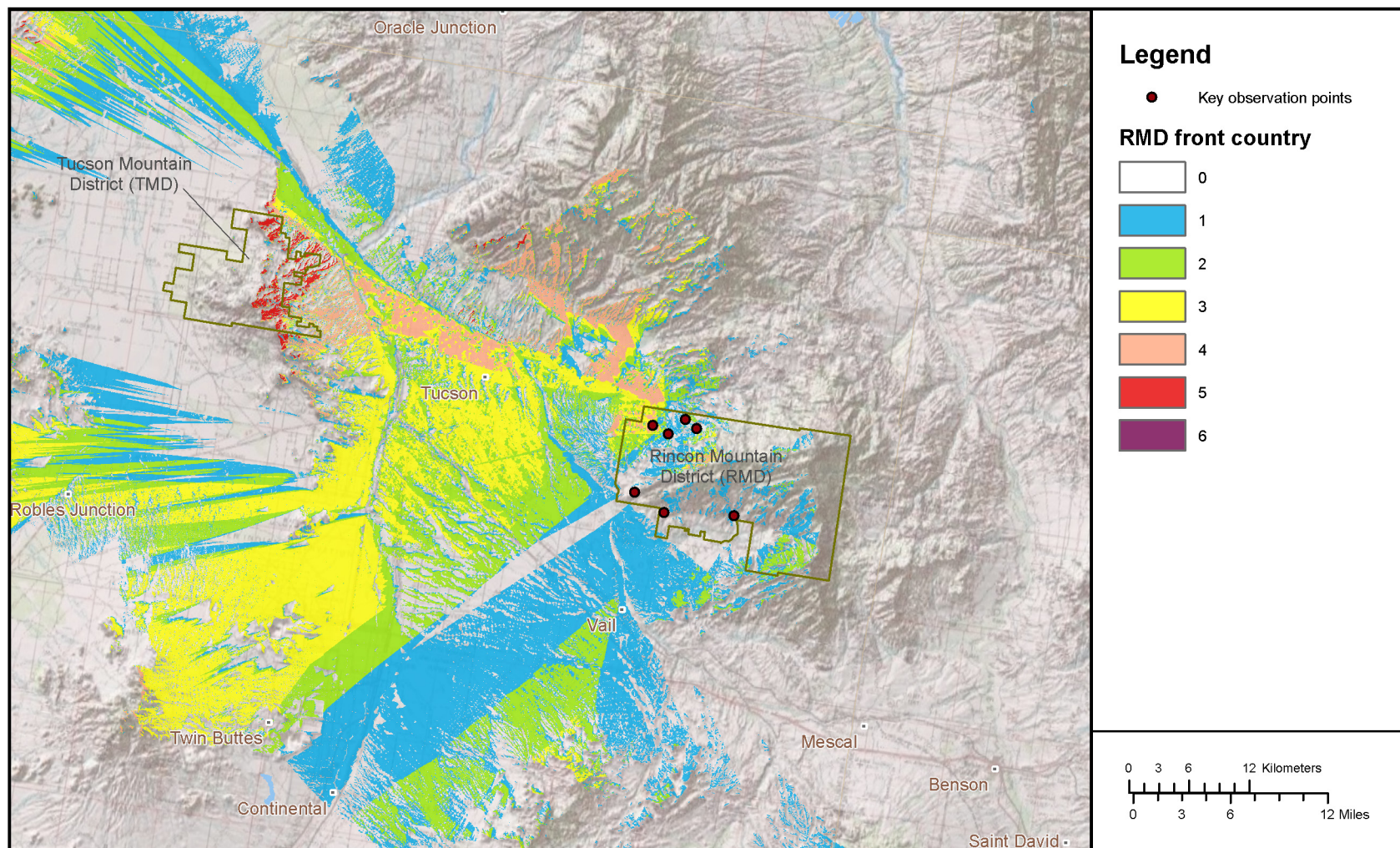
Map 123. Viewsheds from key observation points along roads in TMD. Colors in the map legend indicate the number of road observation points that areas are visible from. The viewshed analysis was constrained by a 25 mile buffer around both districts, and points reflect an observer at ground level.



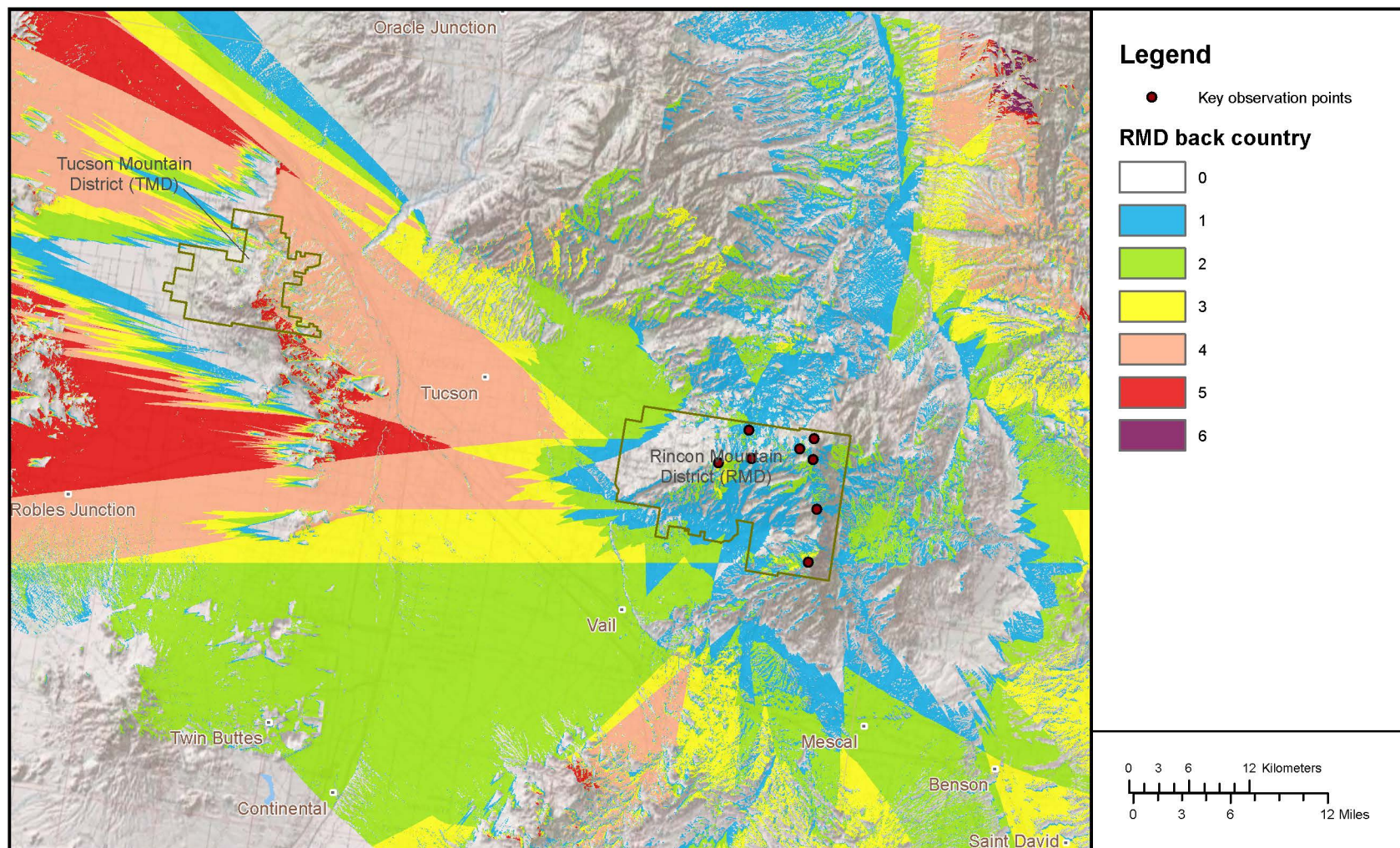
Map 124. Viewsheds from key observation points in the front country of TMD. Colors in the map legend indicate the number of front country observation points that areas are visible from. The viewshed analysis was constrained by a 25 mile buffer around both districts, and points reflect an observer at ground level.



Map 125. Viewsheds from key observation points along roads in RMD. Colors in the map legend indicate the number of road observation points that areas are visible from. The viewshed analysis was constrained by a 25 mile buffer around both districts, and points reflect an observer at ground level.

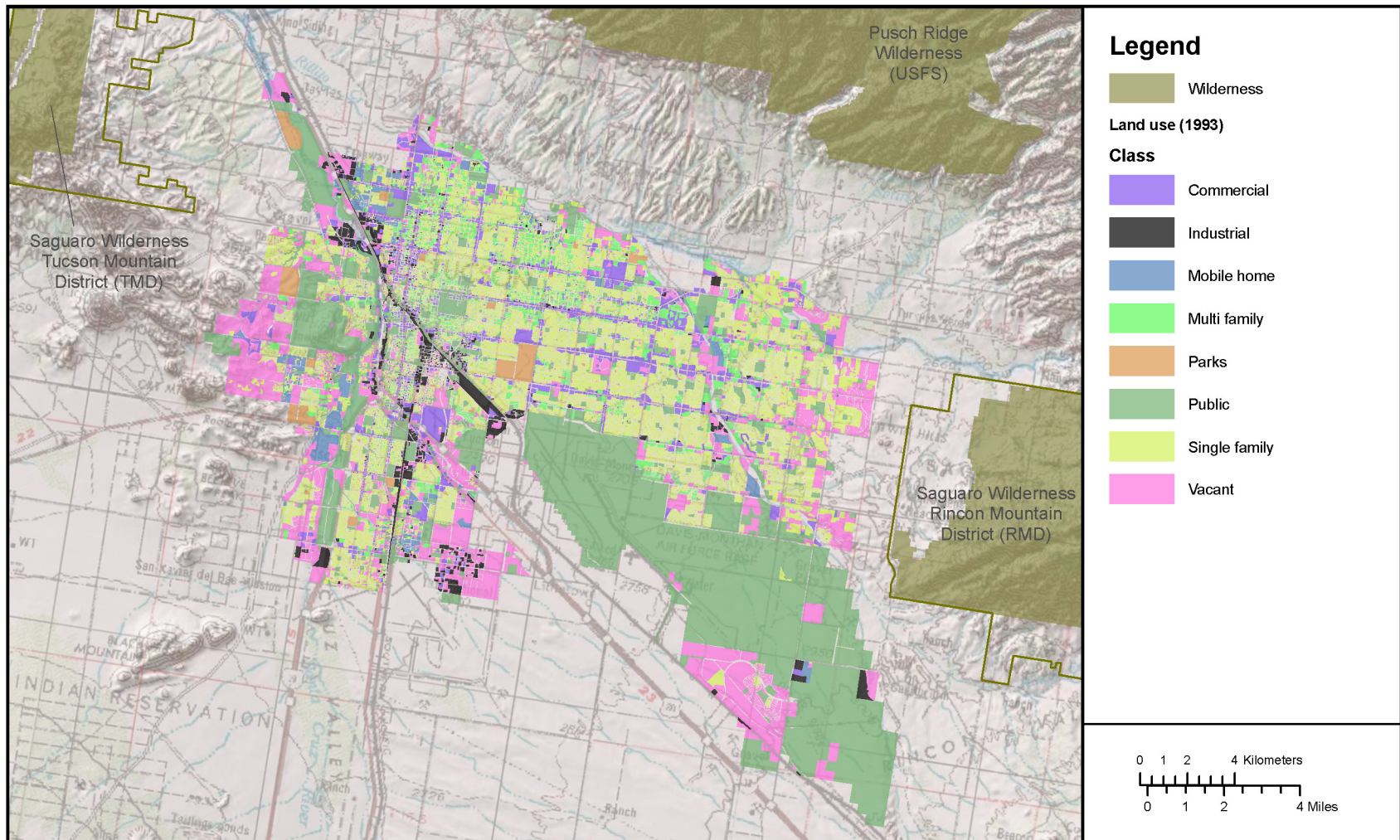


Map 126. Viewsheds from key observation points in the front country of RMD. Colors in the map legend indicate the number of front country observation points that areas are visible from. The viewshed analysis was constrained by a 25 mile buffer around both districts, and points reflect an observer at ground level.

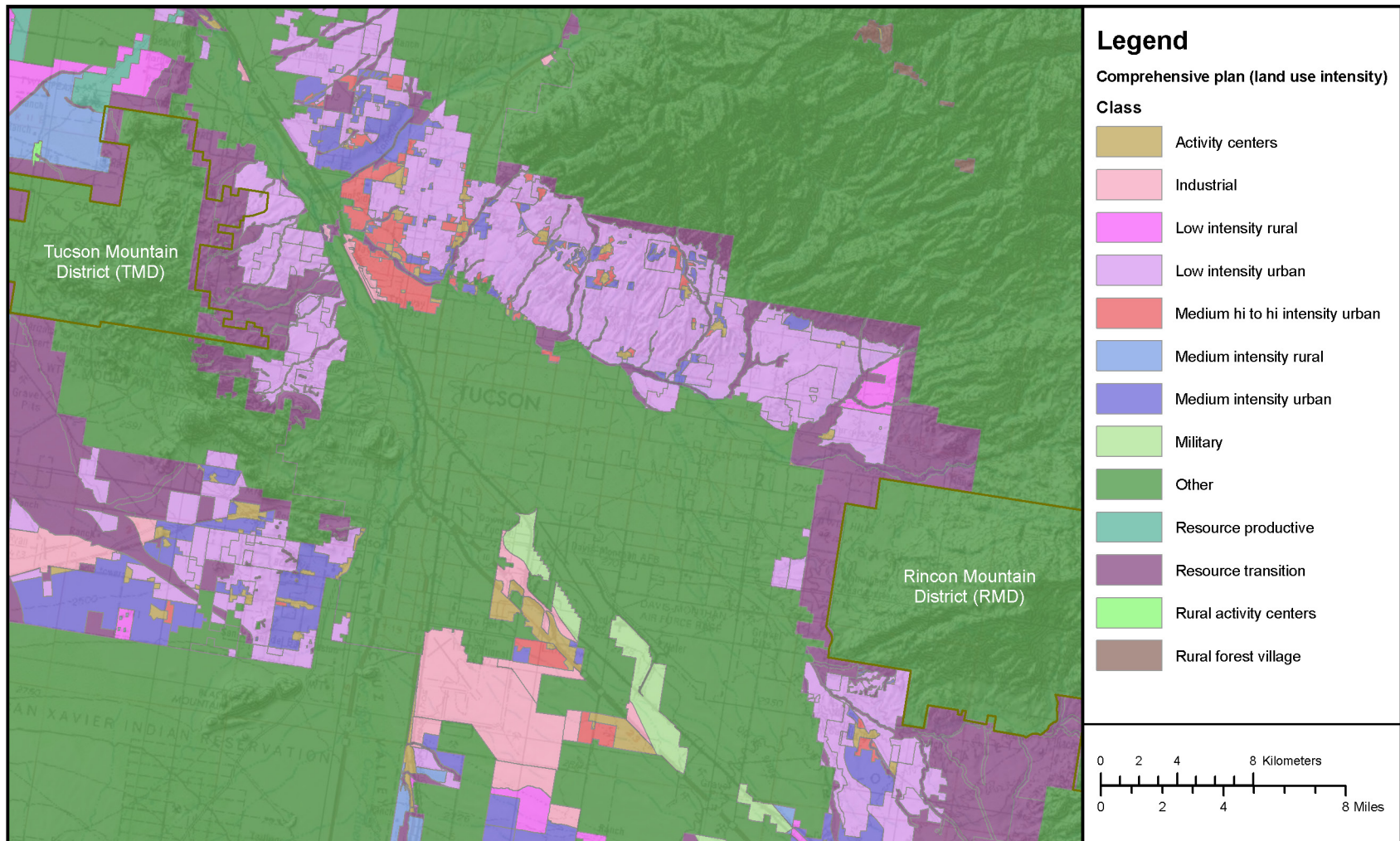


Map 127. Viewsheds from key observation points in the back country of RMD. Colors in the map legend indicate the number of back country observation points that areas are visible from. The viewshed analysis was constrained by a 25 mile buffer around both districts, and points reflect an observer at ground level.

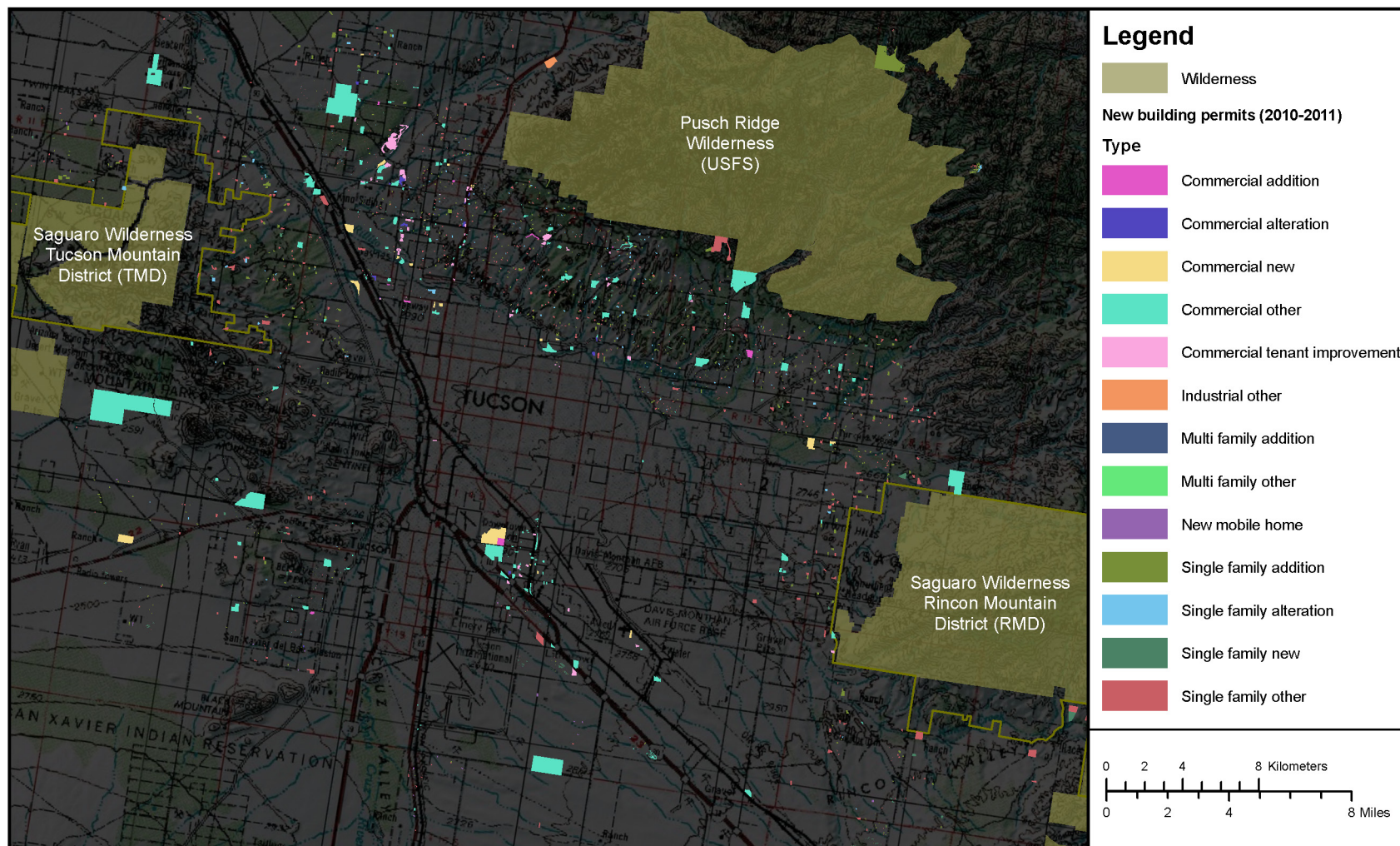
Land Use & Zoning



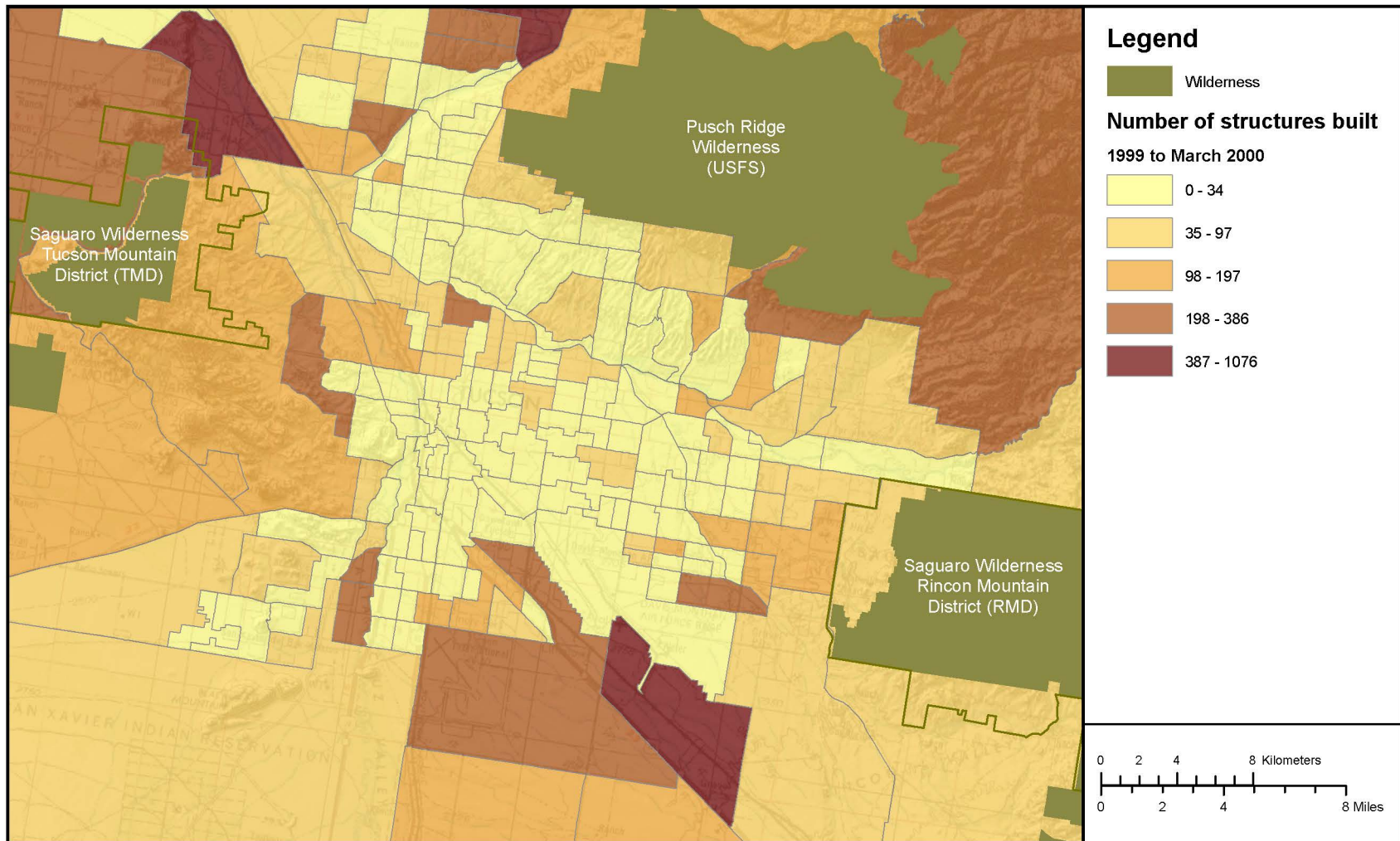
Map 128. City of Tucson land use (dated 1993) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



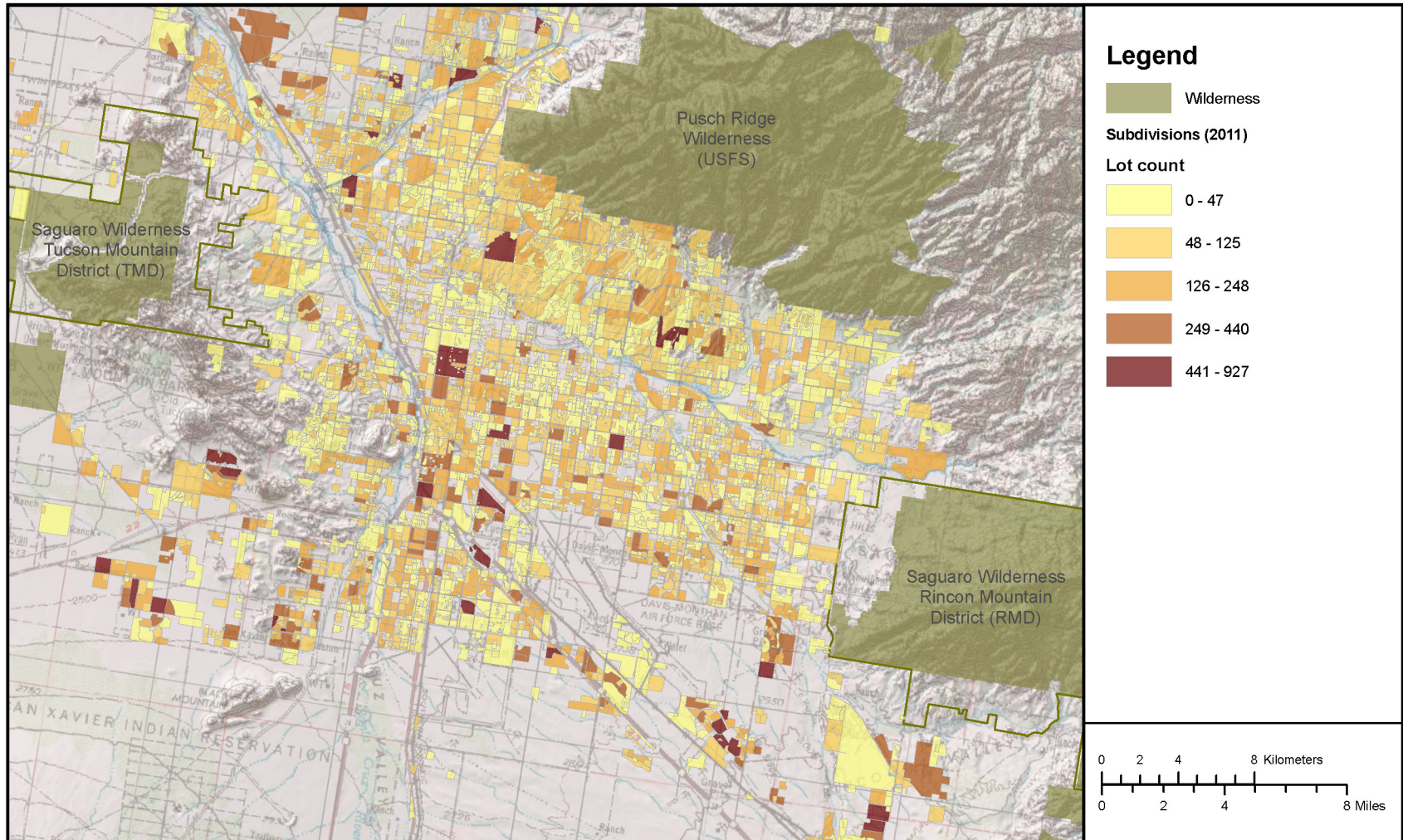
Map 129. Pima County comprehensive plan for land use intensity of unincorporated areas in the local area surrounding Saguaro National Park. Plan data (dated 2009) obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



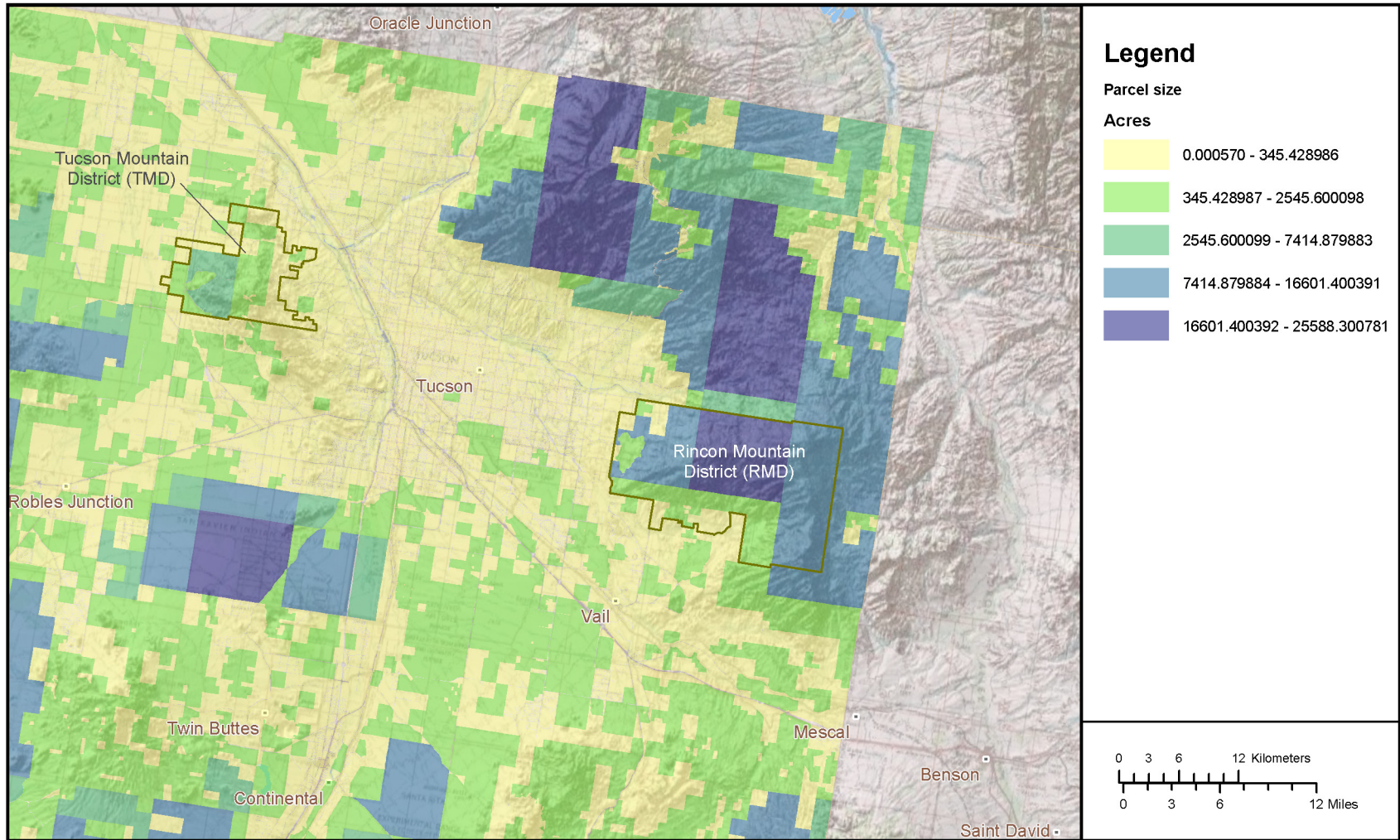
Map 130. Pima County new building permits (2010-2011) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



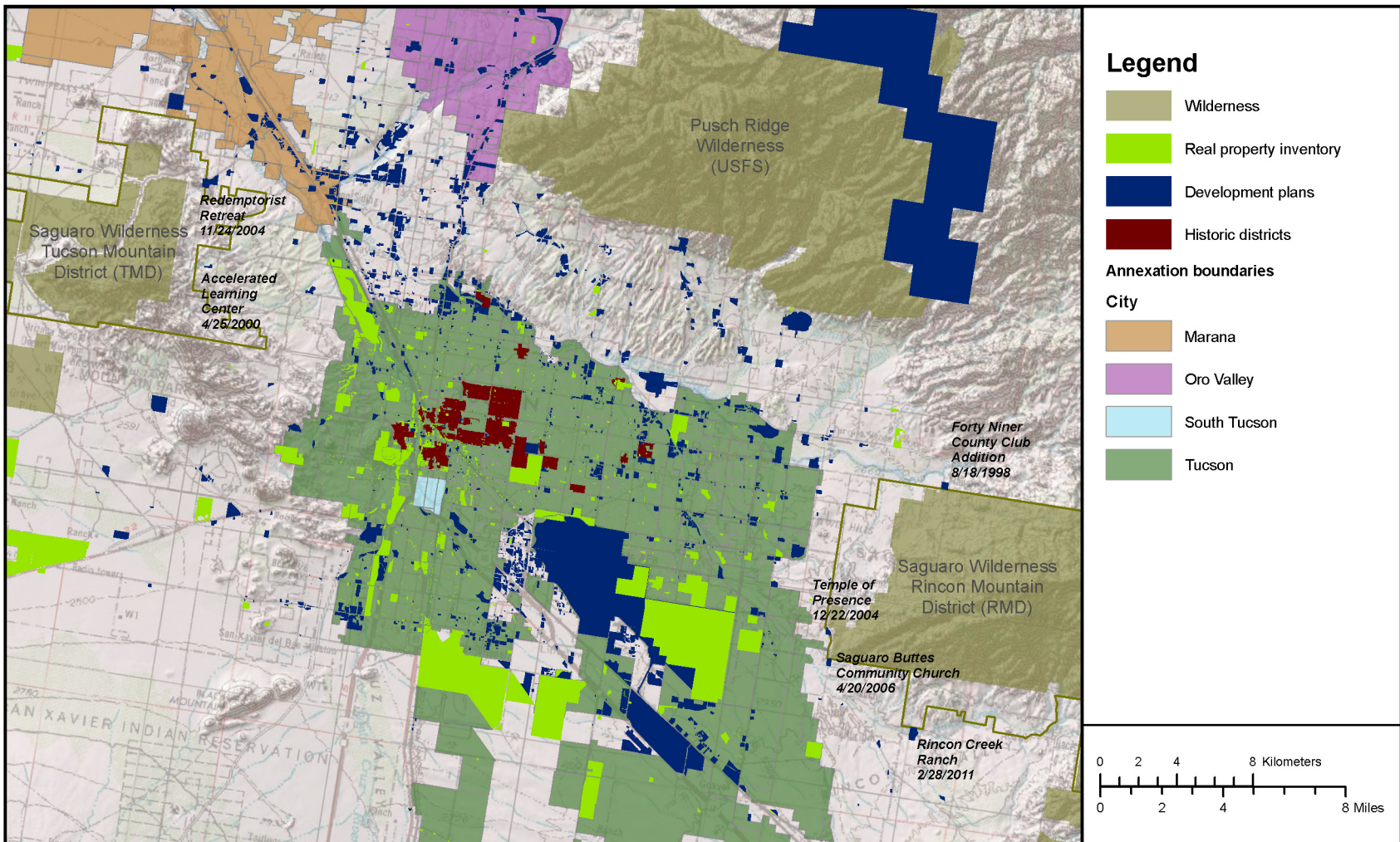
Map 131. Number of structures built between 1999 and March 2000 (US Census Bureau) in the local area surrounding Saguaro National Park. Structure and wilderness data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



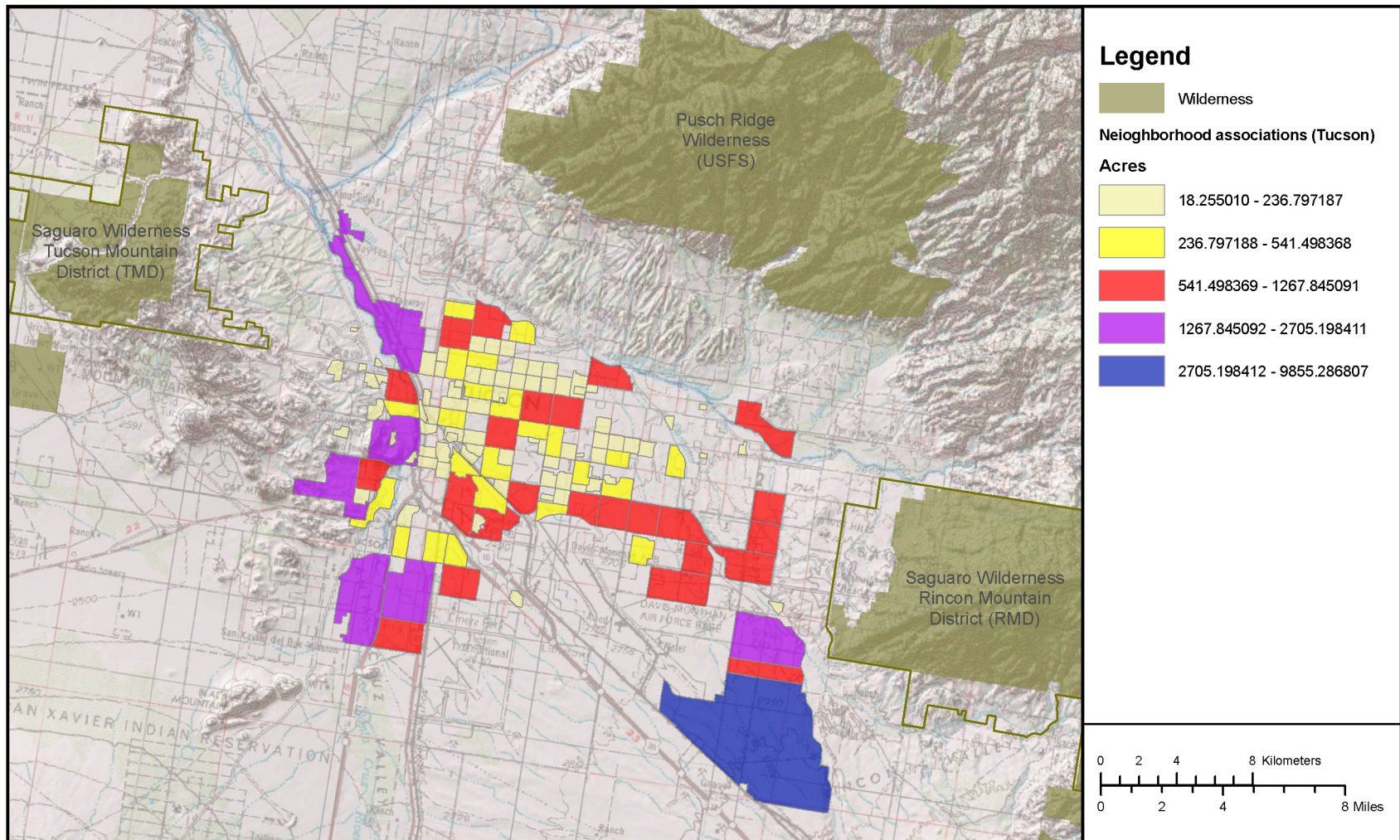
Map 132. Pima County subdivisions by lot count (dated April 2011) in the local area surrounding Saguaro National Park. Subdivision and wilderness data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



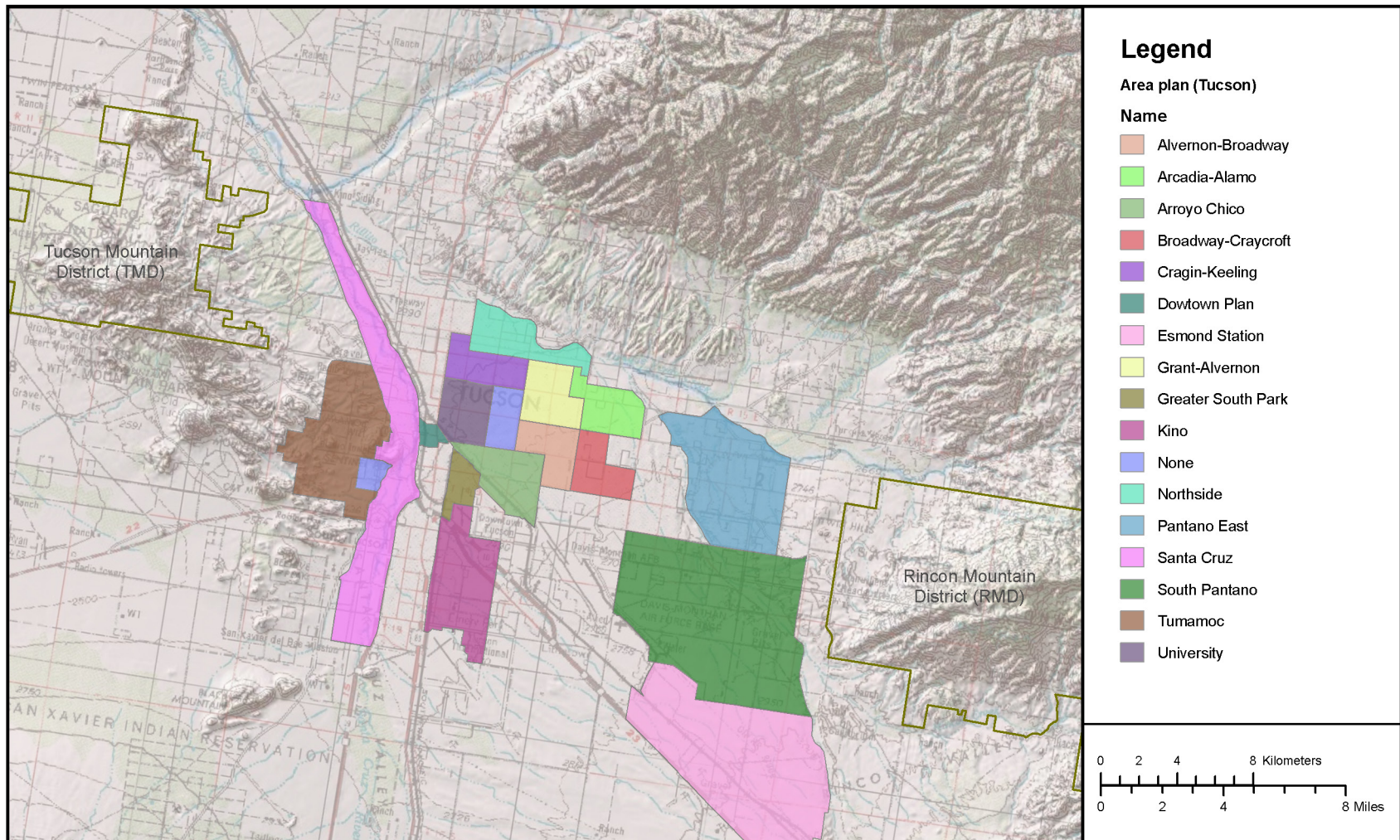
Map 133. Pima County parcels by size in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



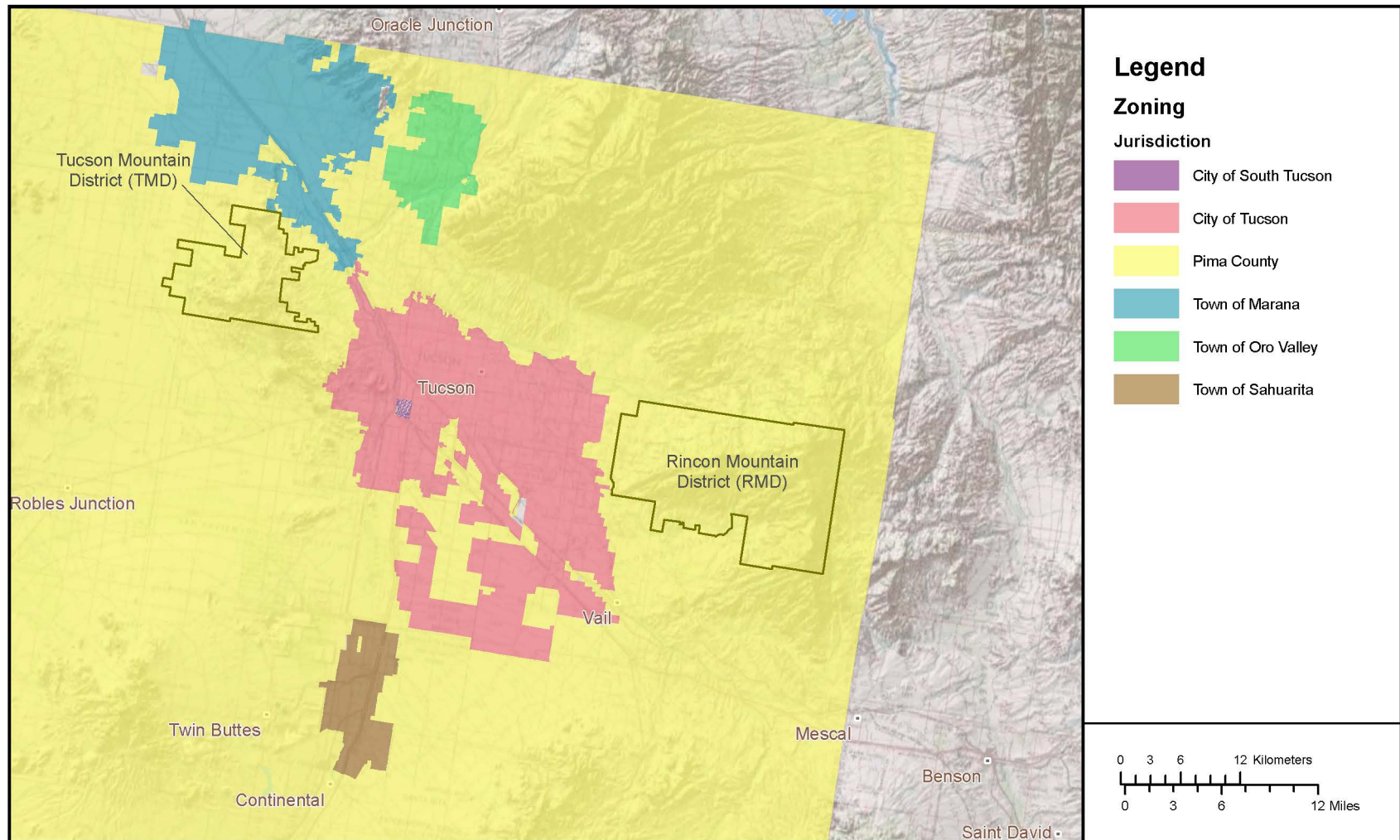
Map 134. Pima County real property inventory, areas with development plans, historic districts, and annexation boundaries in the local area surrounding Saguaro National Park. Map data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



Map 135. City of Tucson neighborhood associations (dated 2007) in the local area surrounding Saguaro National Park. Association and wilderness data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

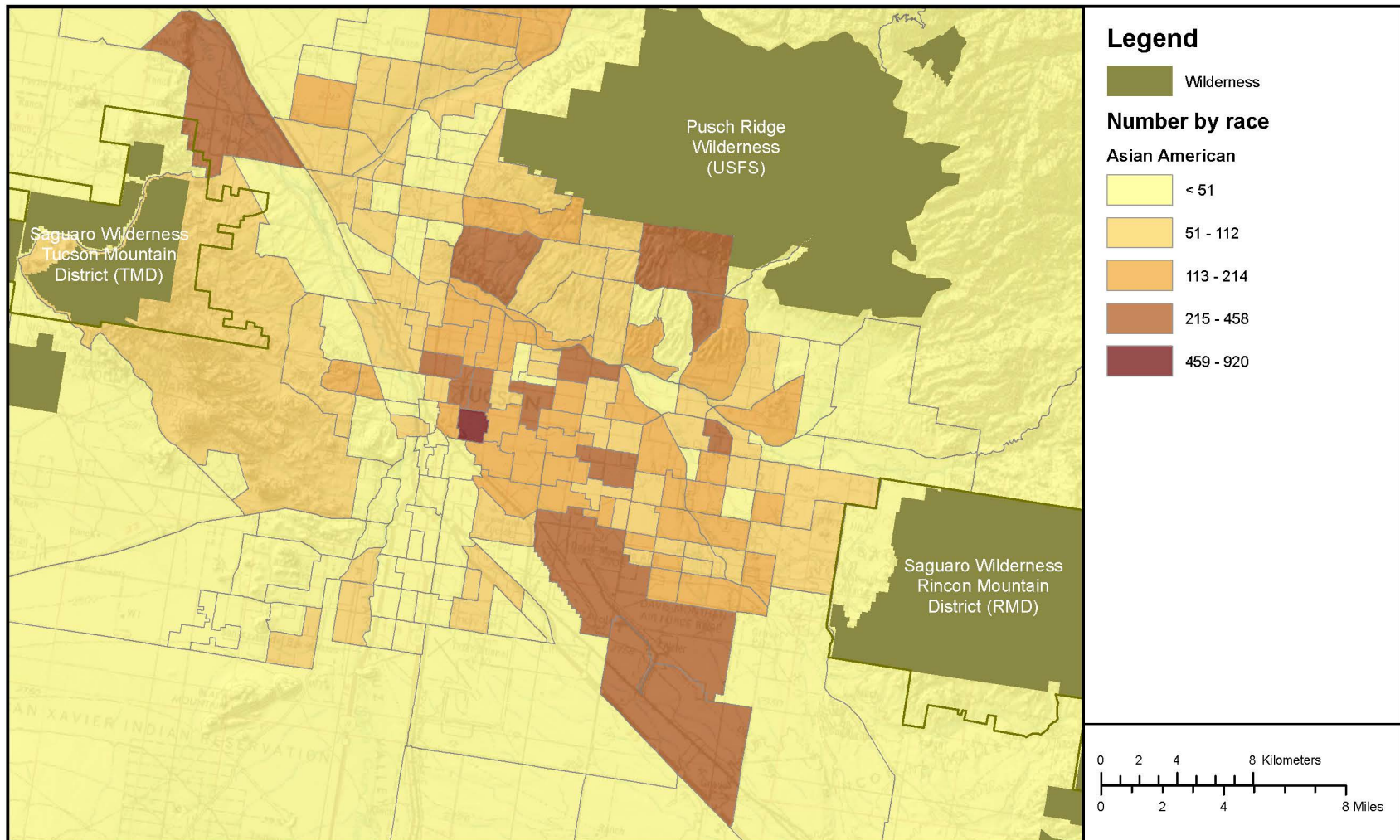


Map 136. City of Tucson area plan (dated 2000) in the local area surrounding Saguaro National Park. Area plan data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

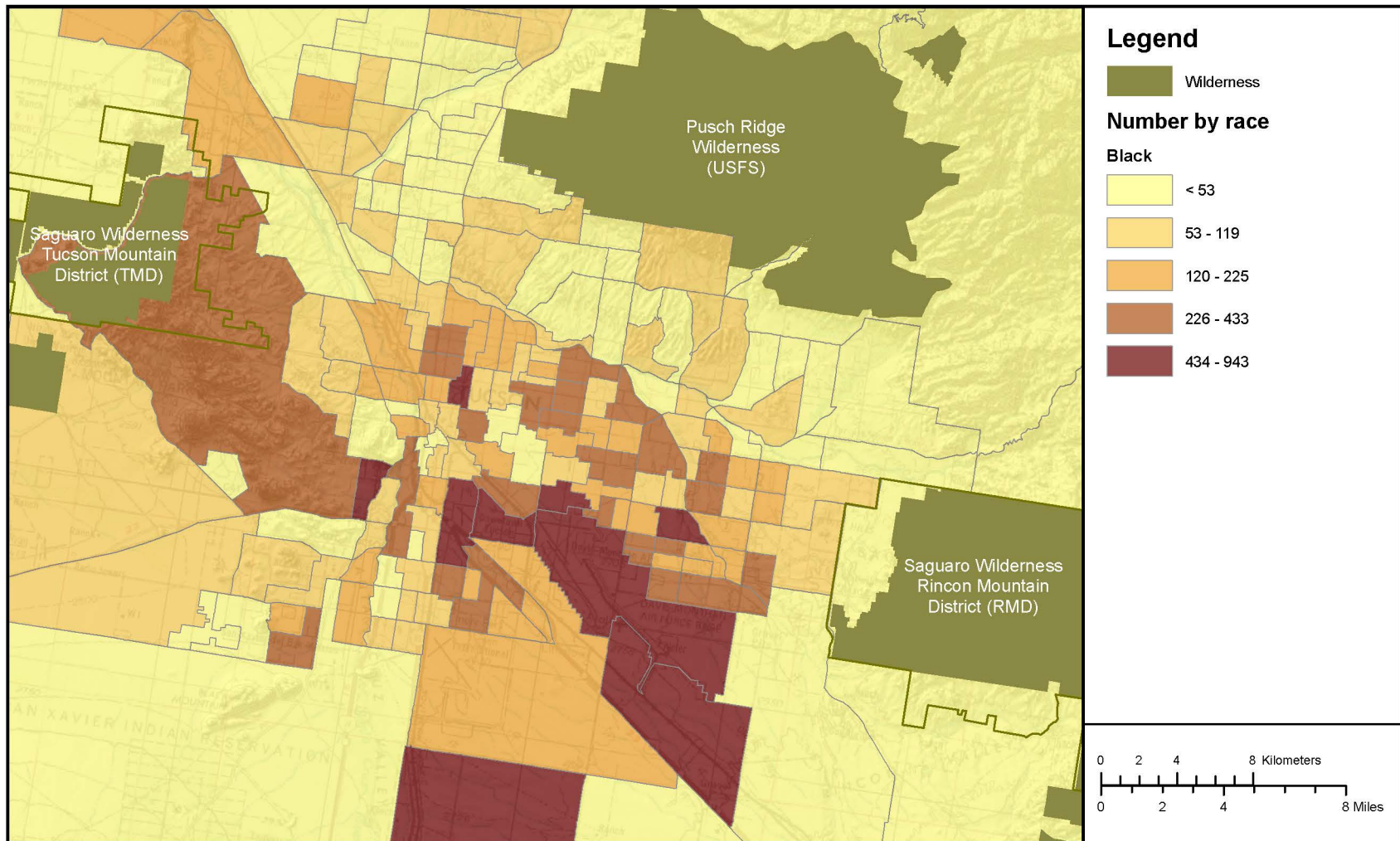


Map 137. Pima County incorporated and unincorporated zoning jurisdictions (dated 2007) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

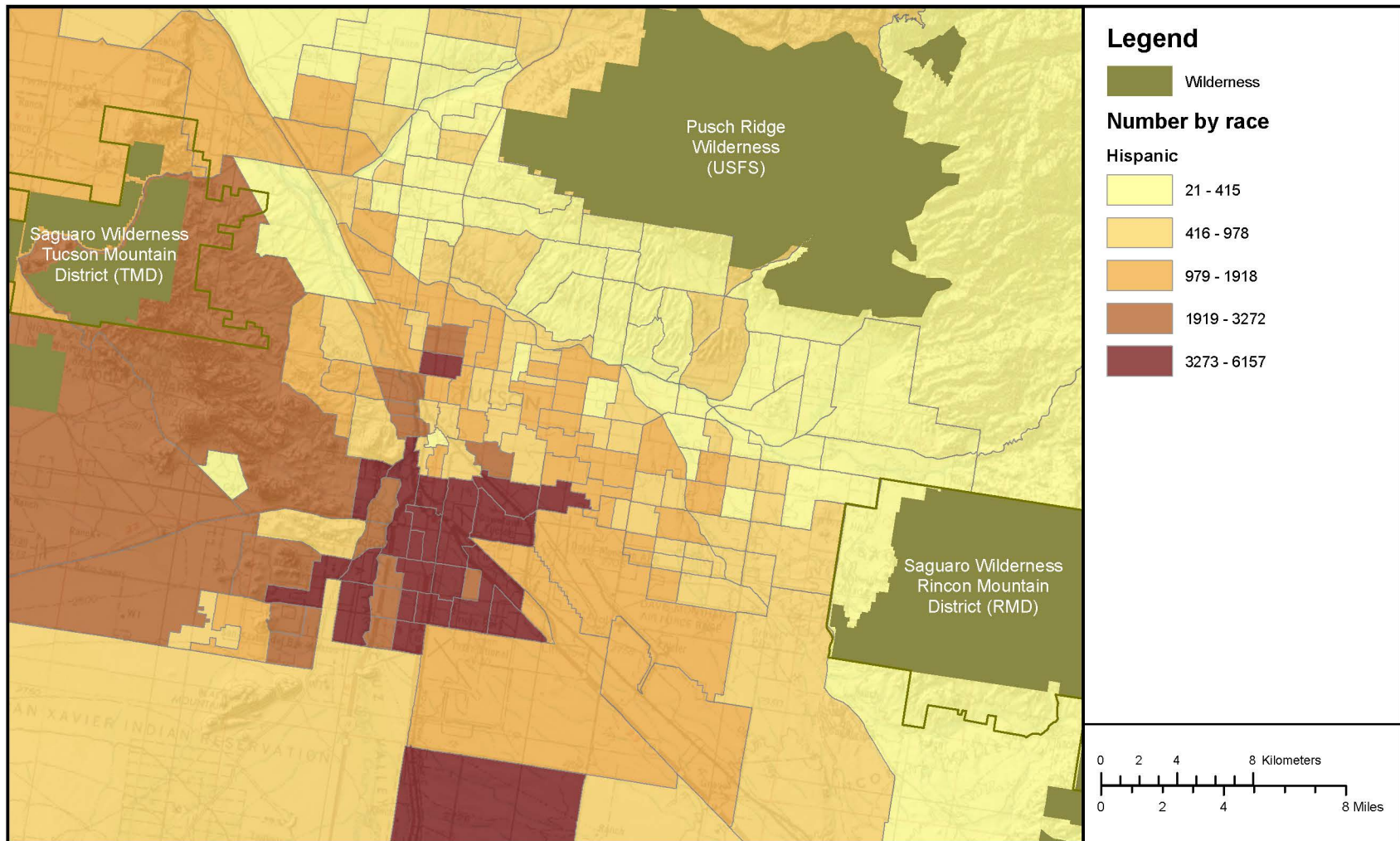
Socioeconomics



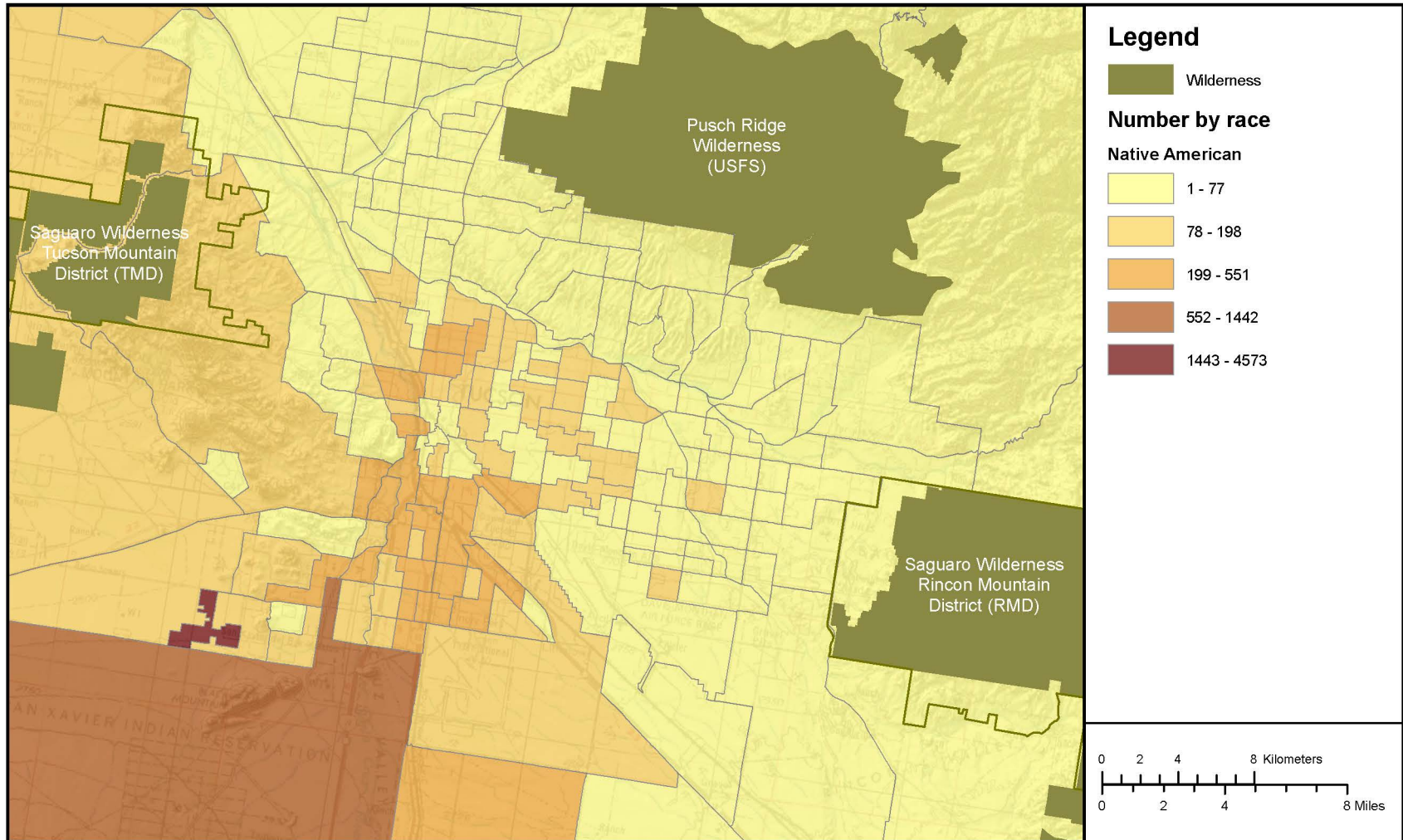
Map 138. Number of Asian Americans (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



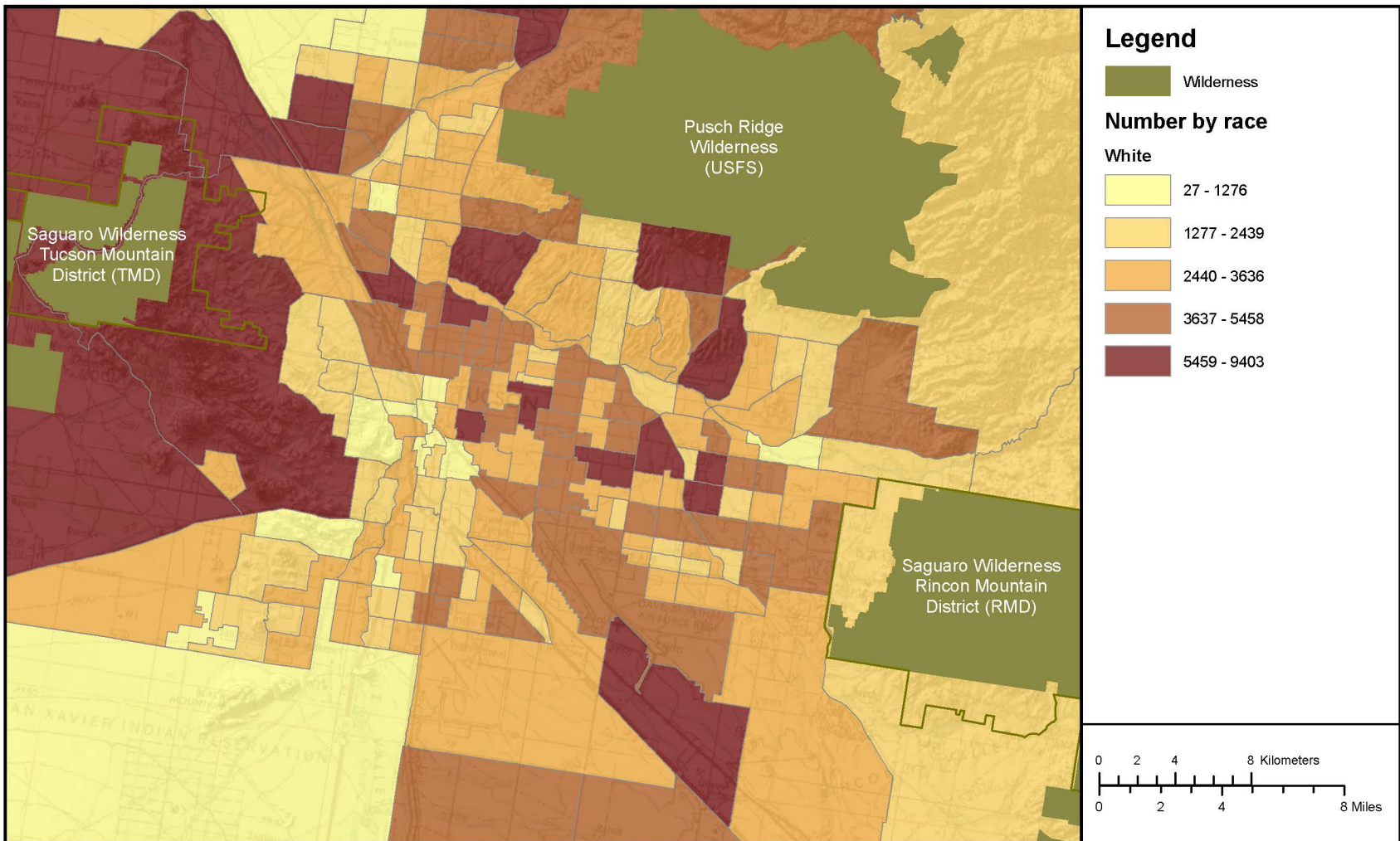
Map 139. Number of Blacks (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



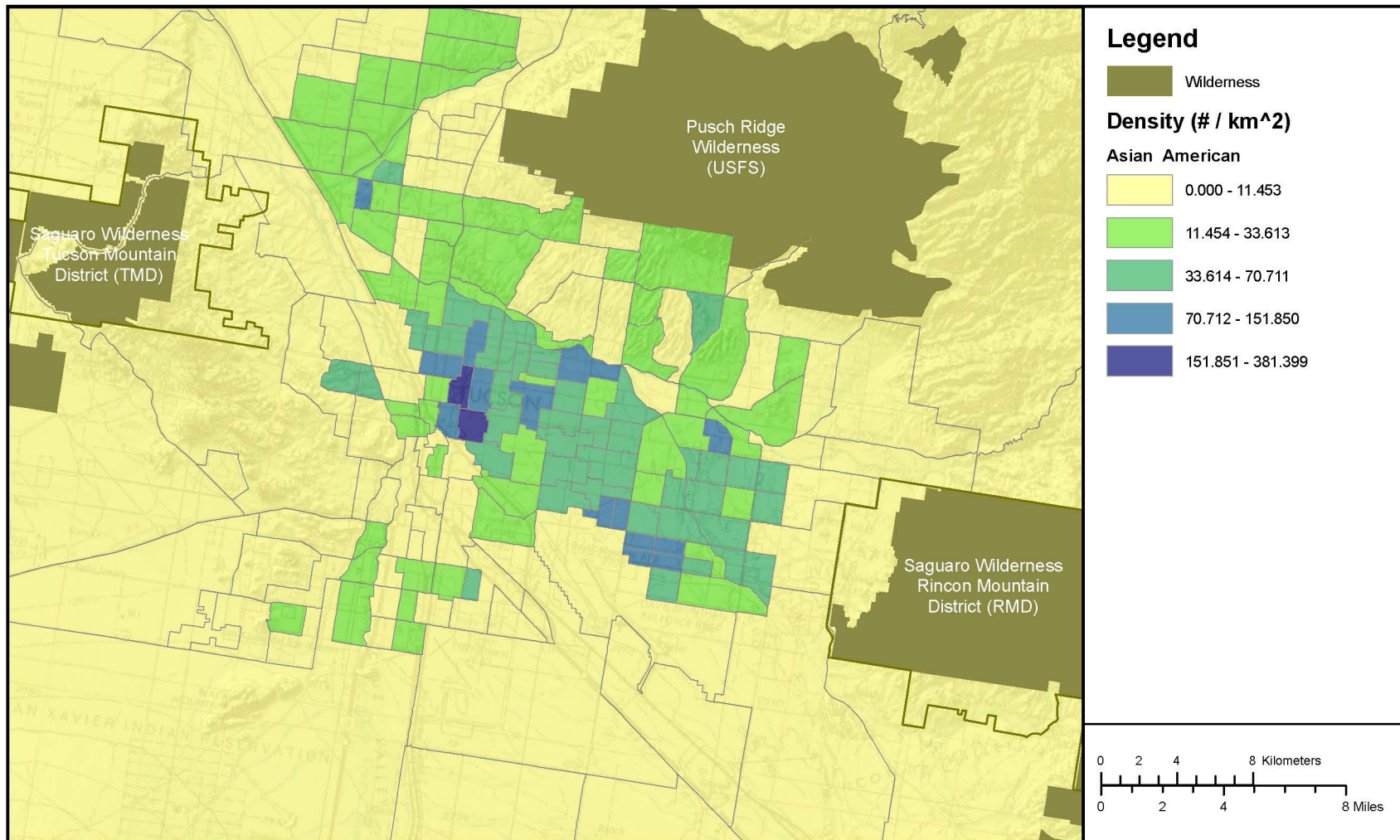
Map 140. Number of Hispanics (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



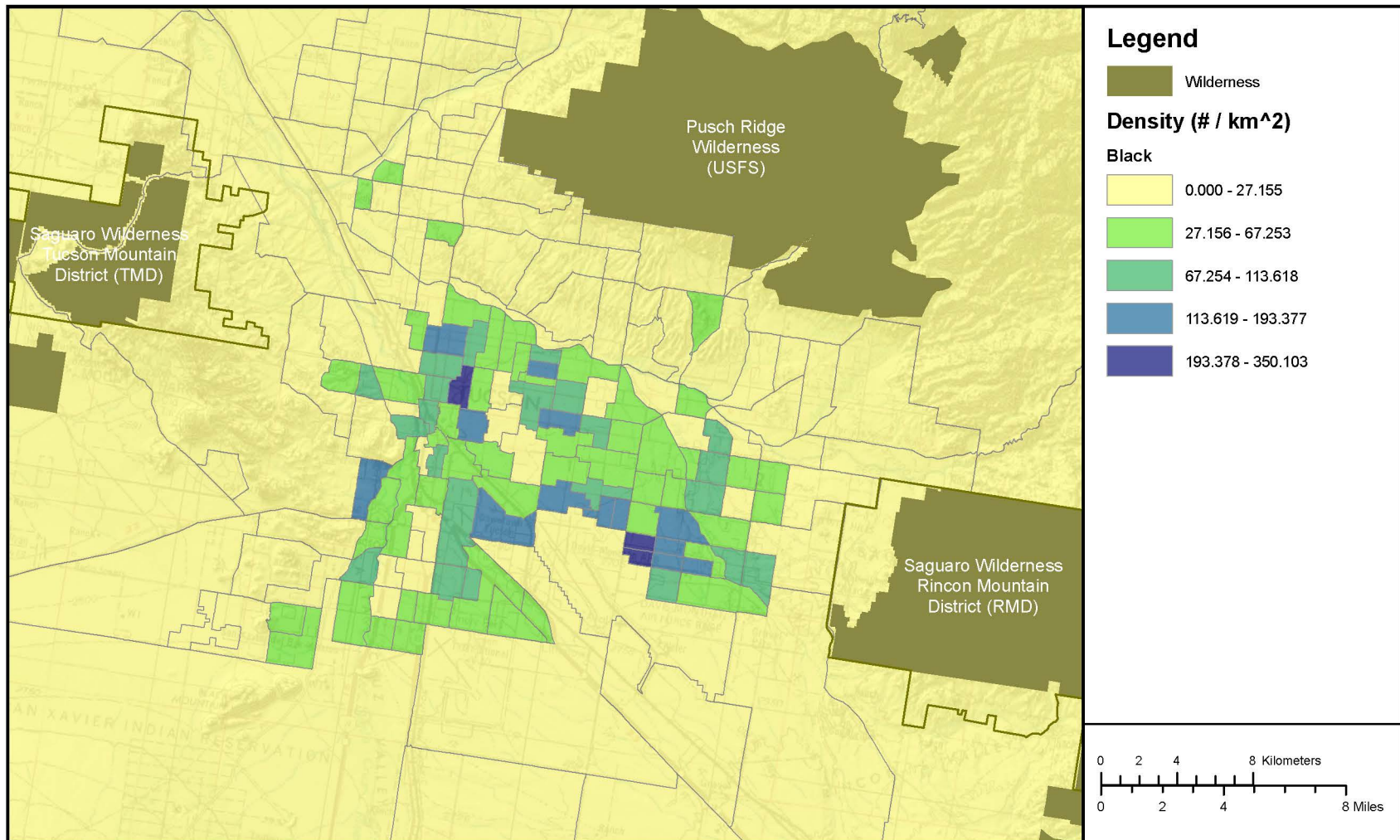
Map 141. Number of Native Americans (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



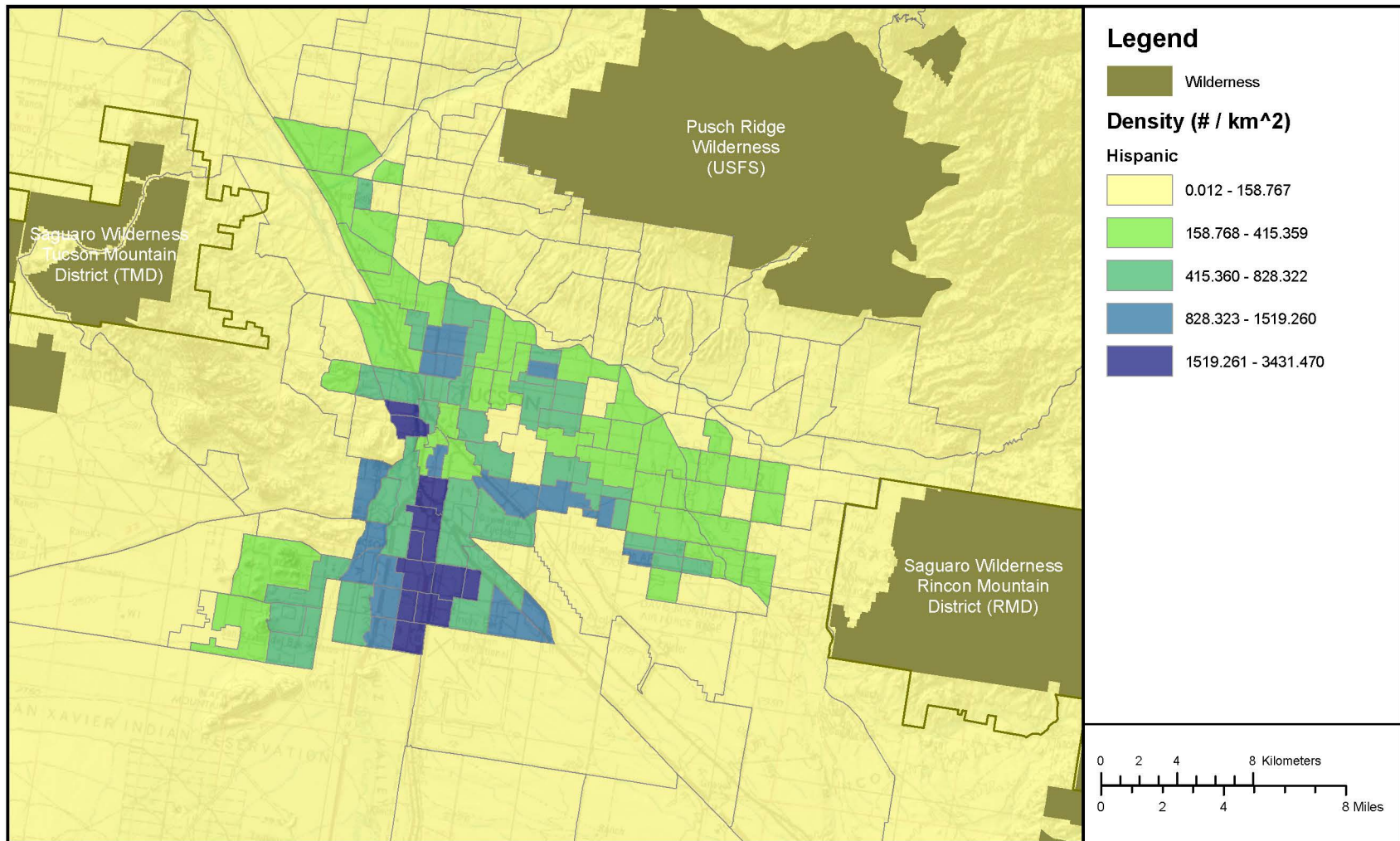
Map 142. Number of Whites (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



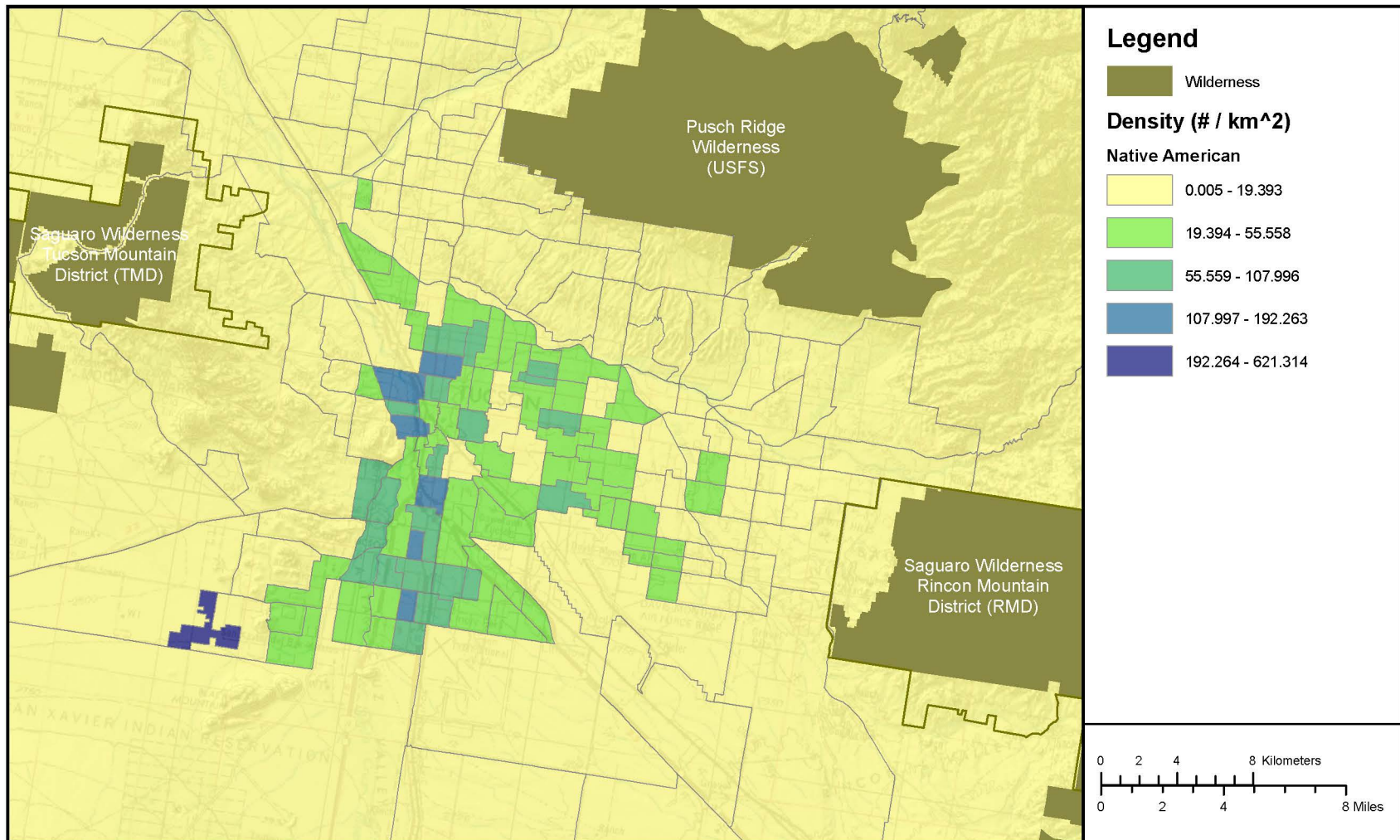
Map 143. Density of Asian Americans (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



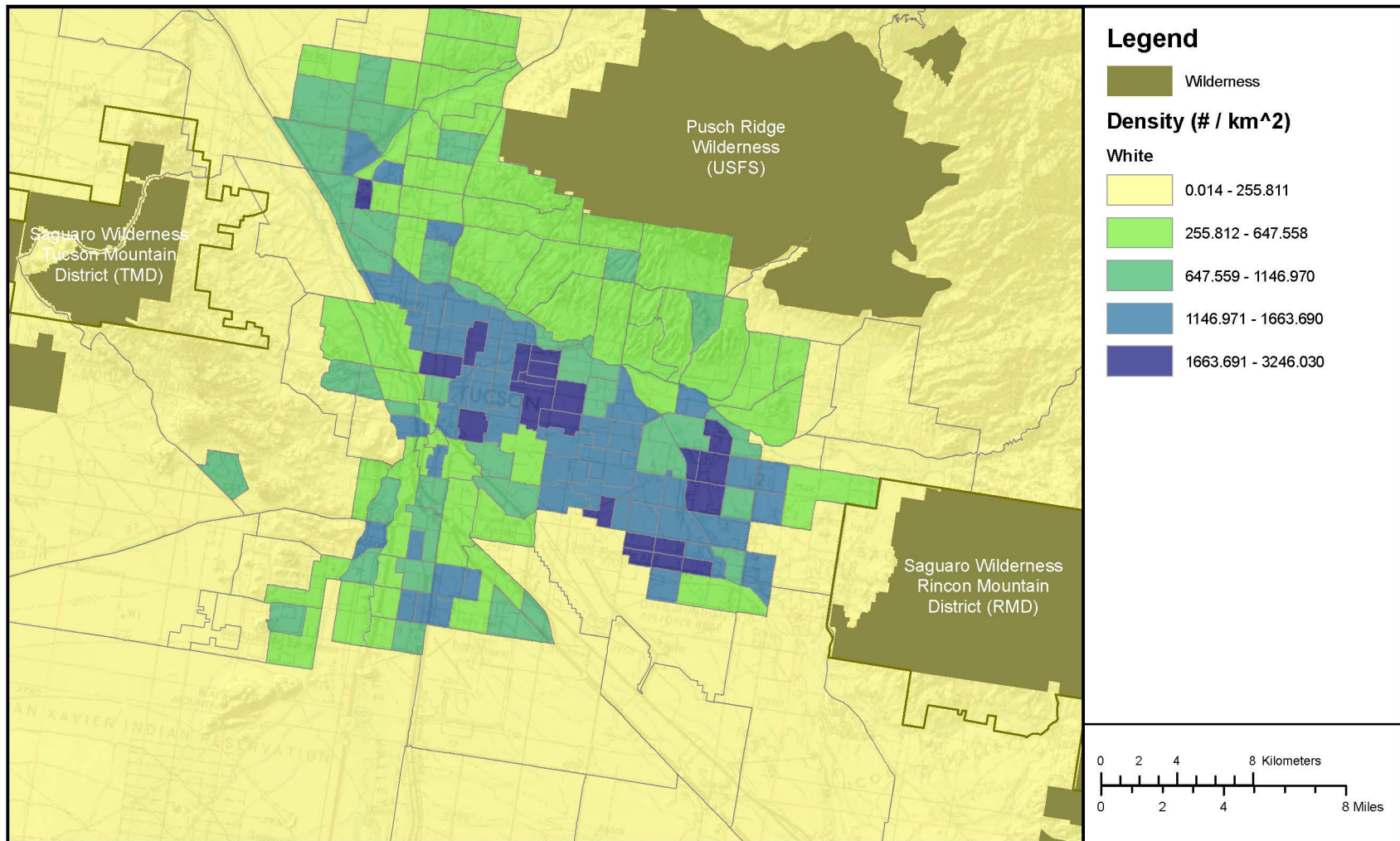
Map 144. Density of Blacks (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



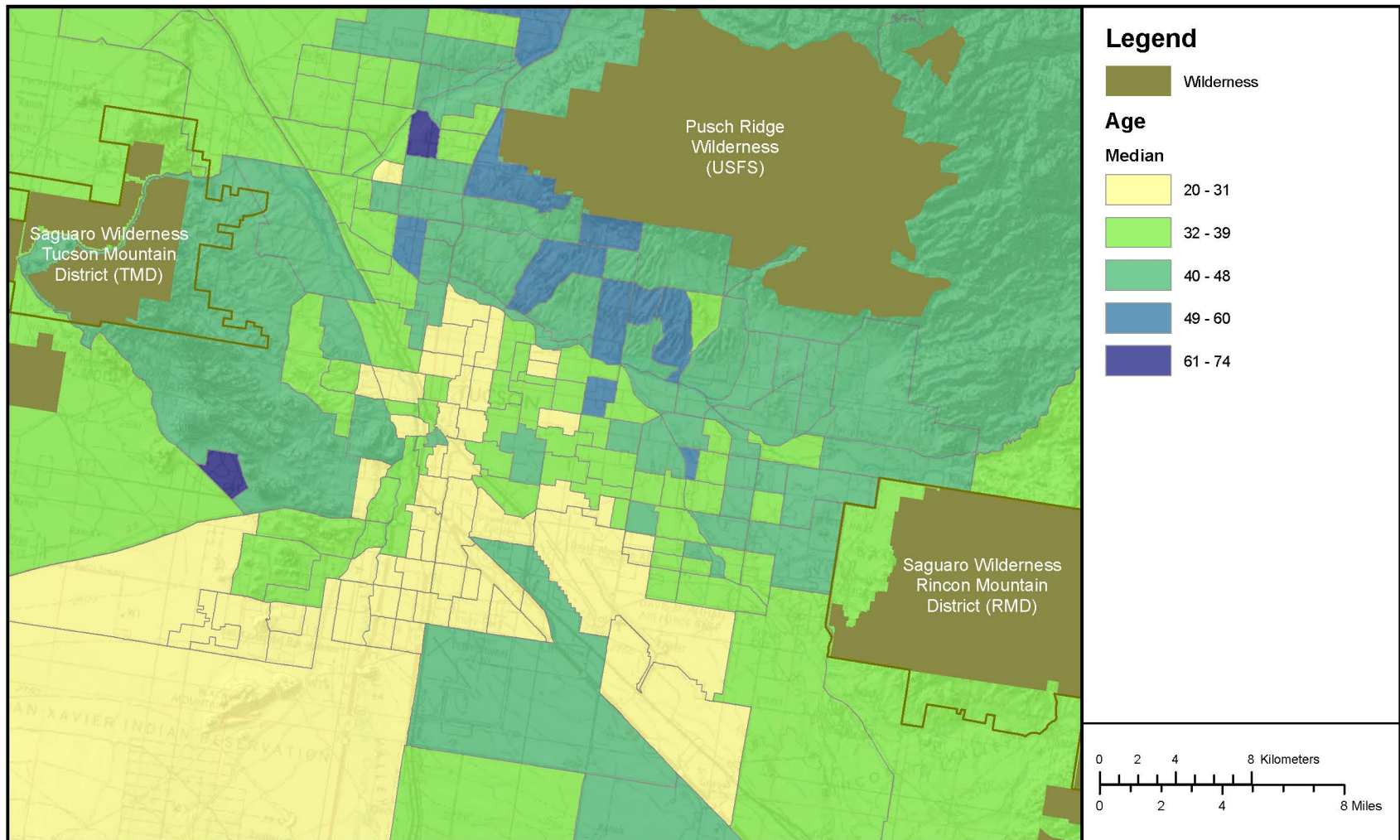
Map 145. Density of Hispanics (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



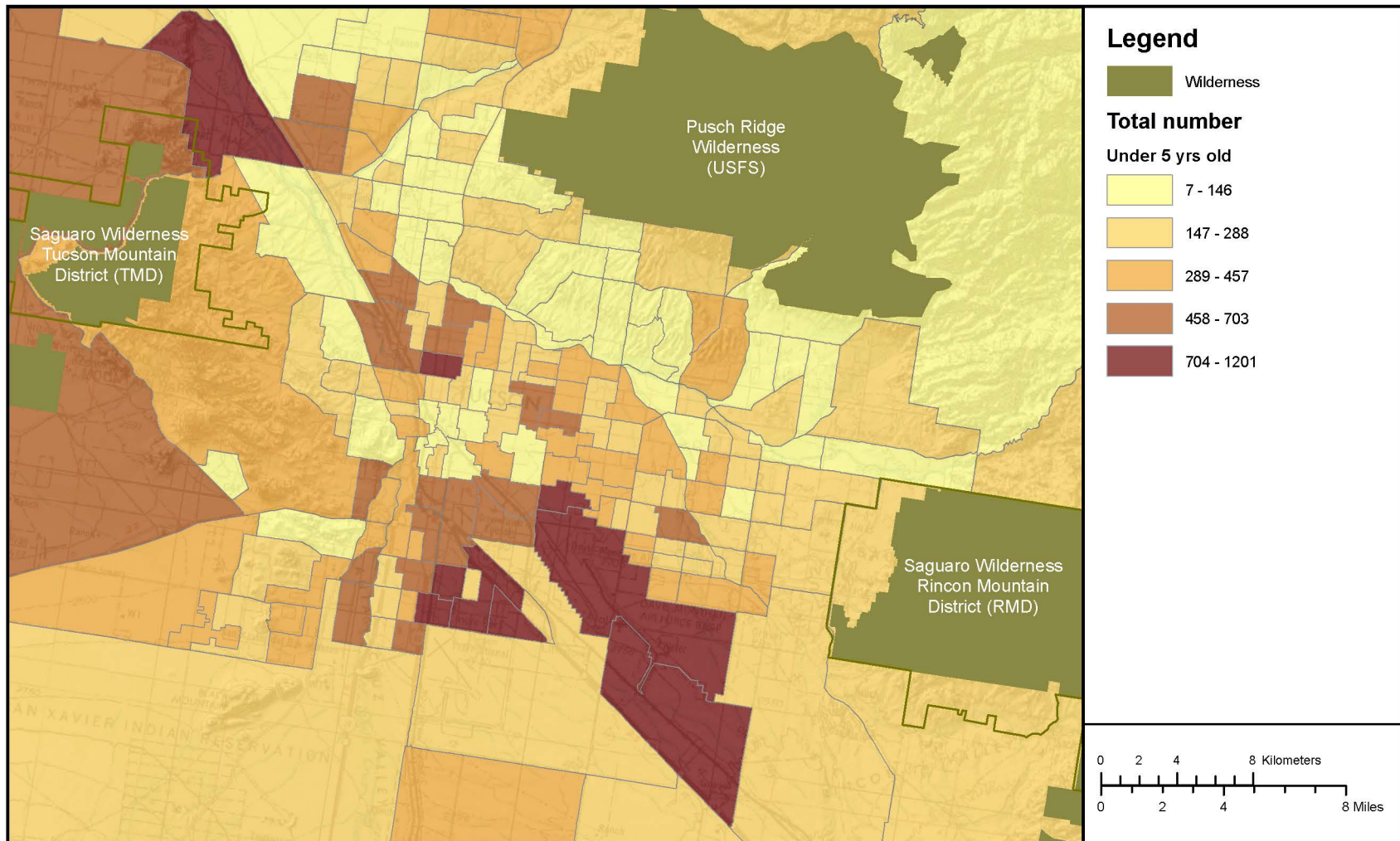
Map 146. Density of Native Americans (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



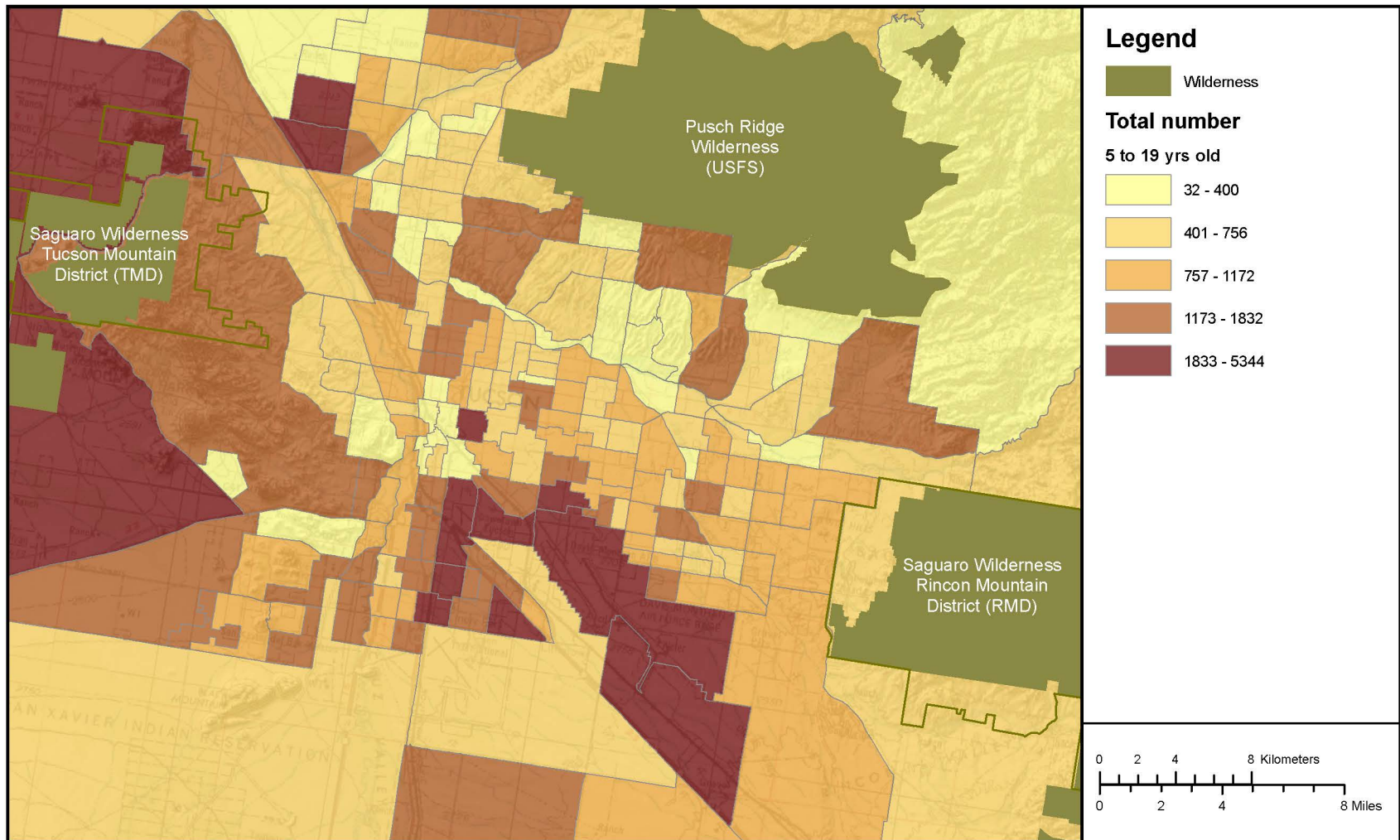
Map 147. Density of Whites (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



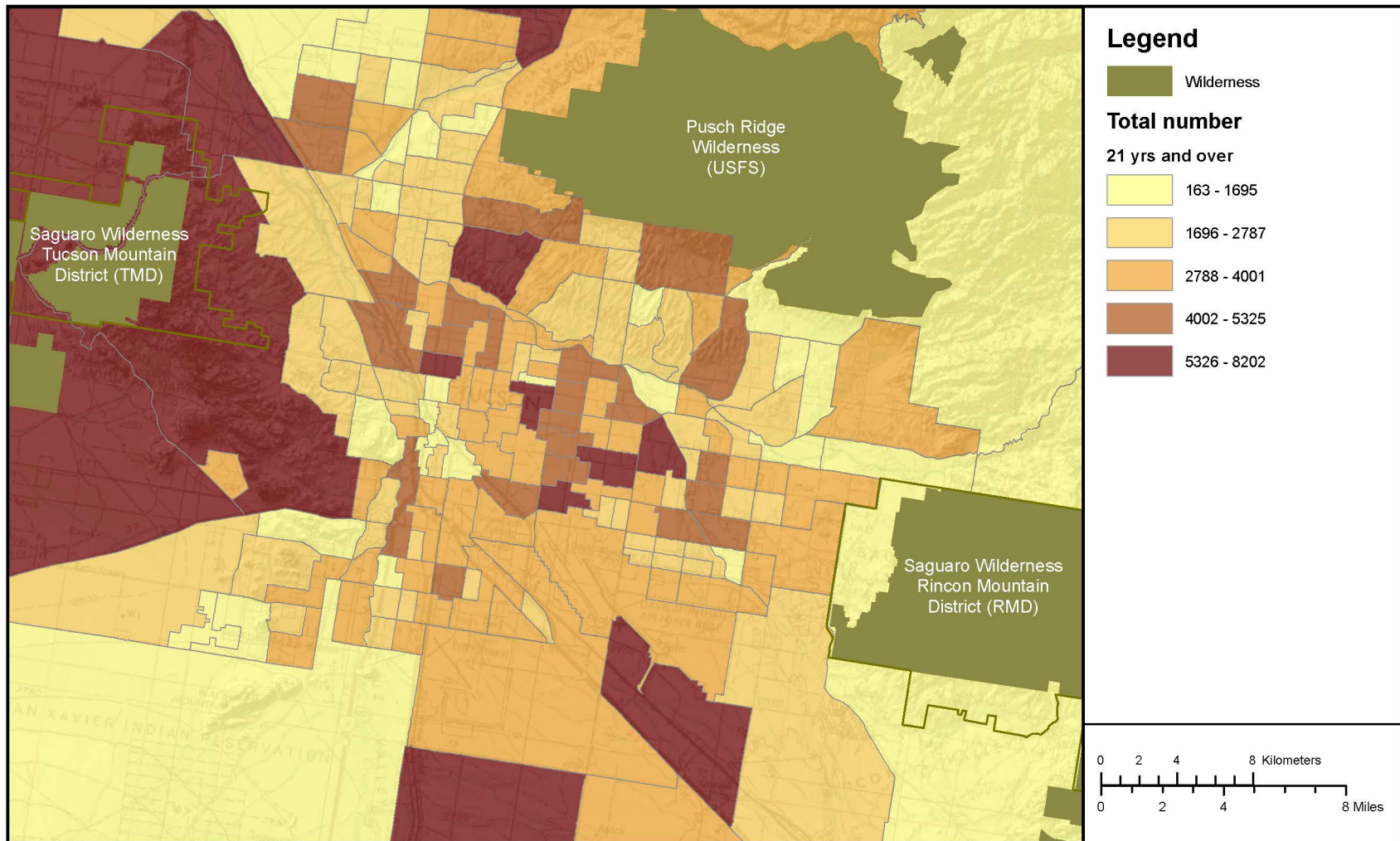
Map 148. Median age (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



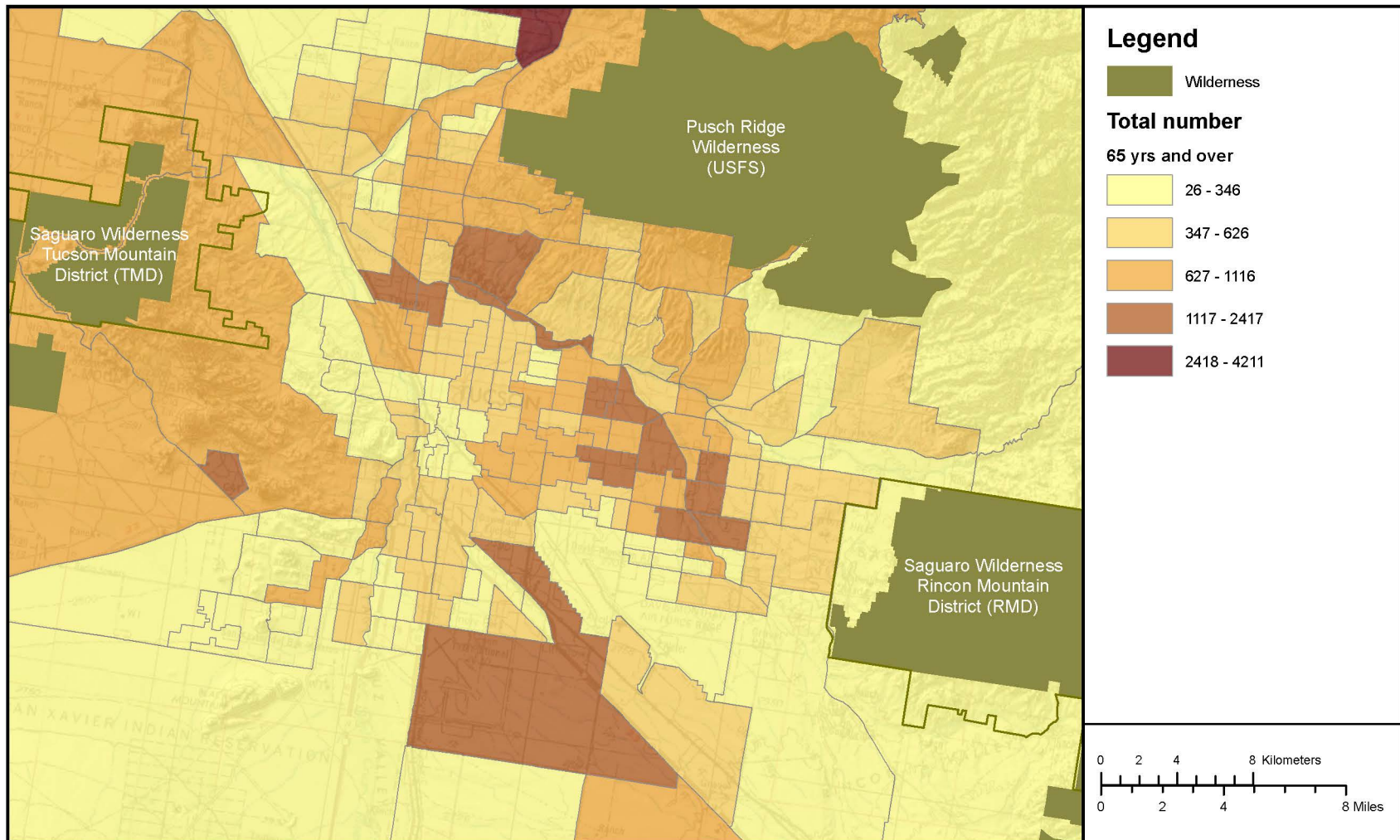
Map 149. Number of 4 year olds and under (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



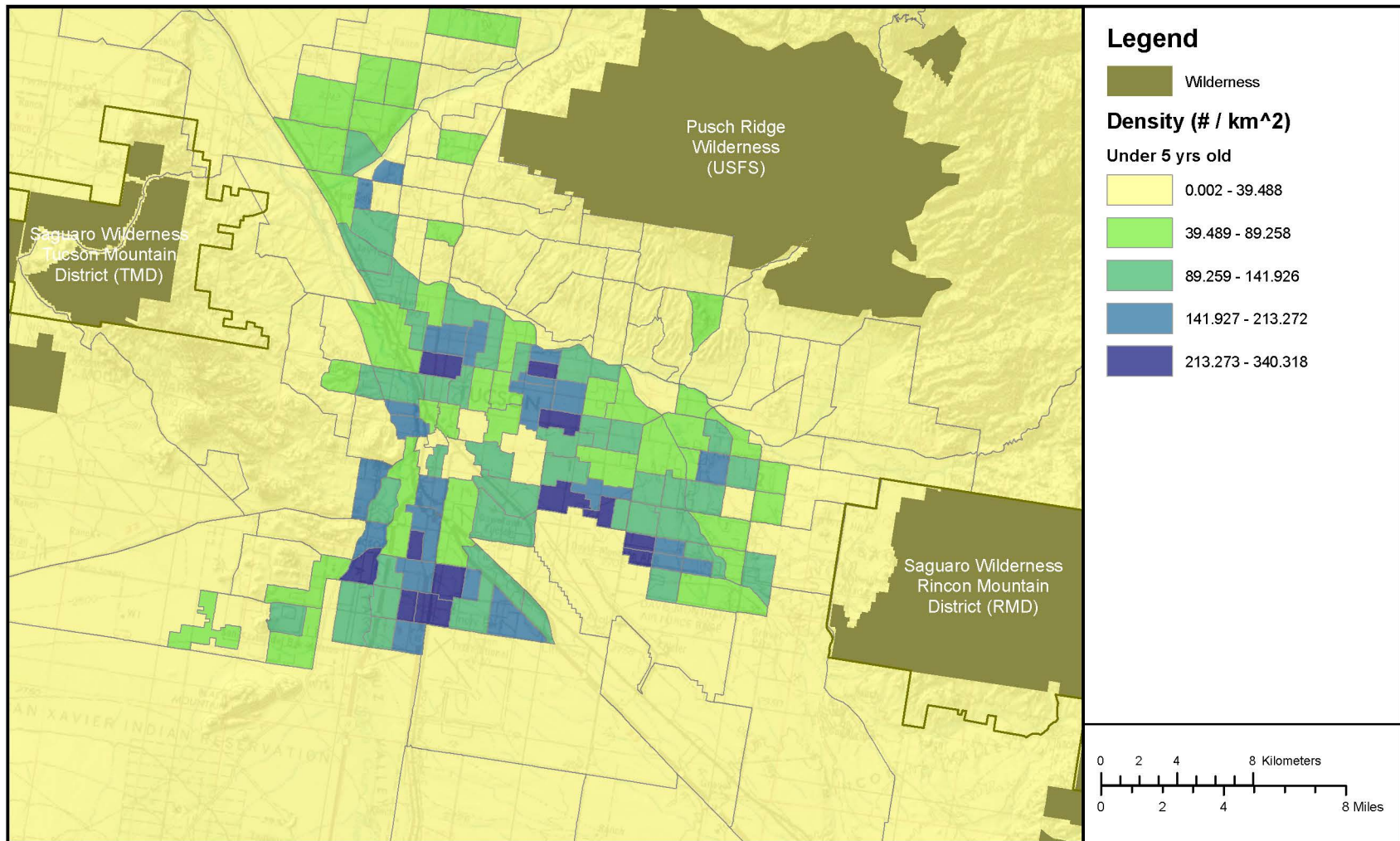
Map 150. Number of 5 to 19 year olds (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



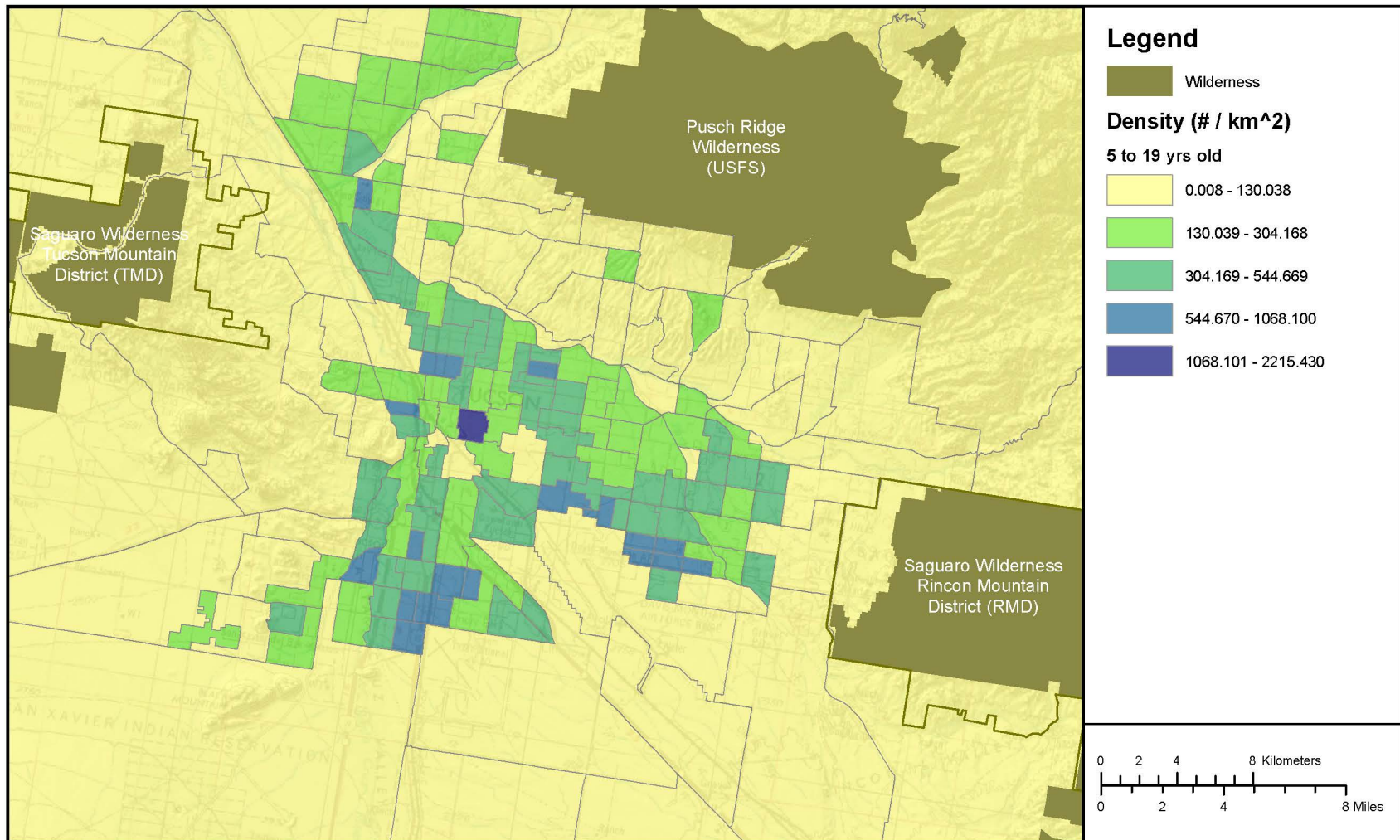
Map 151. Number of 21 year olds and older (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



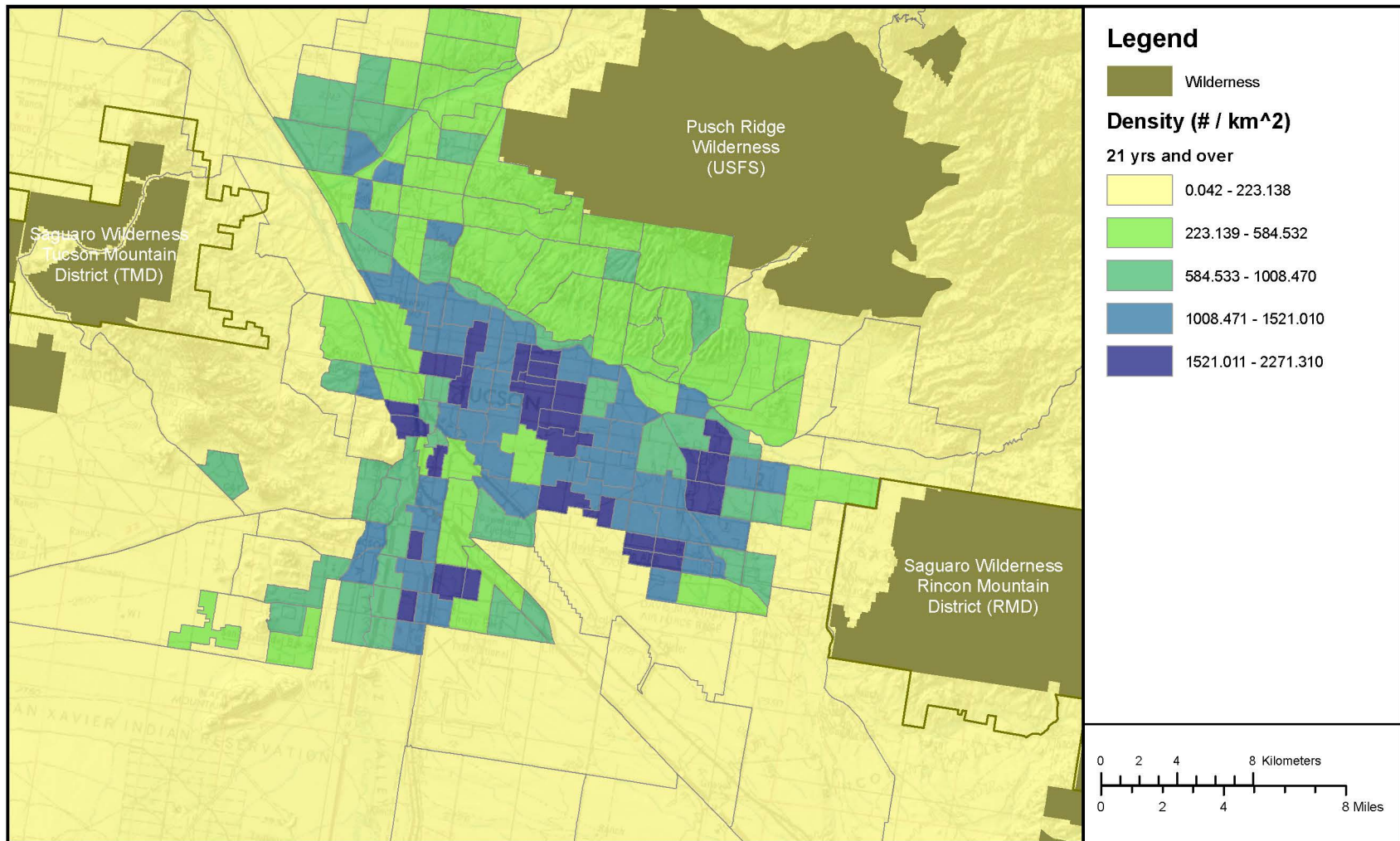
Map 152. Number of 65 year olds and older (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



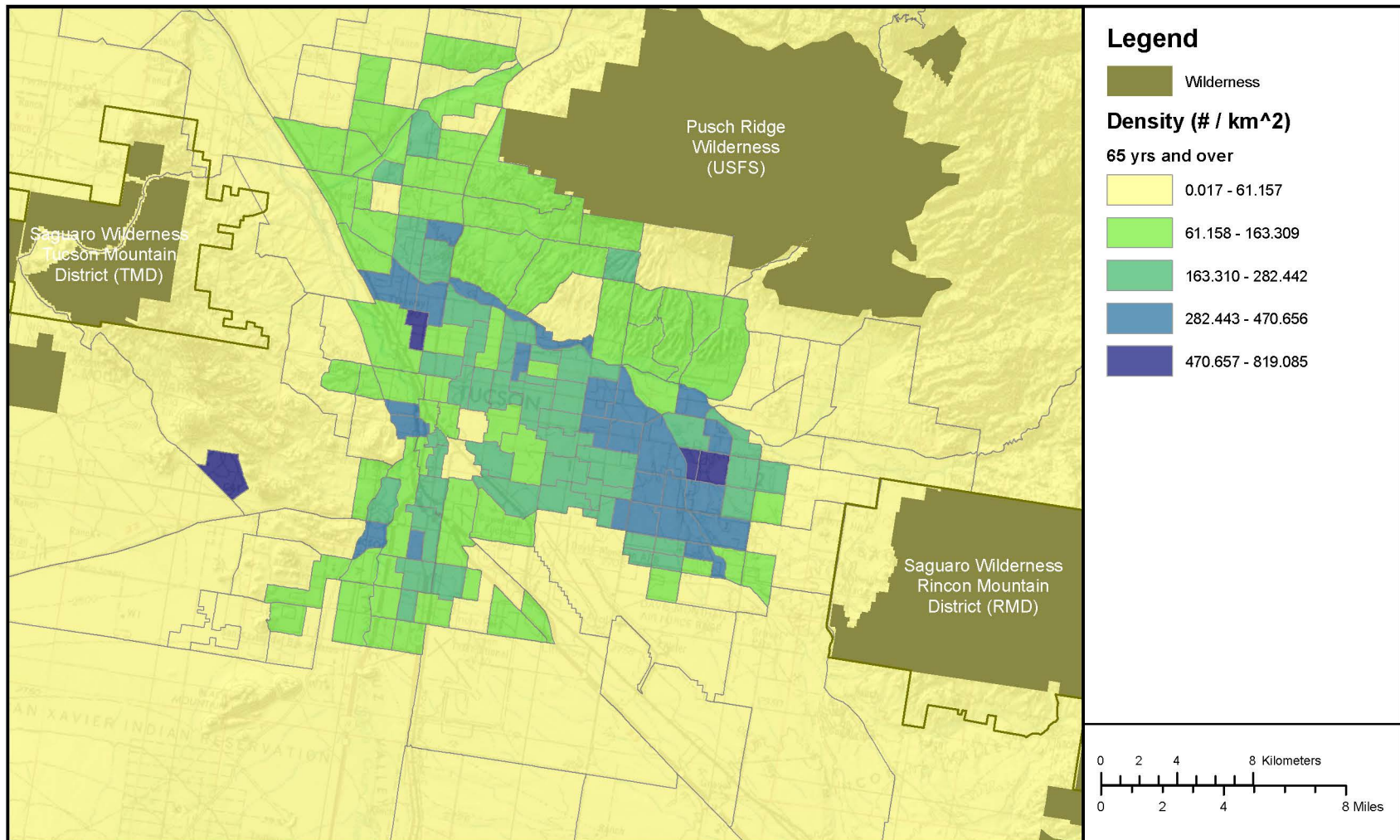
Map 153. Density of 4 year olds and under (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



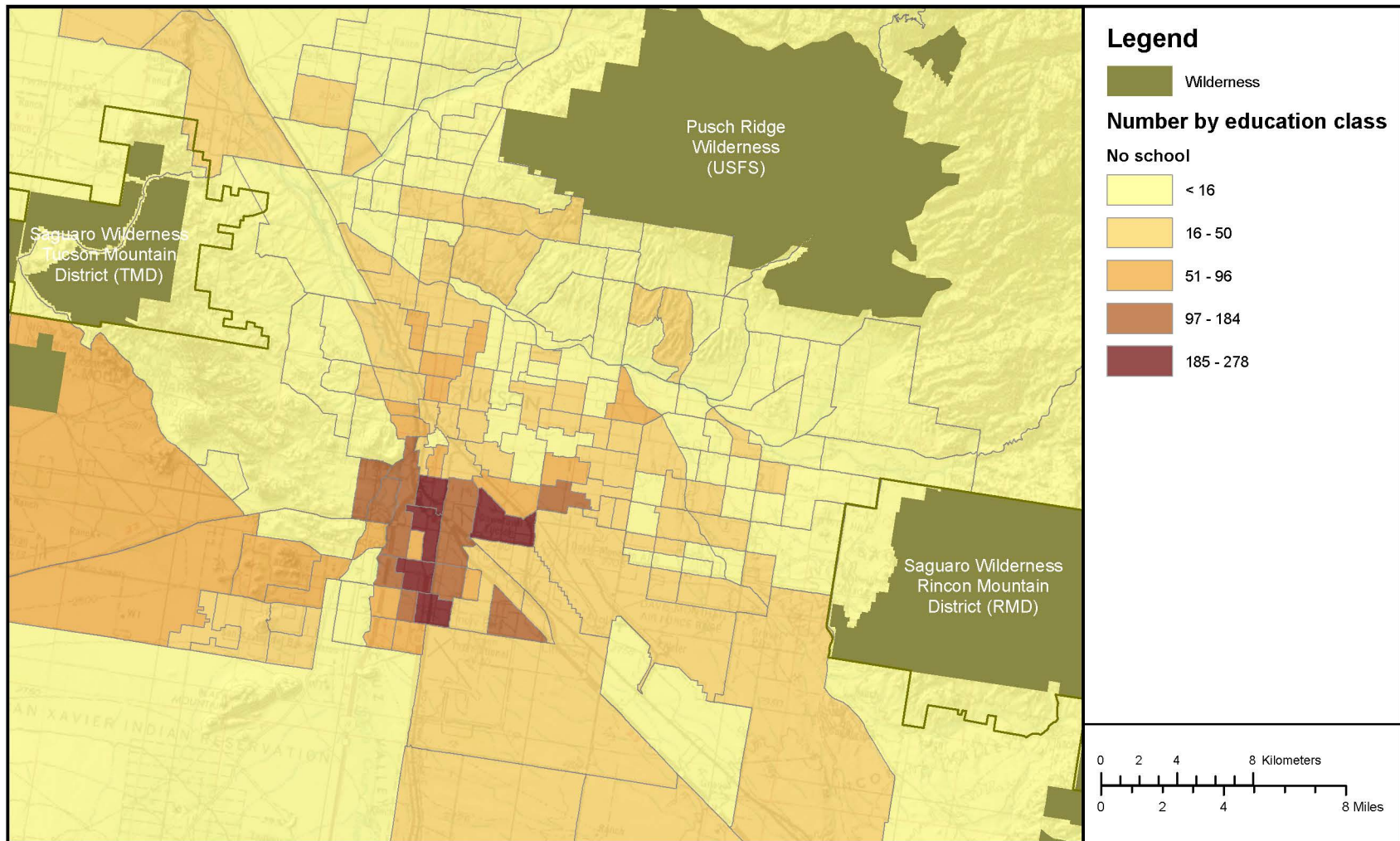
Map 154. Density of 5 to 19 year olds (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



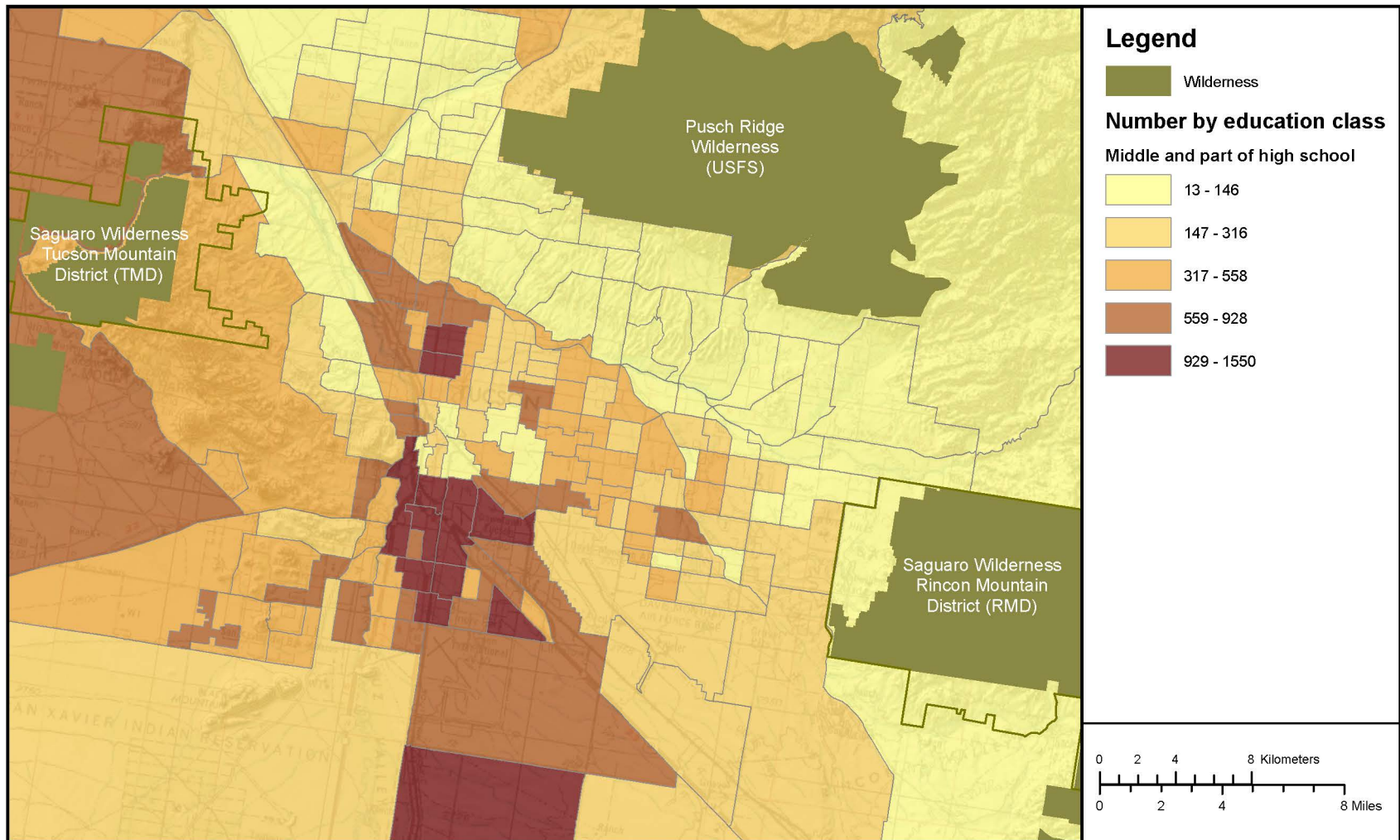
Map 155. Density of 21 year olds and older (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



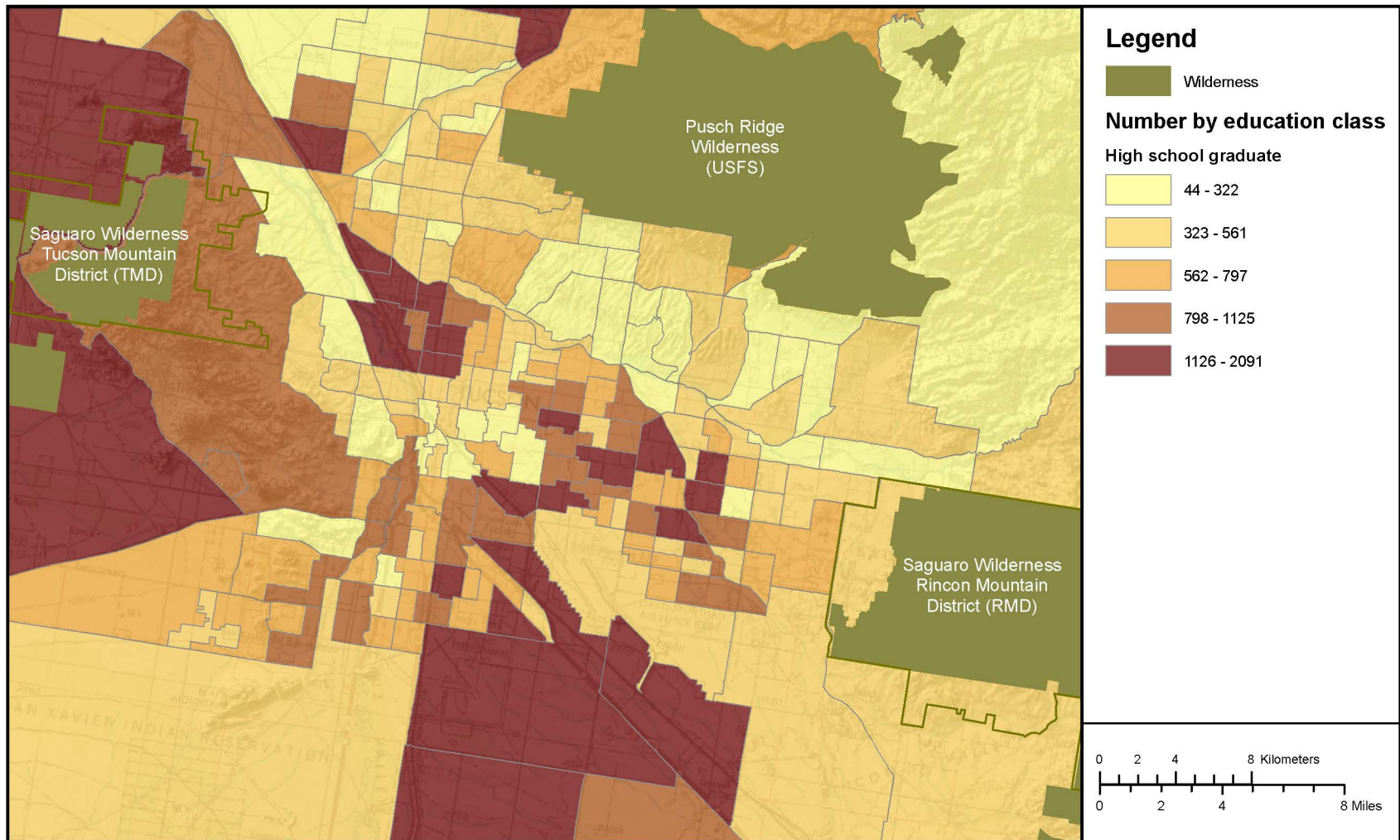
Map 156. Density of 65 year olds and older (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



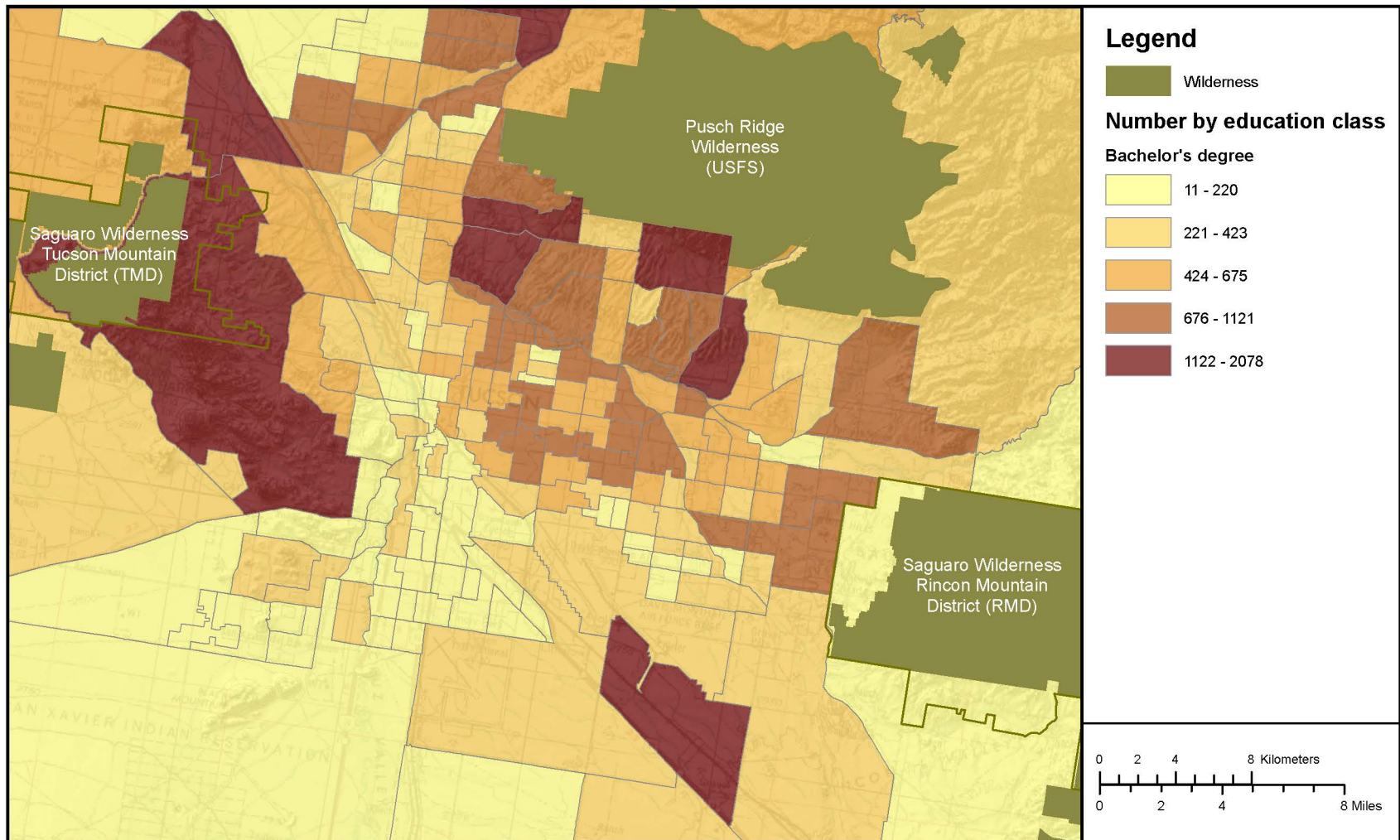
Map 157. Number of people who have received no schooling (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



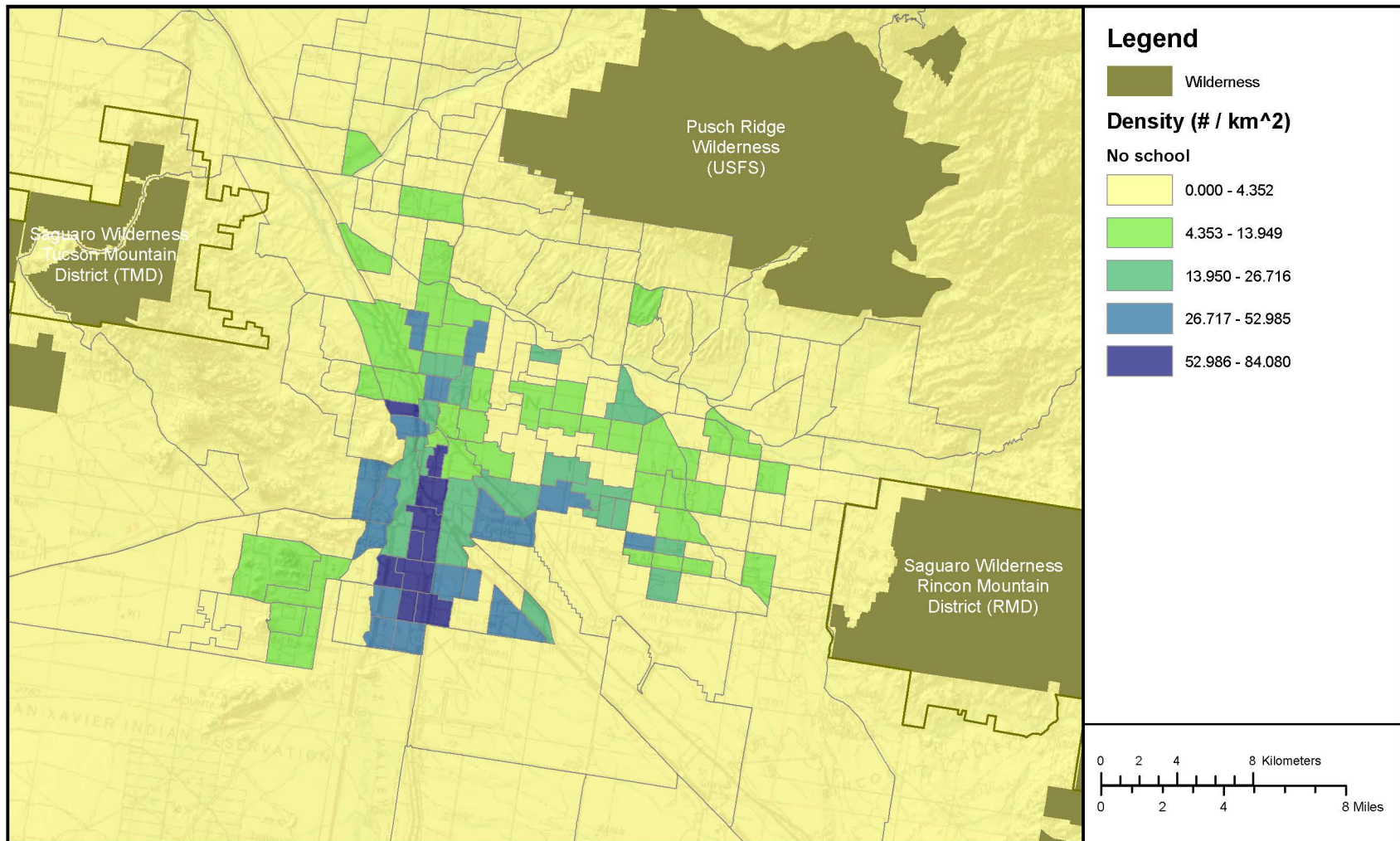
Map 158. Number of people who completed middle and part of high school (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



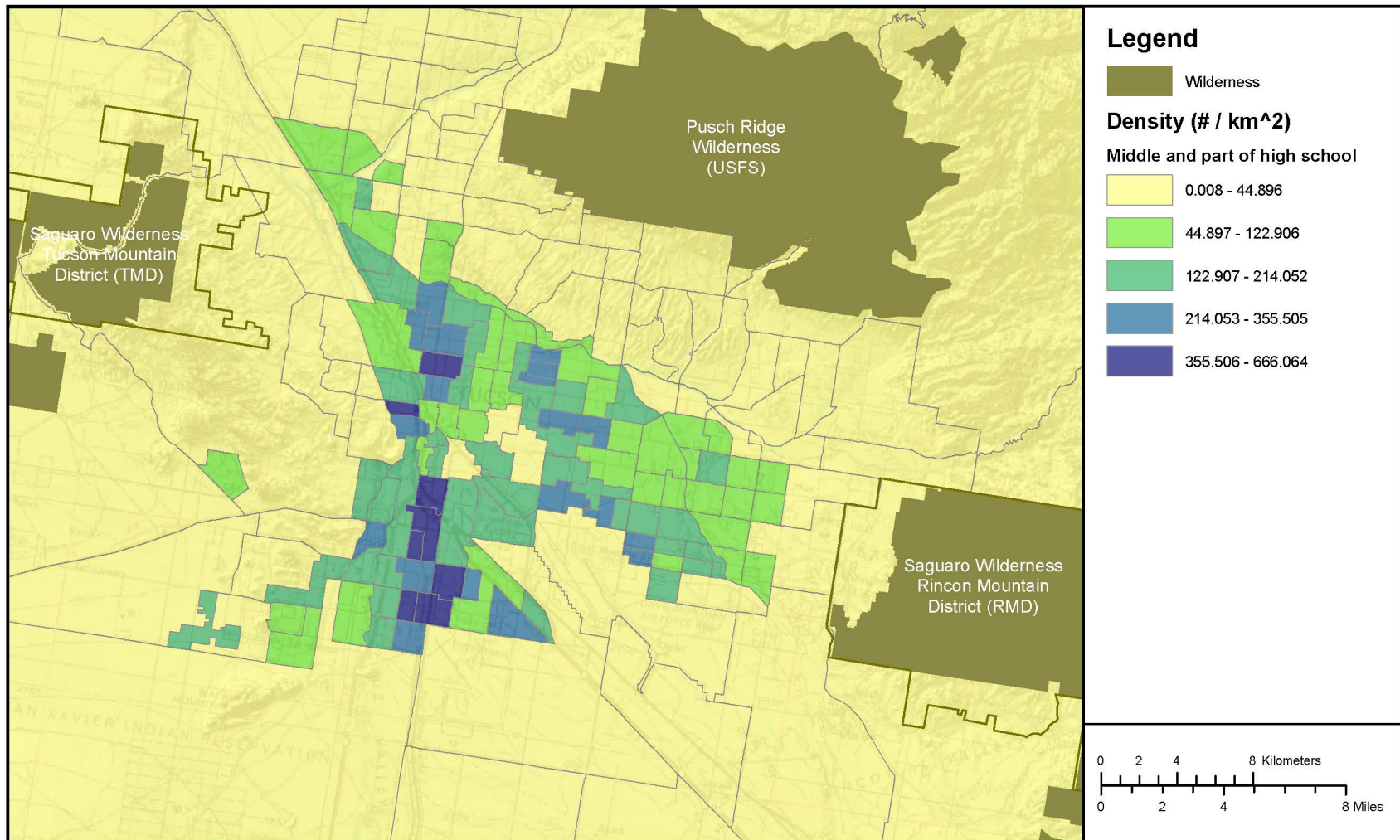
Map 159. Number of high school graduates (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



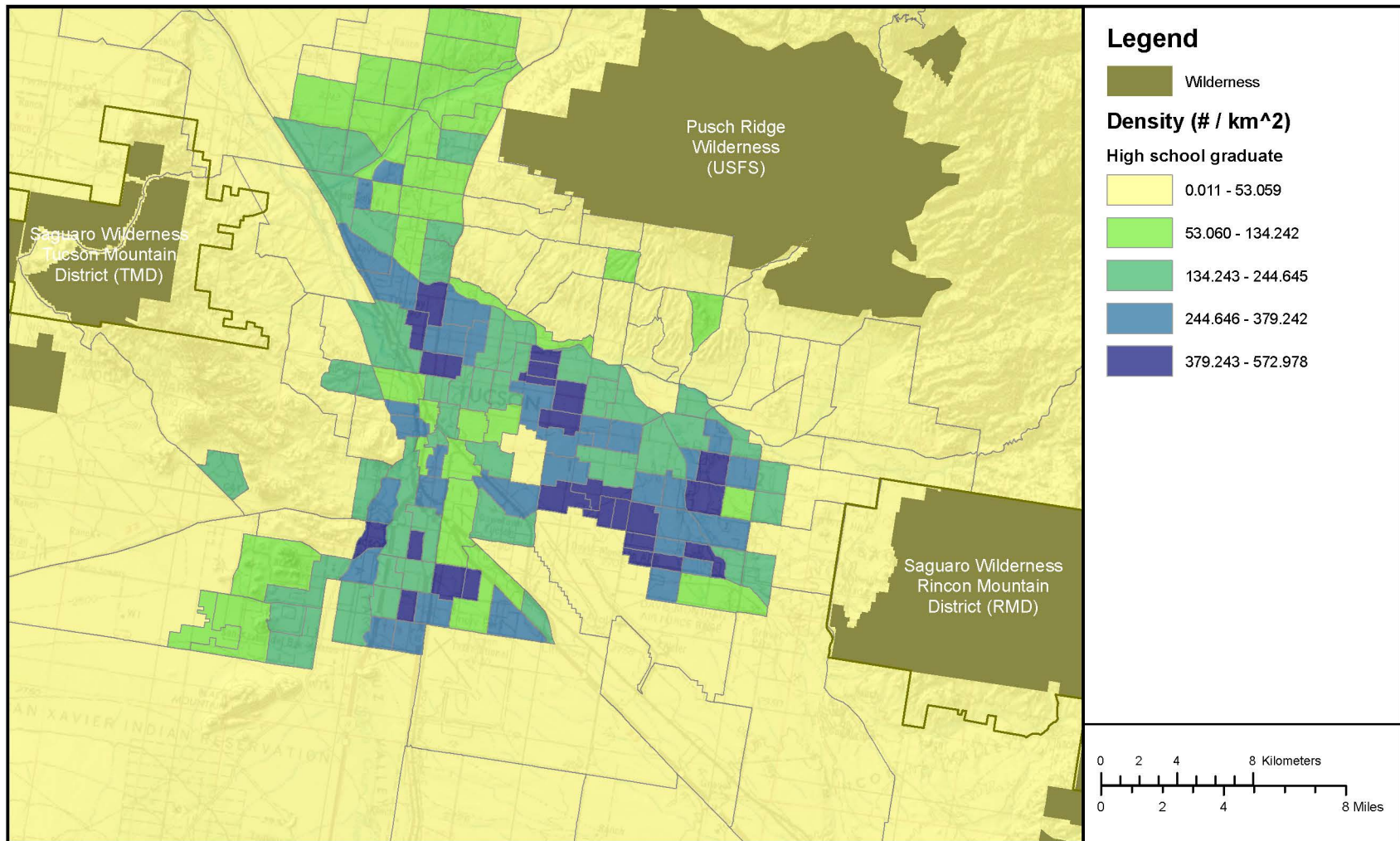
Map 160. Number of people with a Bachelor's education (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



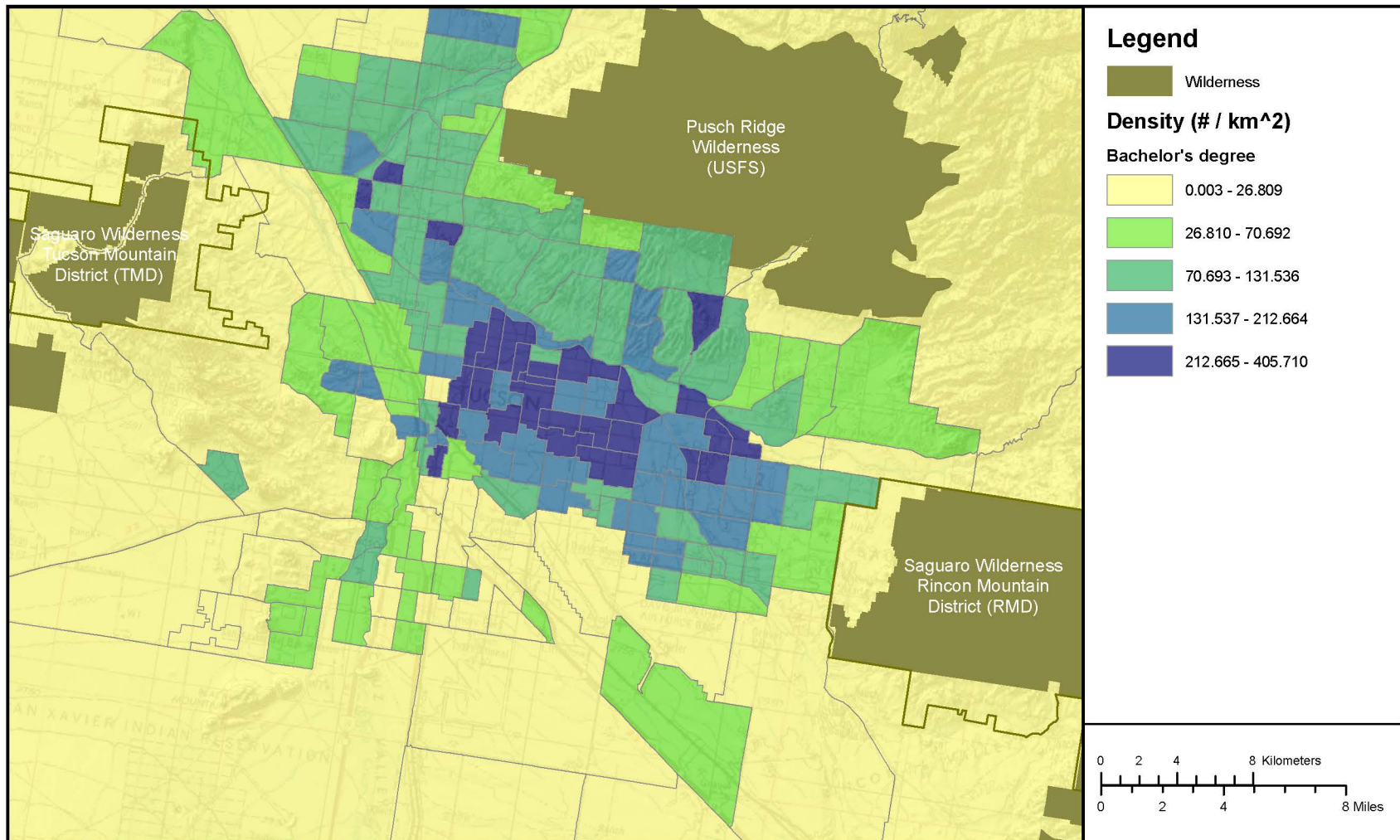
Map 161. Density of people who have received no schooling (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



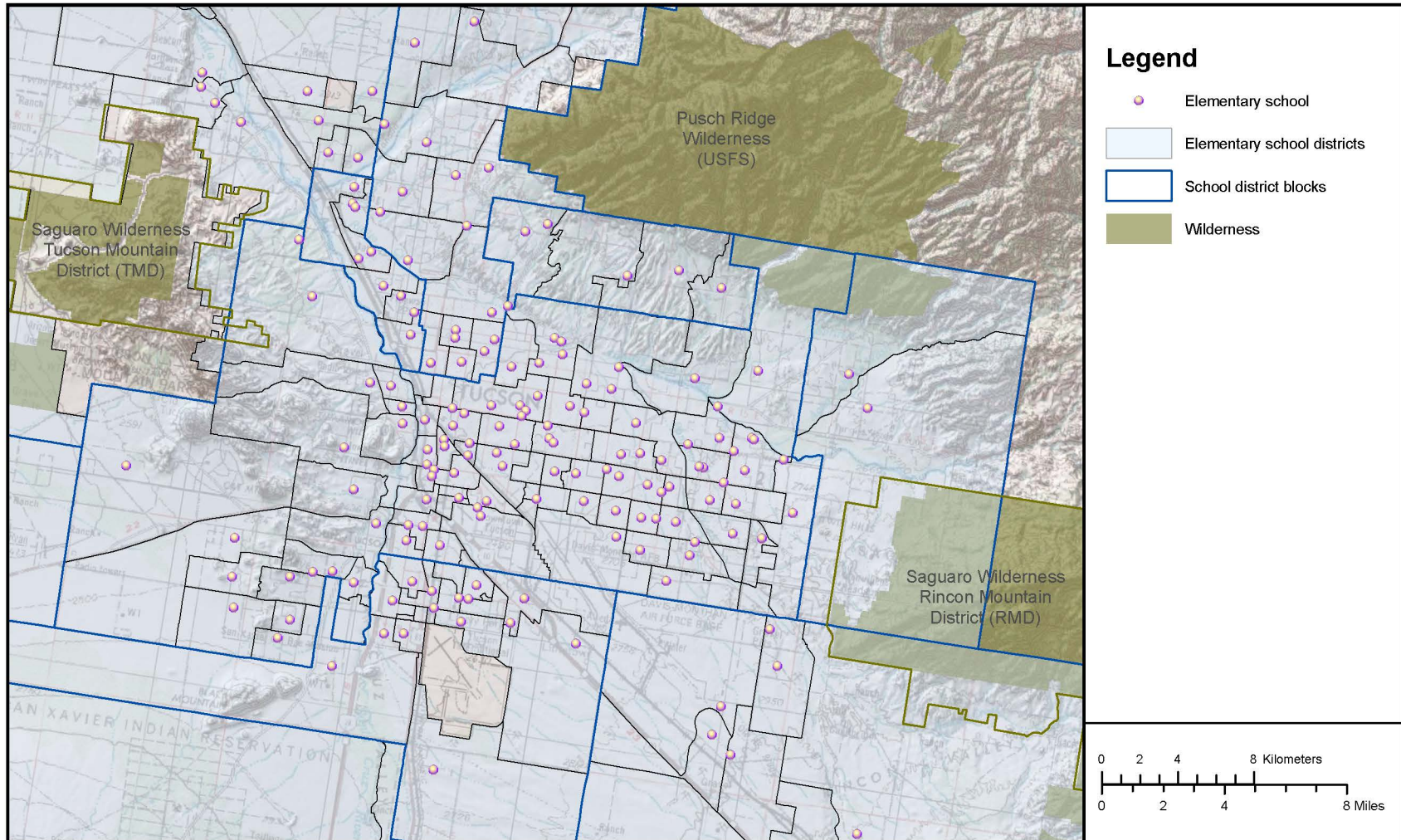
Map 162. Density of people who completed middle and part of high school (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



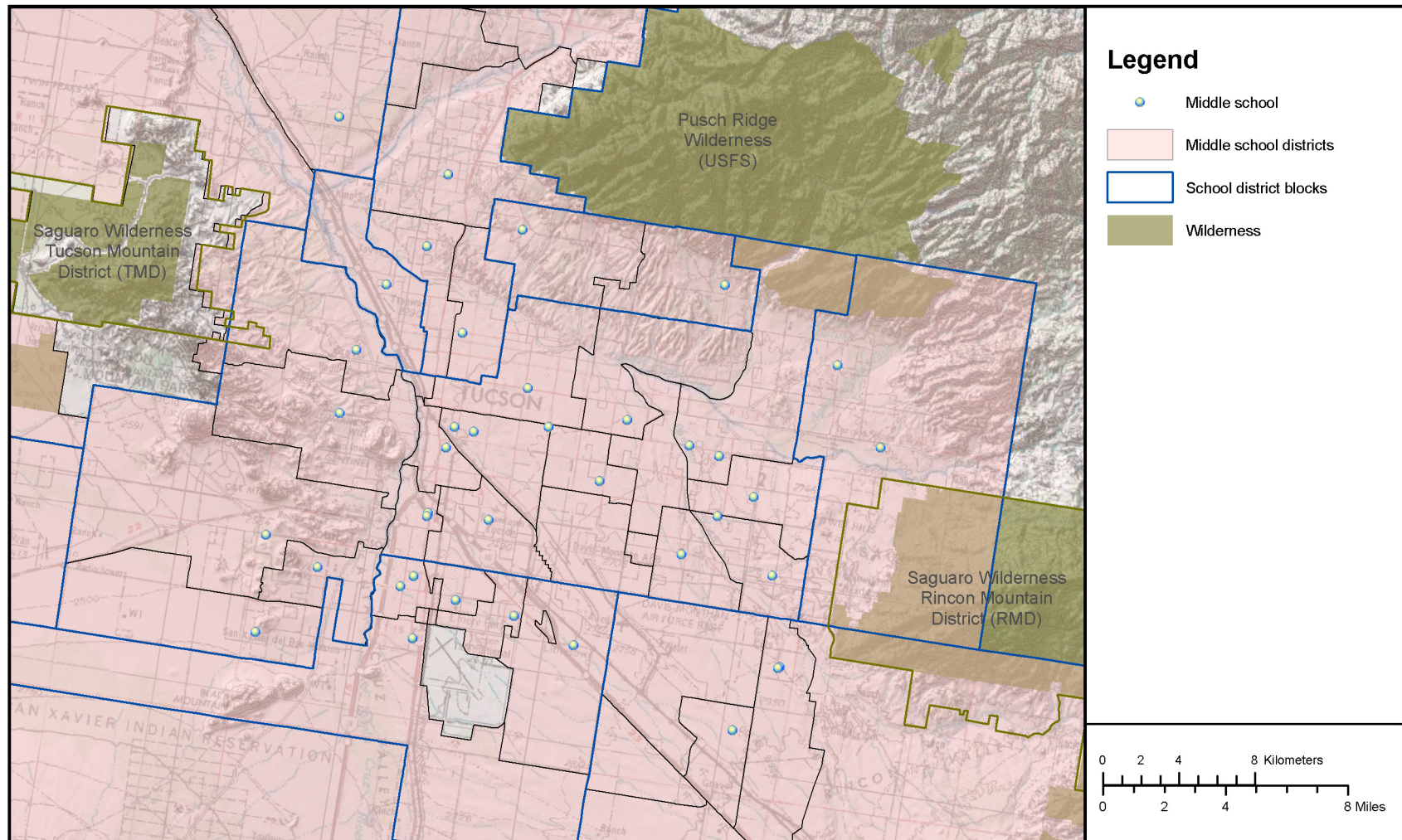
Map 163. Density of high school graduates (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



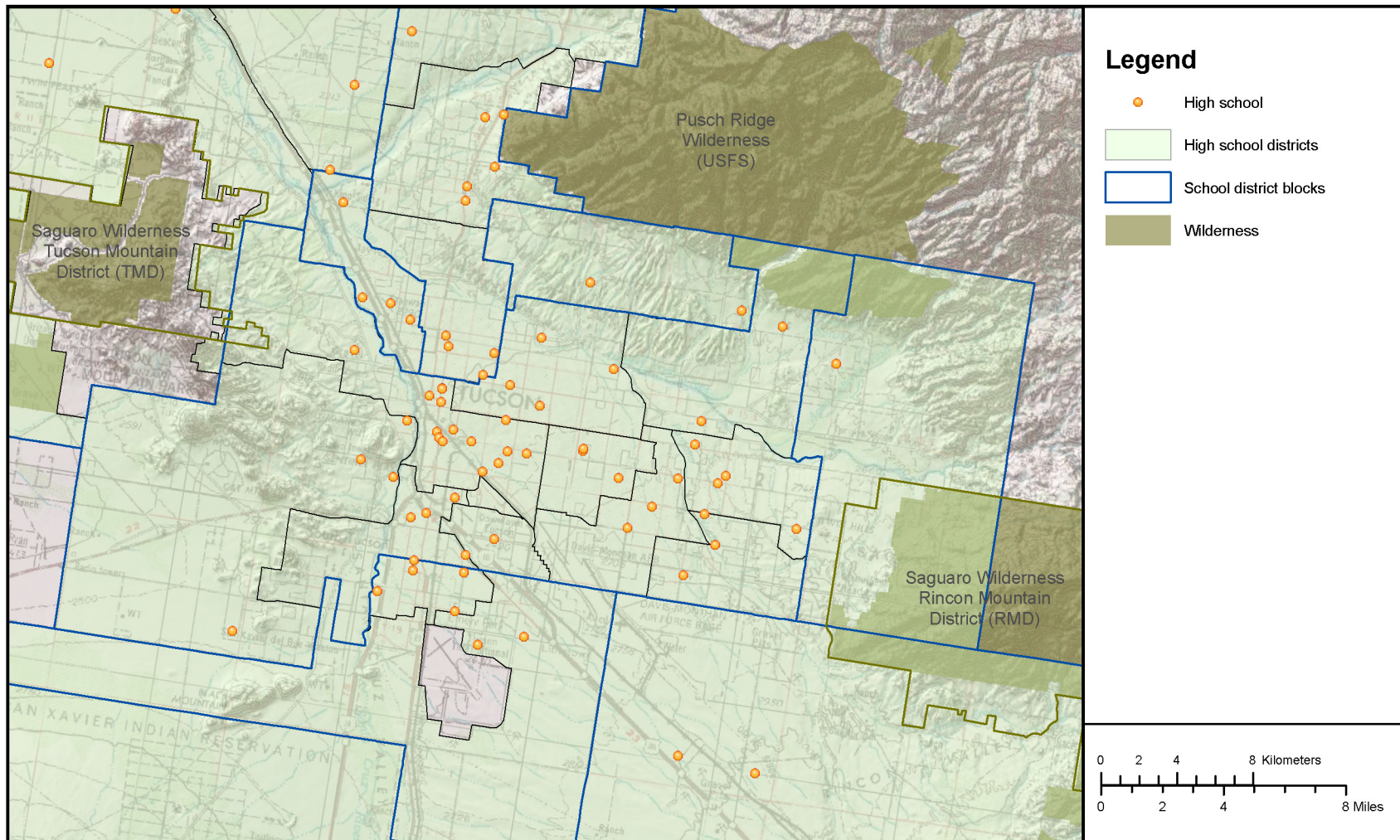
Map 164. Density of people with a Bachelor's education (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



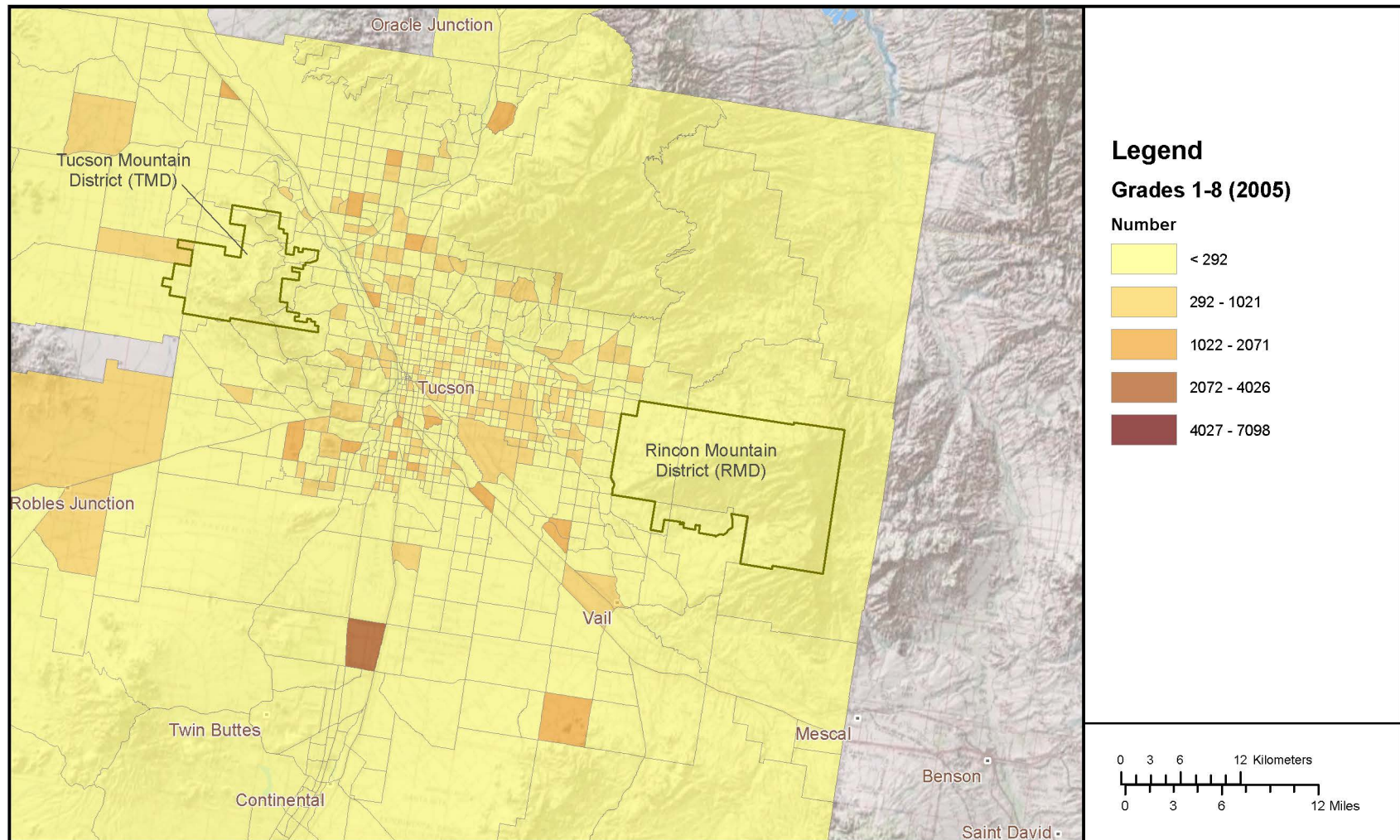
Map 165. Pima County elementary schools, elementary school districts, and school district blocks in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



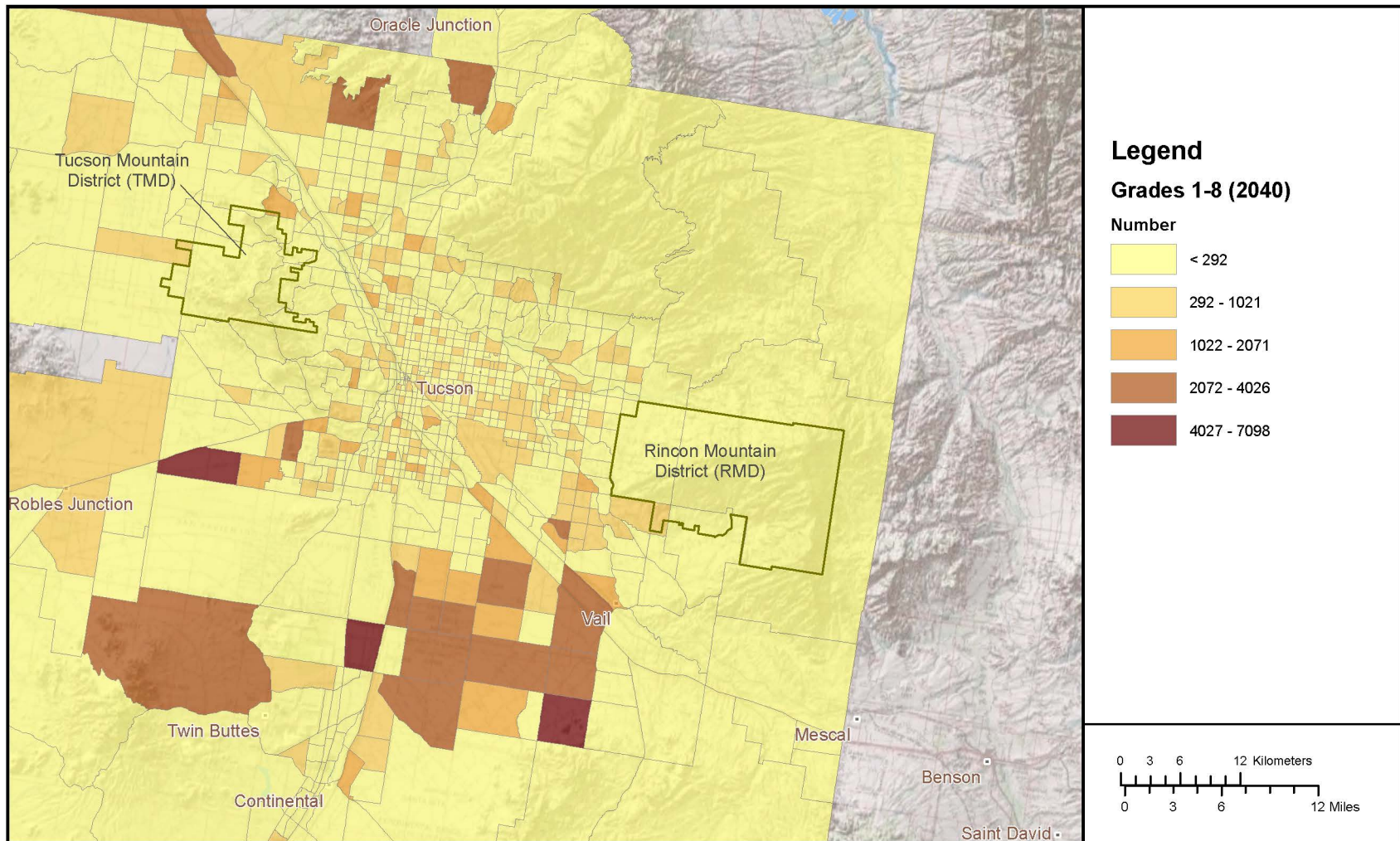
Map 166. Pima County middle schools, middle school districts, and school district blocks in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



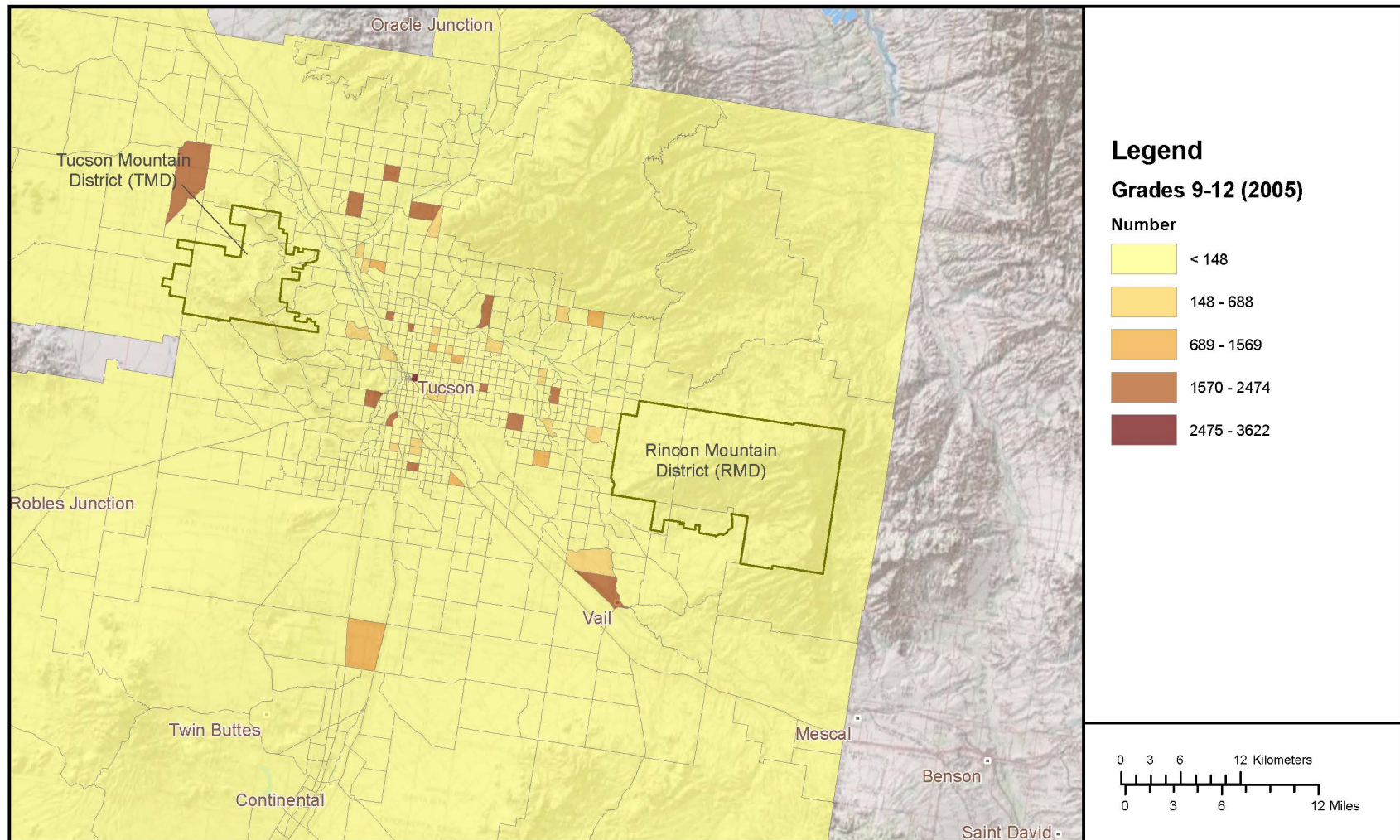
Map 167. Pima County high schools, high school districts, and school district blocks in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



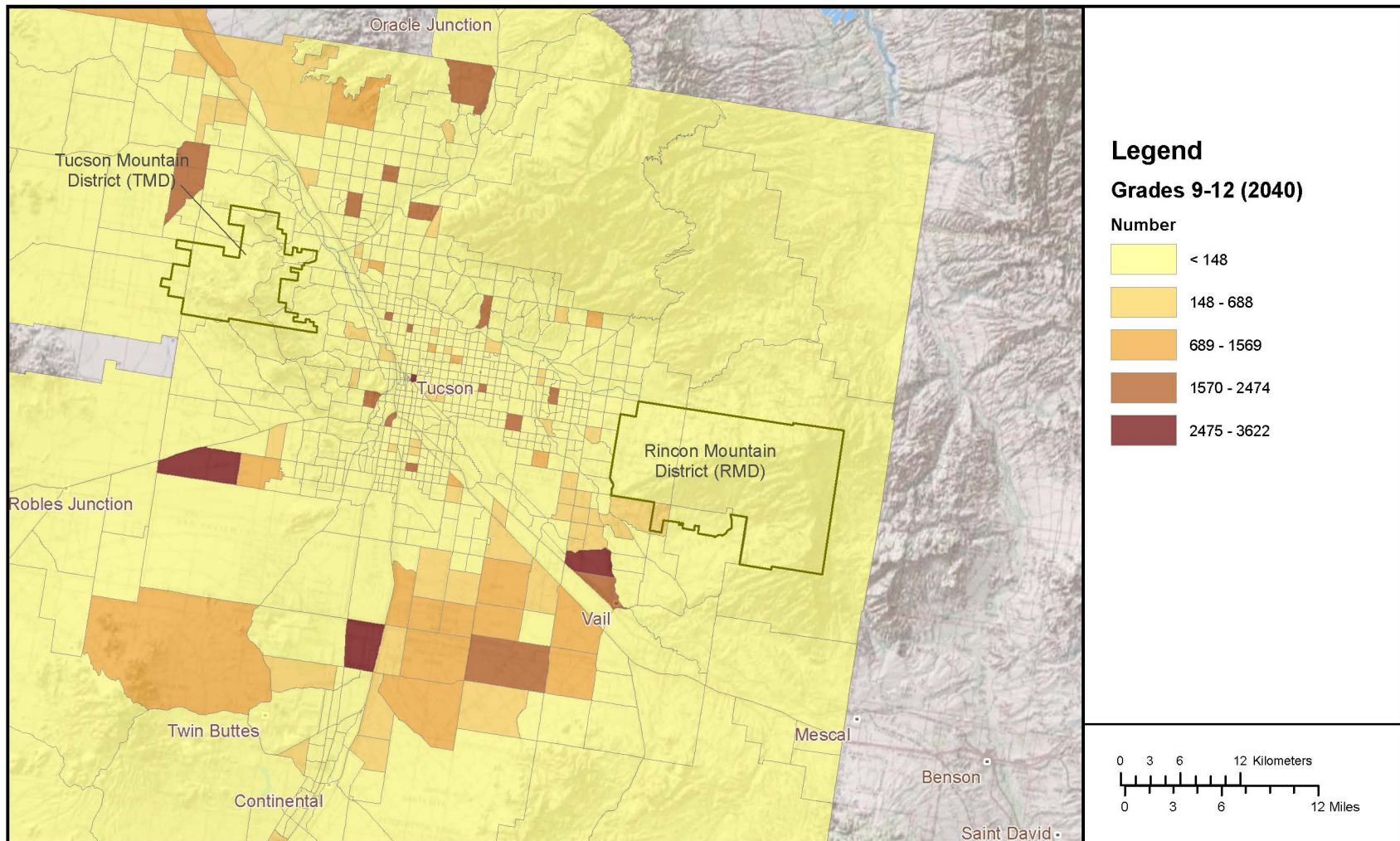
Map 168. Number of school children, grades 1 through 8 (year 2005) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



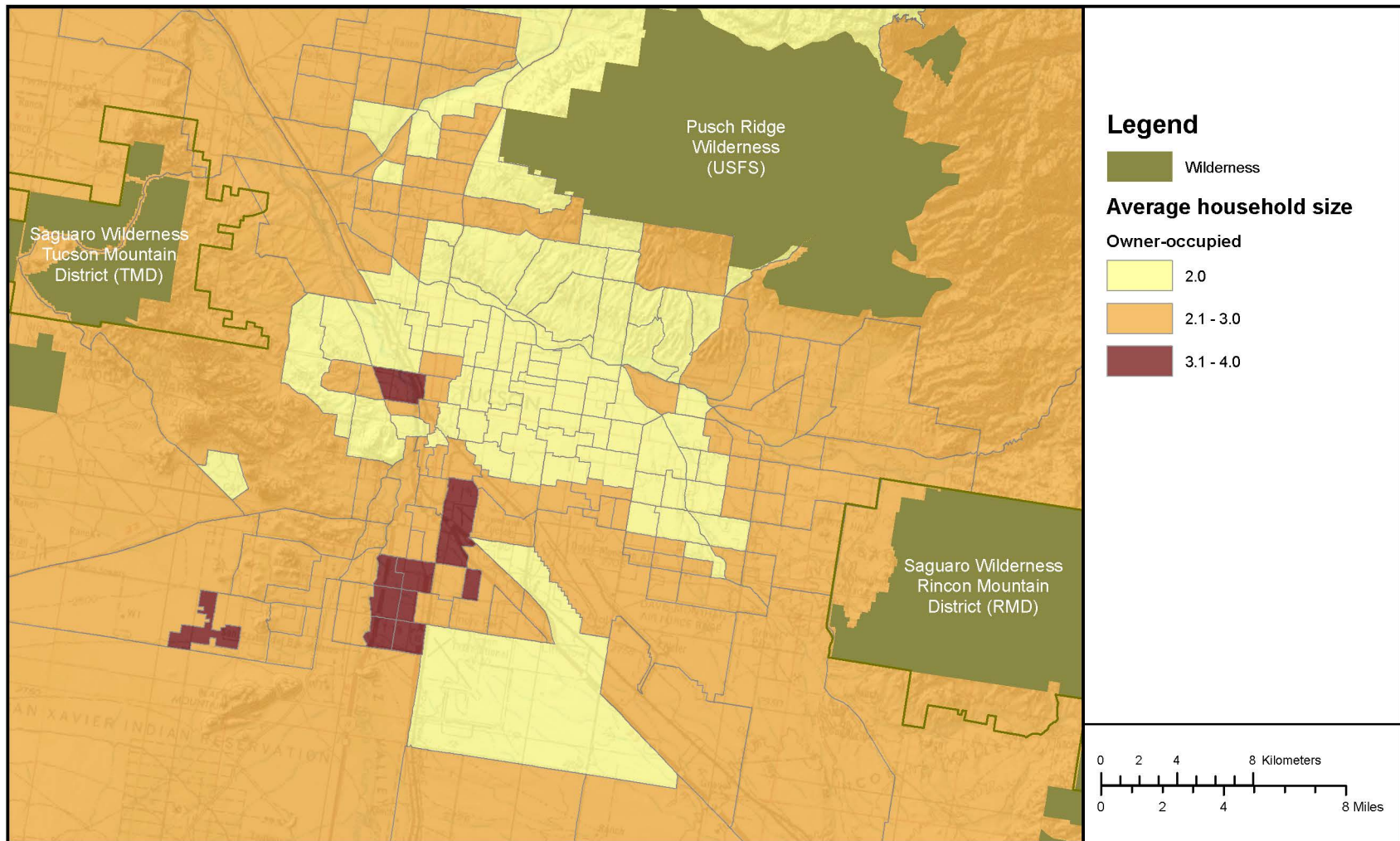
Map 169. Number of school children, grades 1 through 8 (projected to the year 2040) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



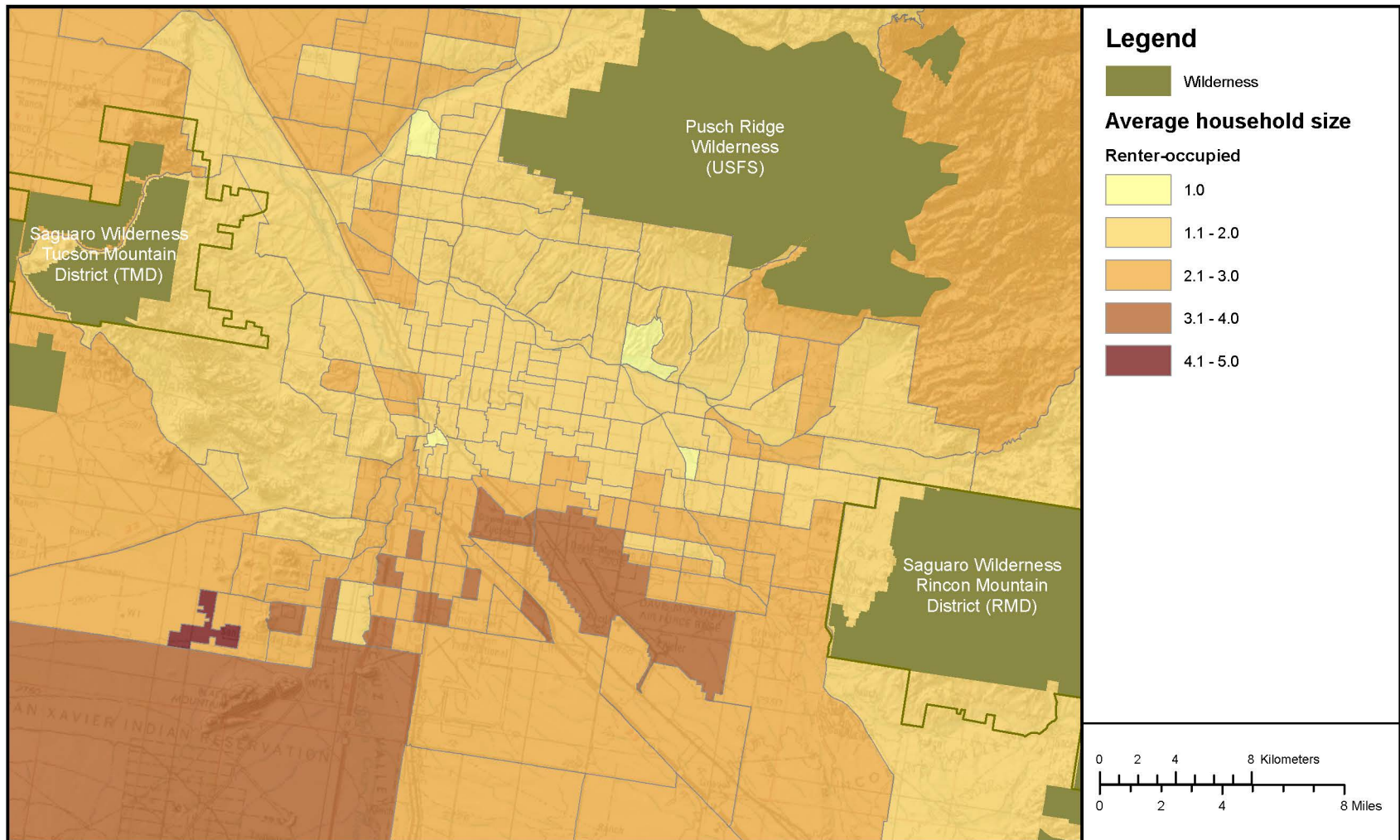
Map 170. Number of school children, grades 9 through 12 (year 2005) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



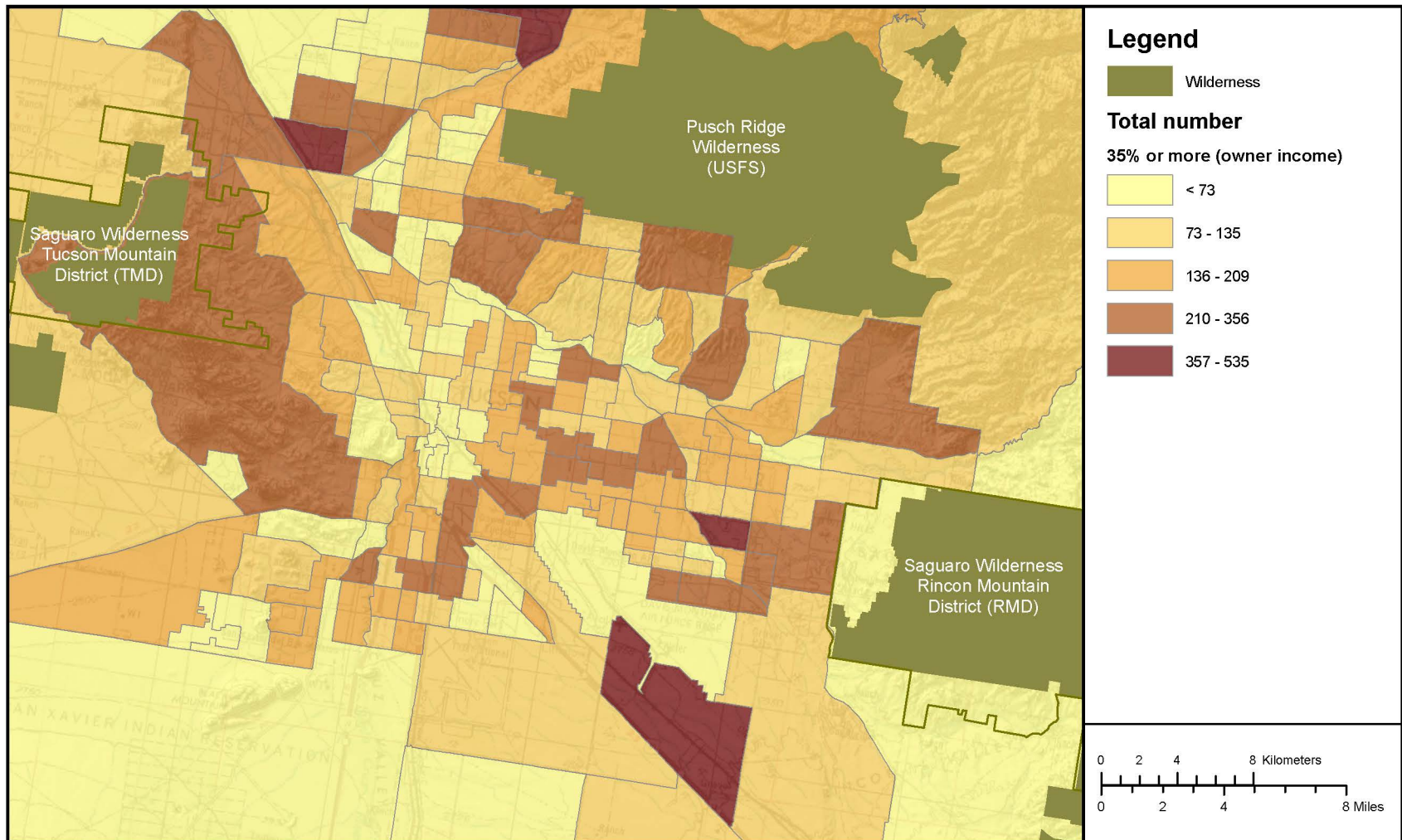
Map 171. Number of school children, grades 9 through 12 (projected to the year 2040) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



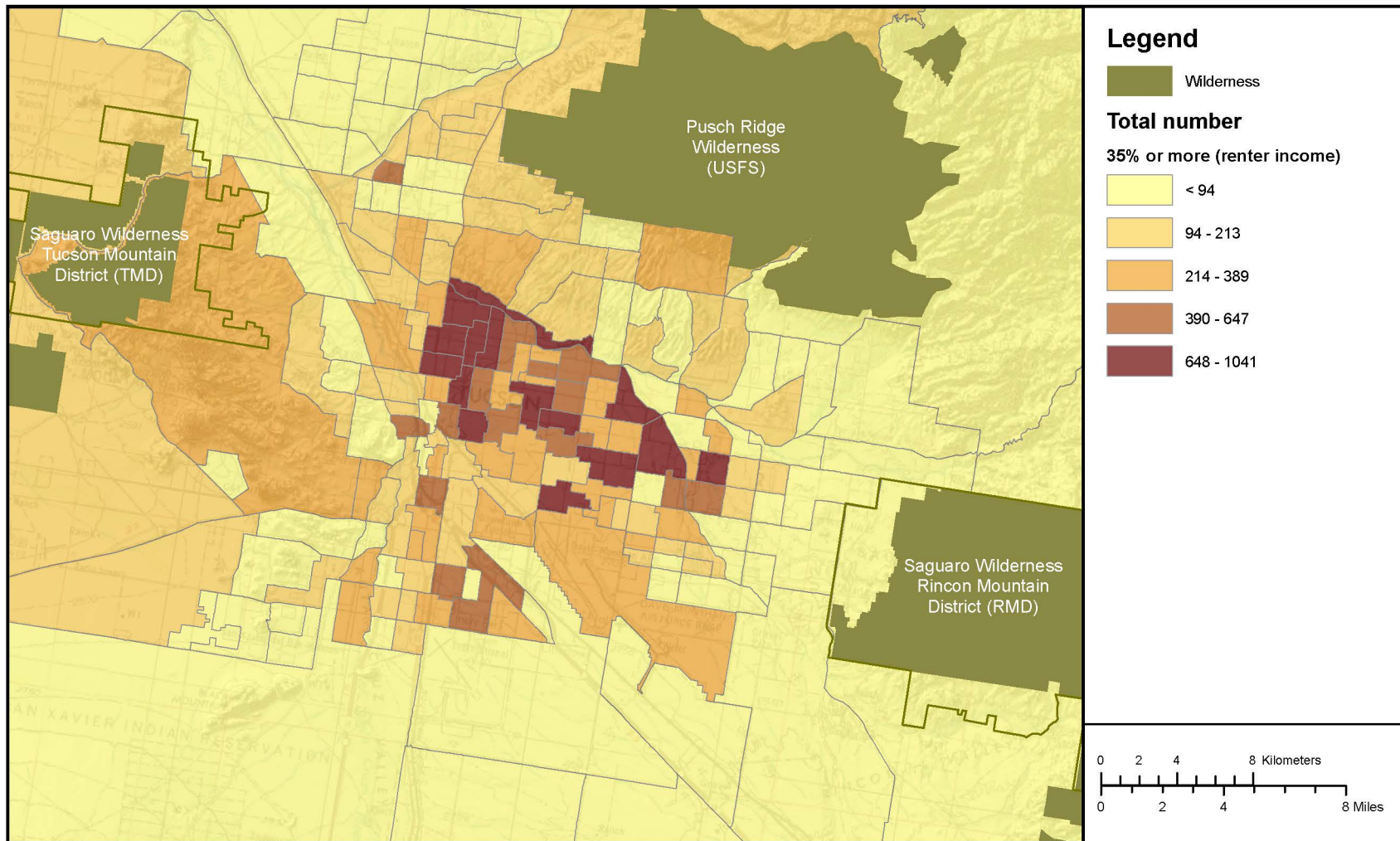
Map 172. Average household size of owner-occupied units (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



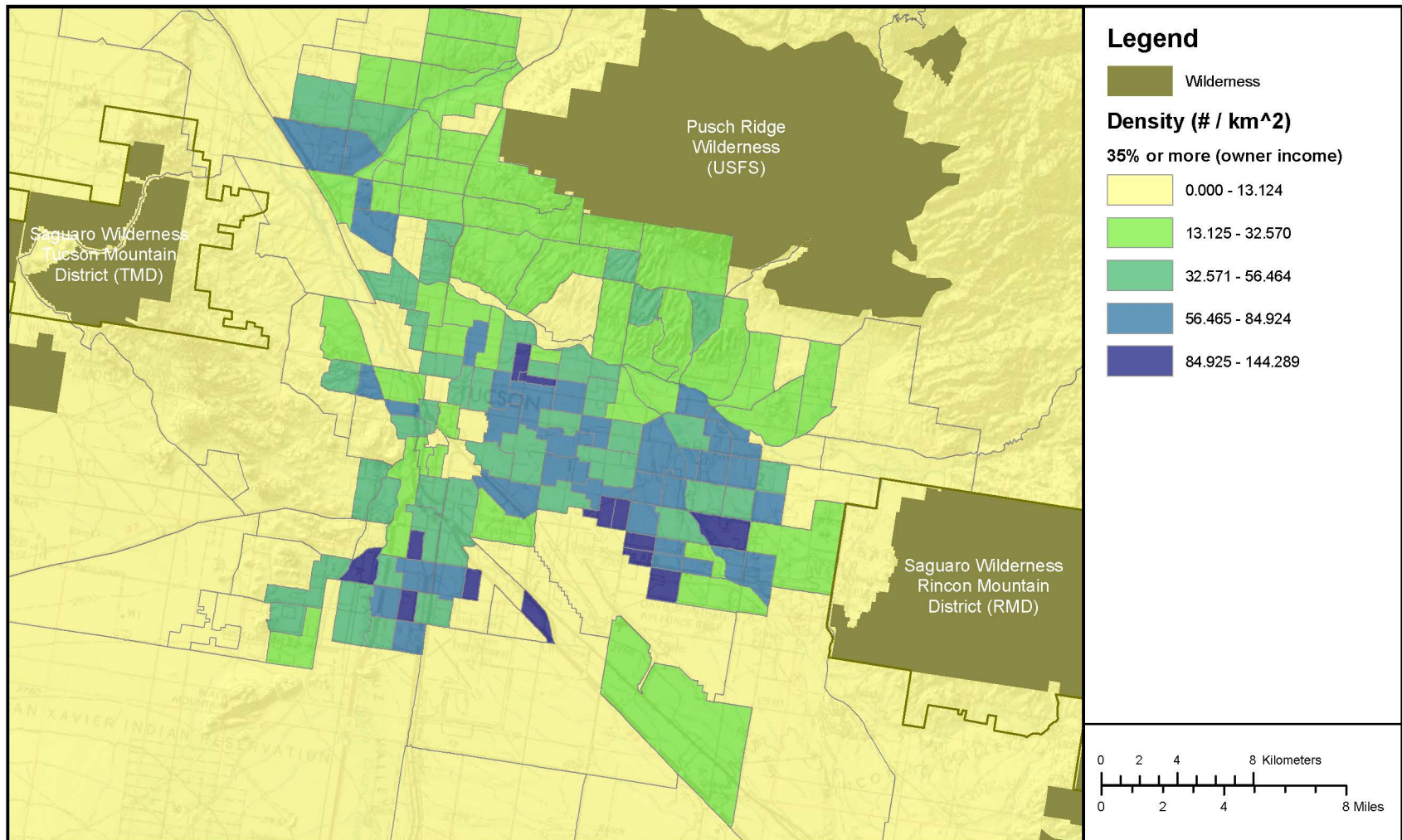
Map 173. Average household size of renter-occupied units (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



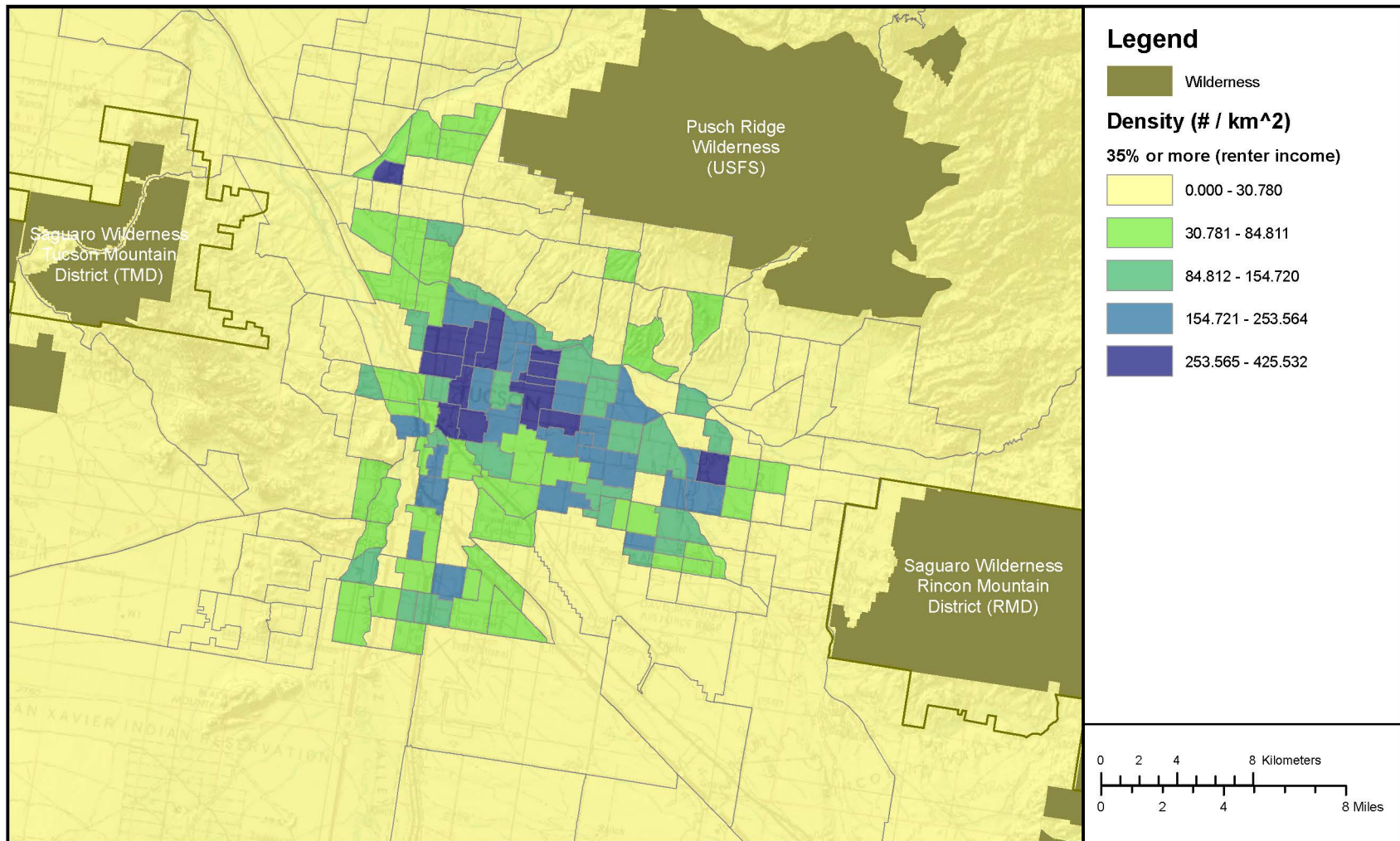
Map 174. Number of homeowners whose monthly costs as a percentage of household income is 35% or more (US Census Bureau 2000). Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



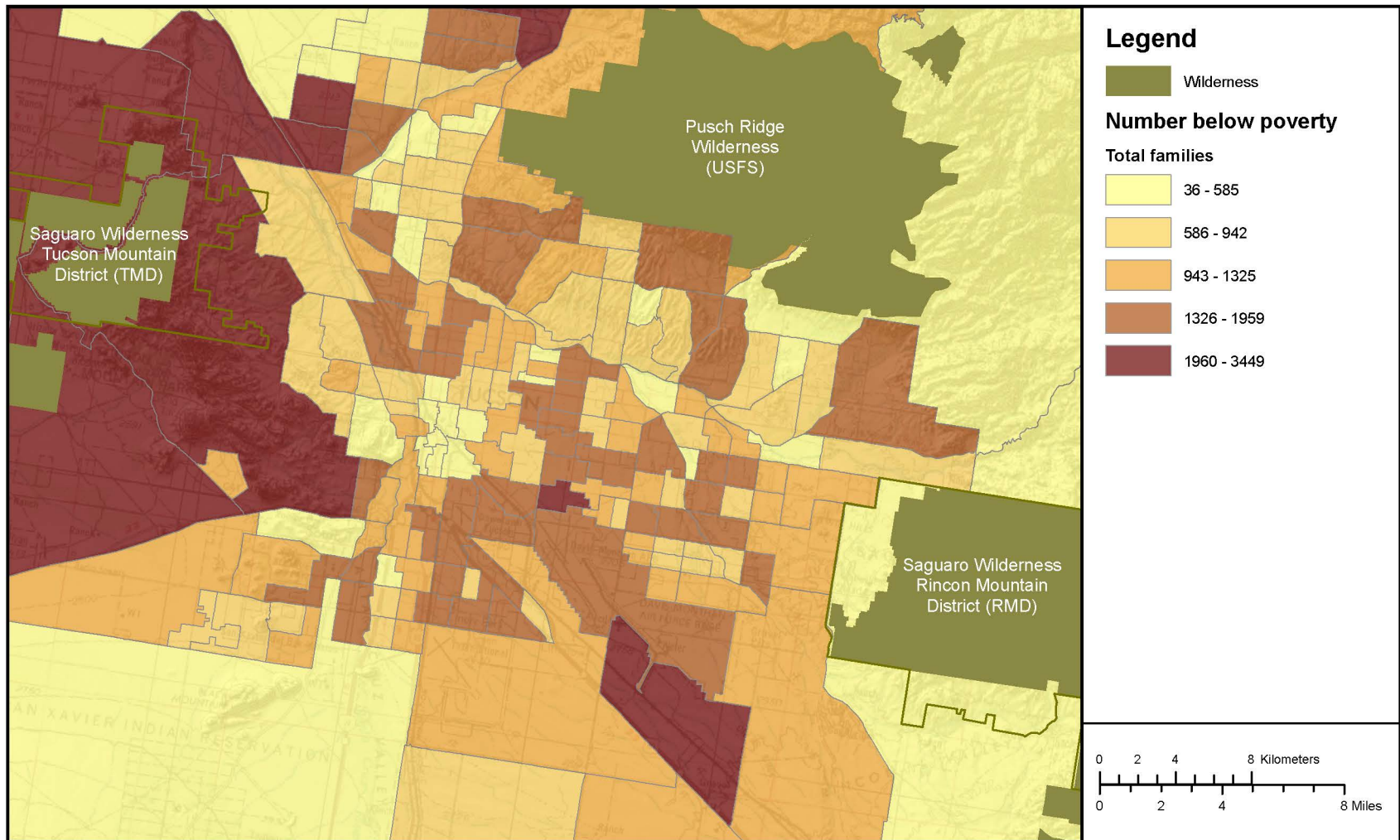
Map 175. Number of tenants whose gross rent as a percentage of household income is 35% or more (US Census Bureau 2000). Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



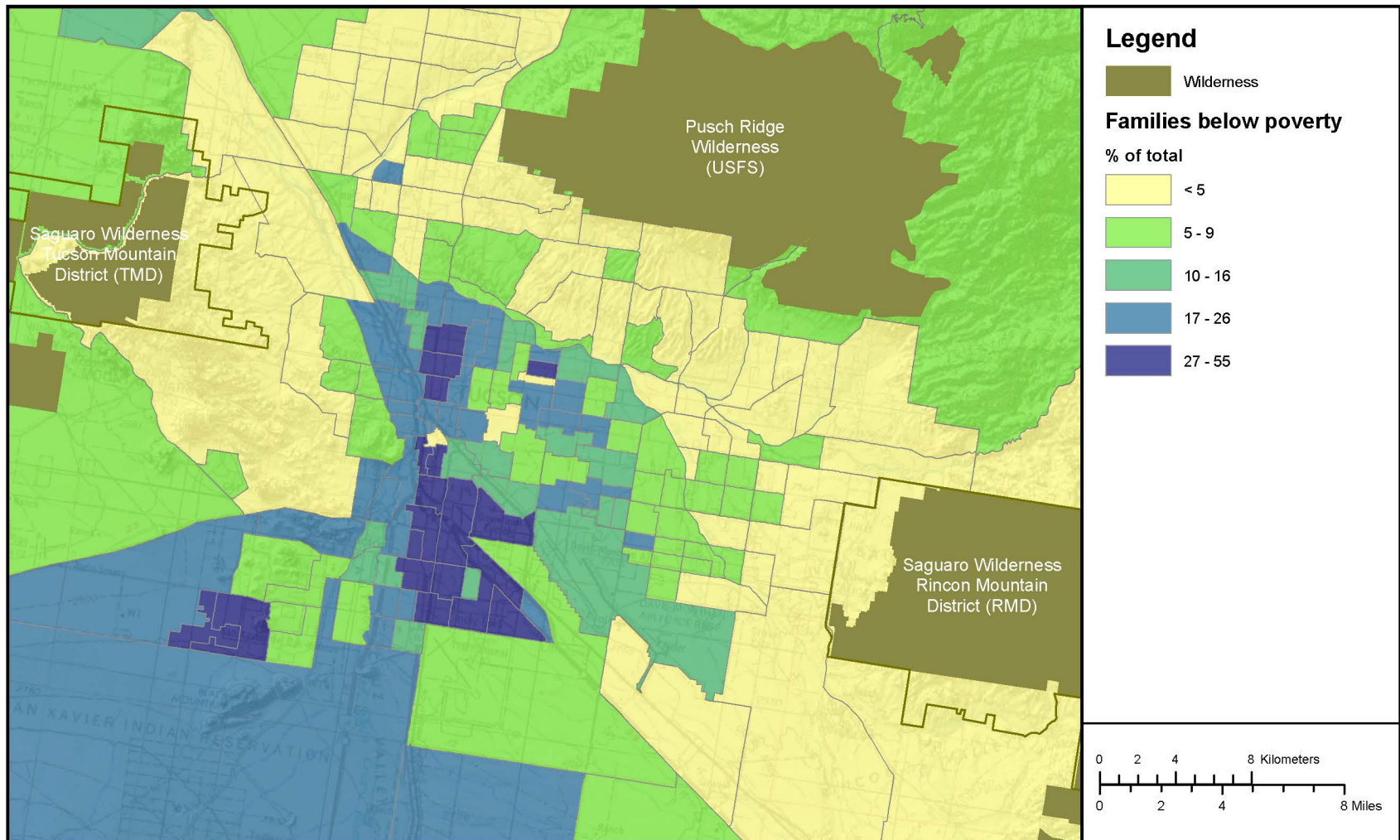
Map 176. Density of homeowners whose monthly costs as a percentage of household income is 35% or more (US Census Bureau 2000). Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



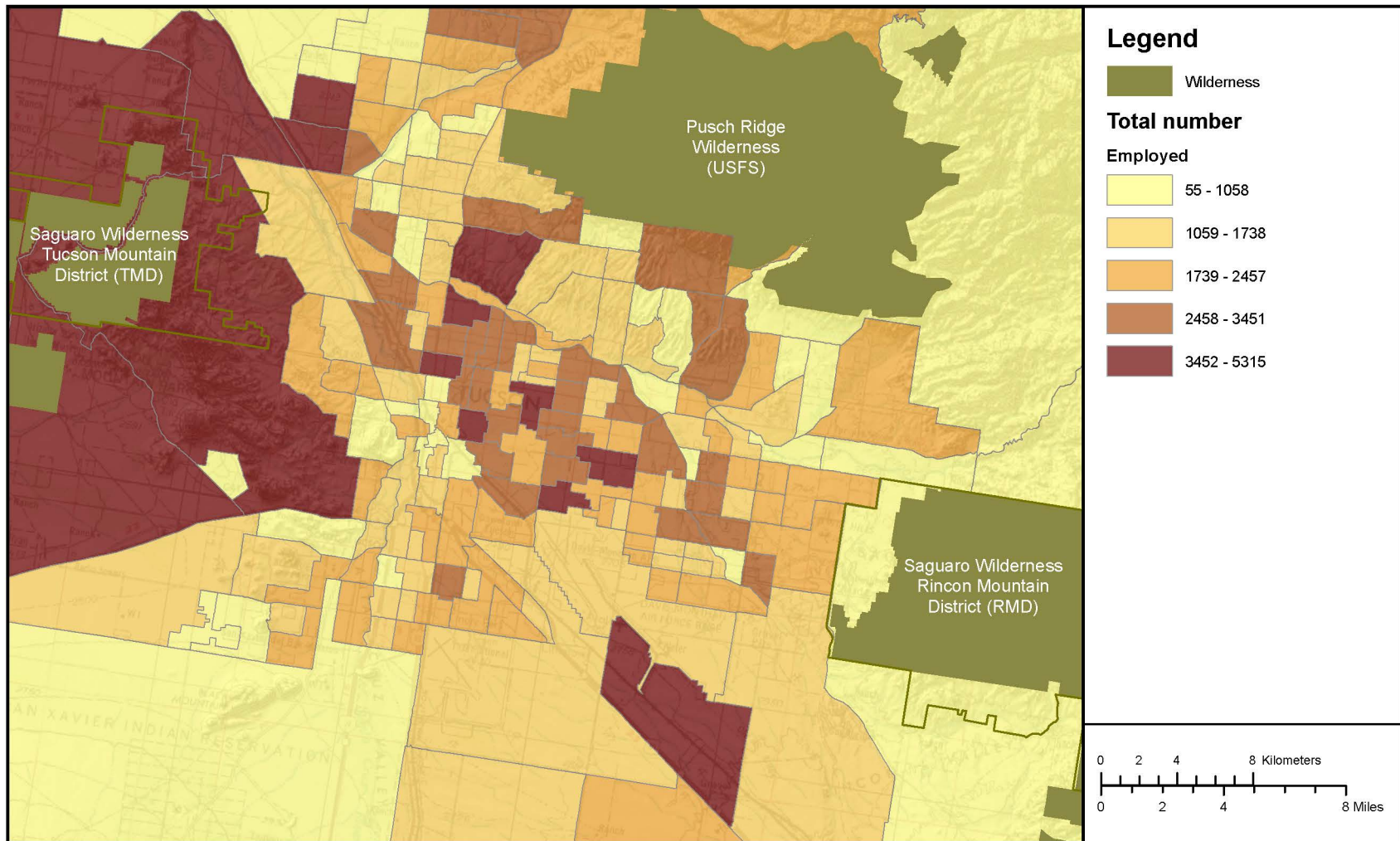
Map 177. Density of tenants whose gross rent as a percentage of household income is 35% or more (US Census Bureau 2000). Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



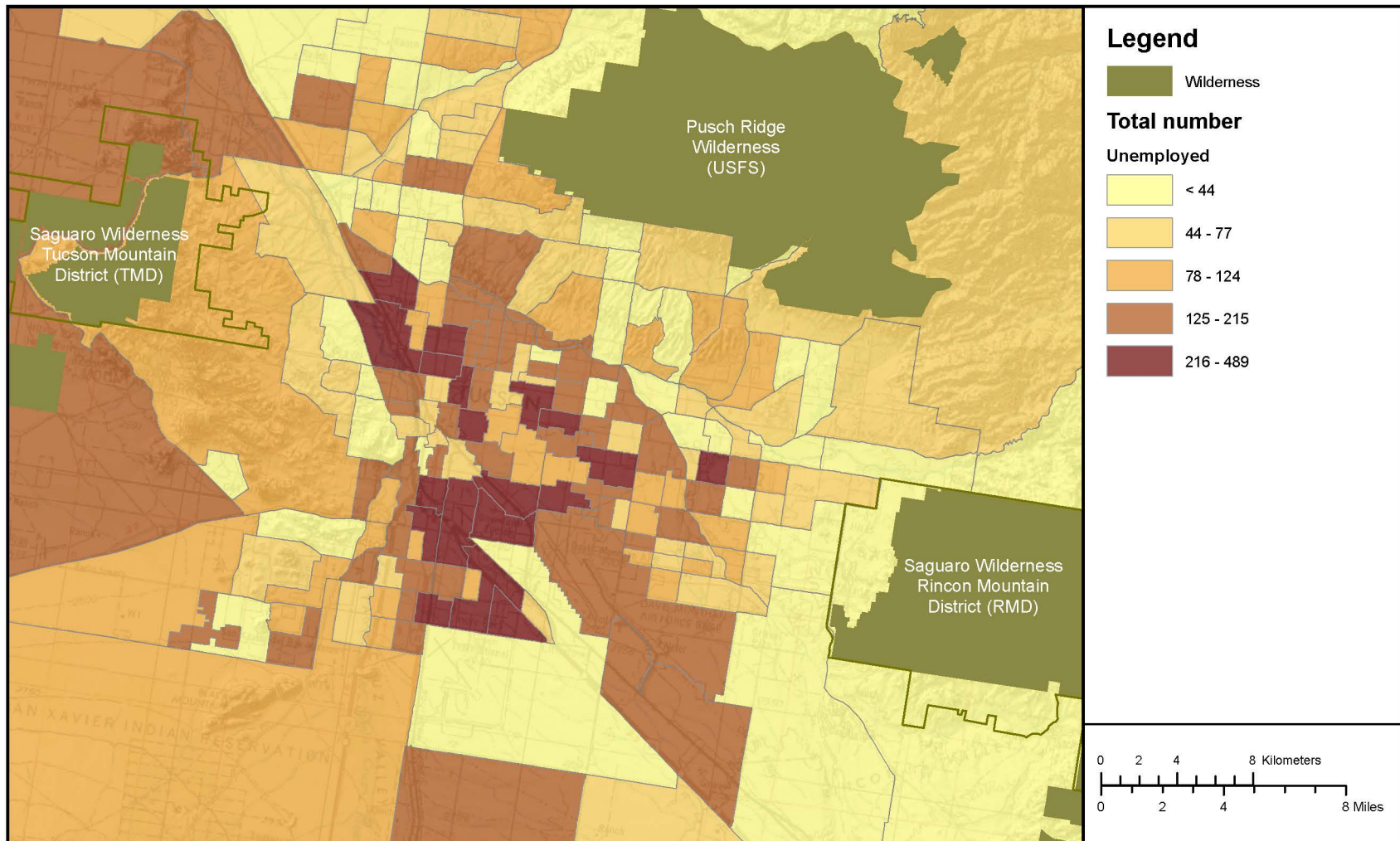
Map 178. Number of families below poverty (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



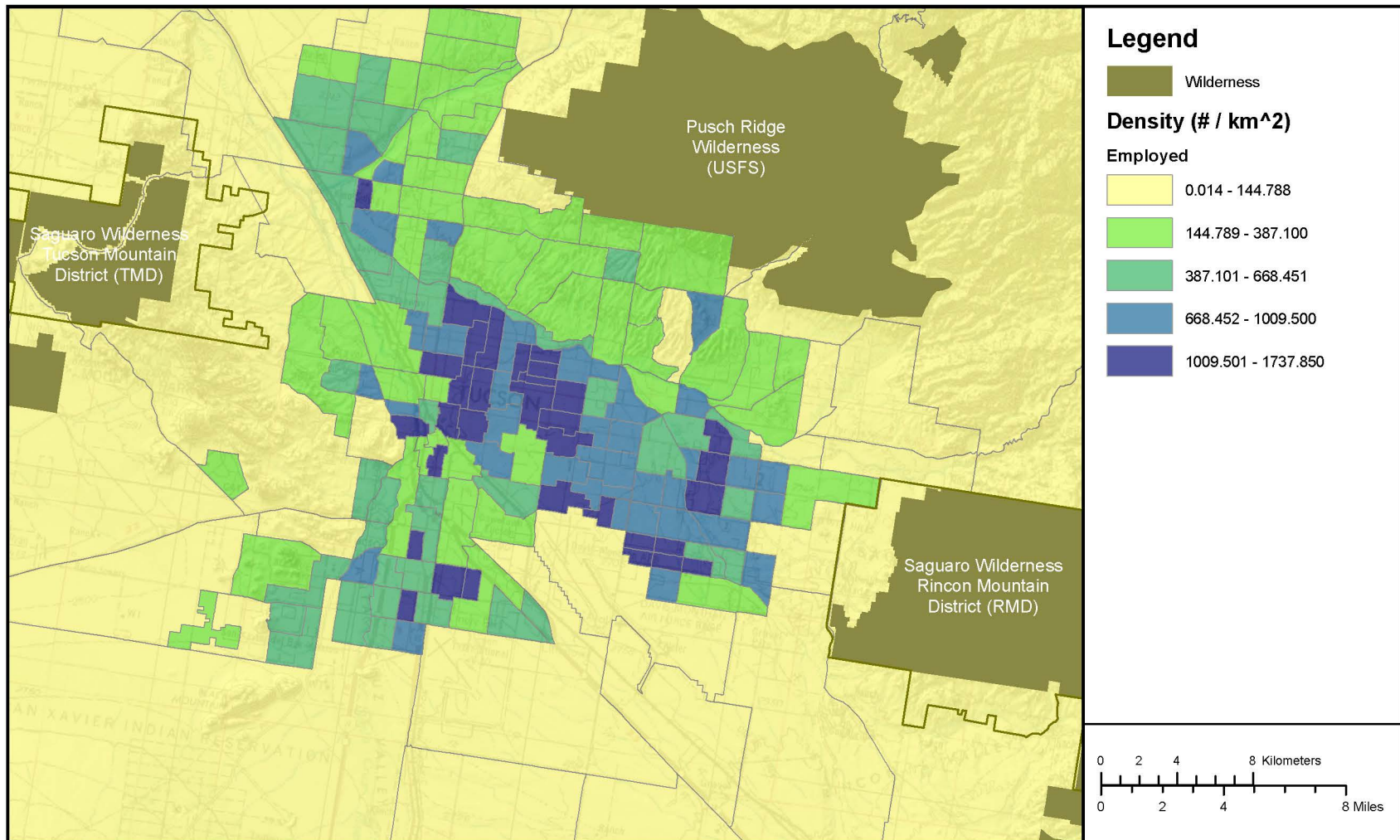
Map 179. Percentage of families below poverty (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



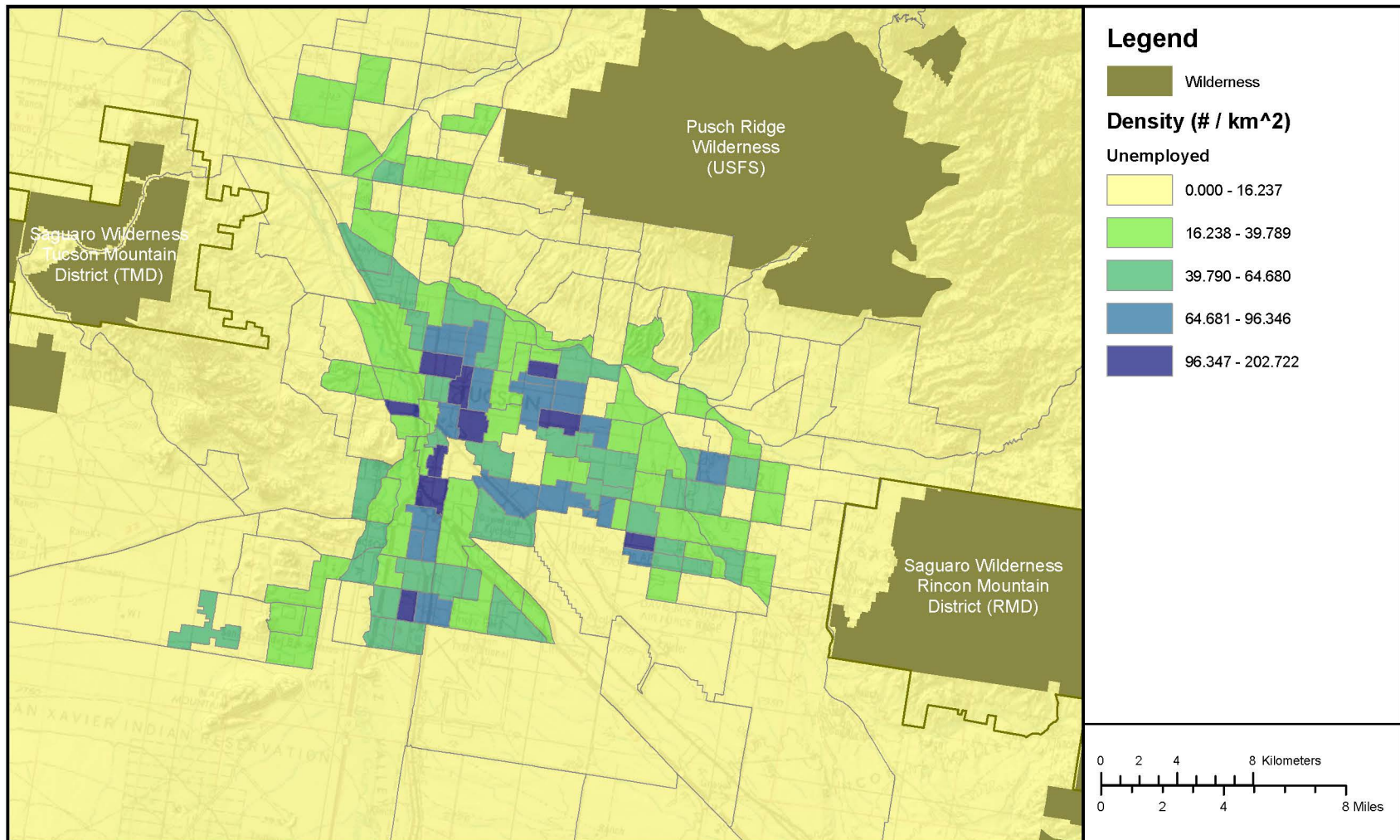
Map 180. Number of people employed (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



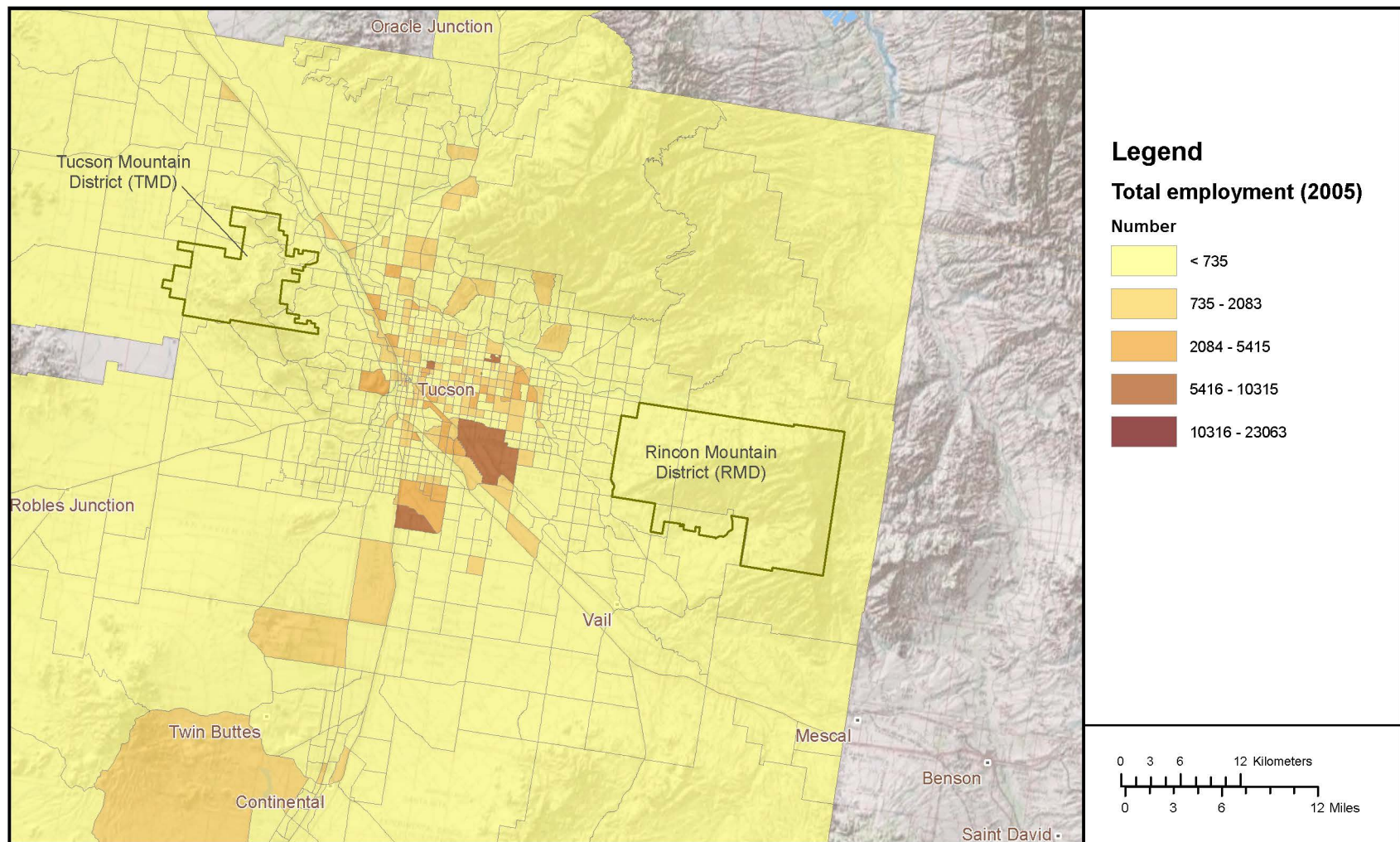
Map 181. Number of people unemployed (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



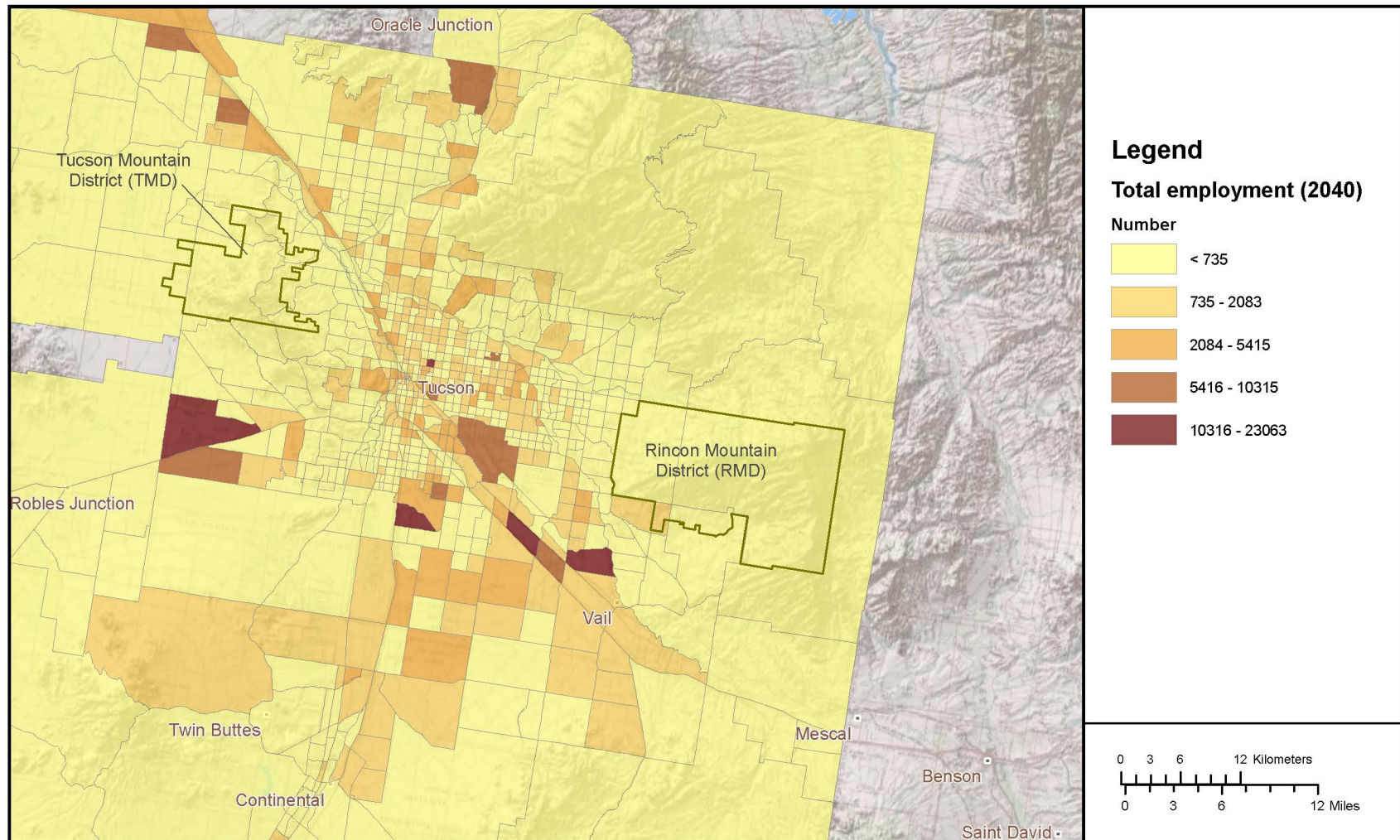
Map 182. Density of people employed (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



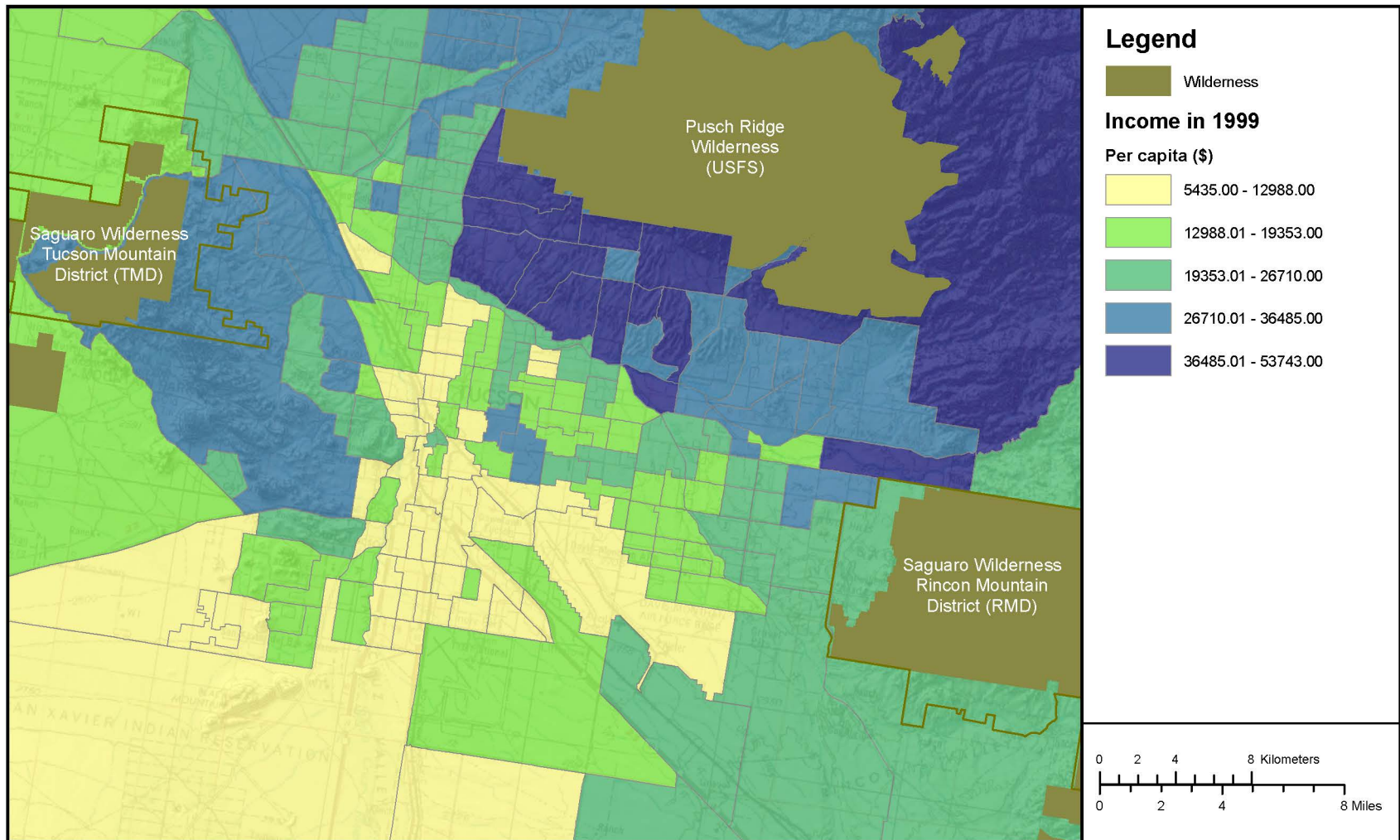
Map 183. Density of people unemployed (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



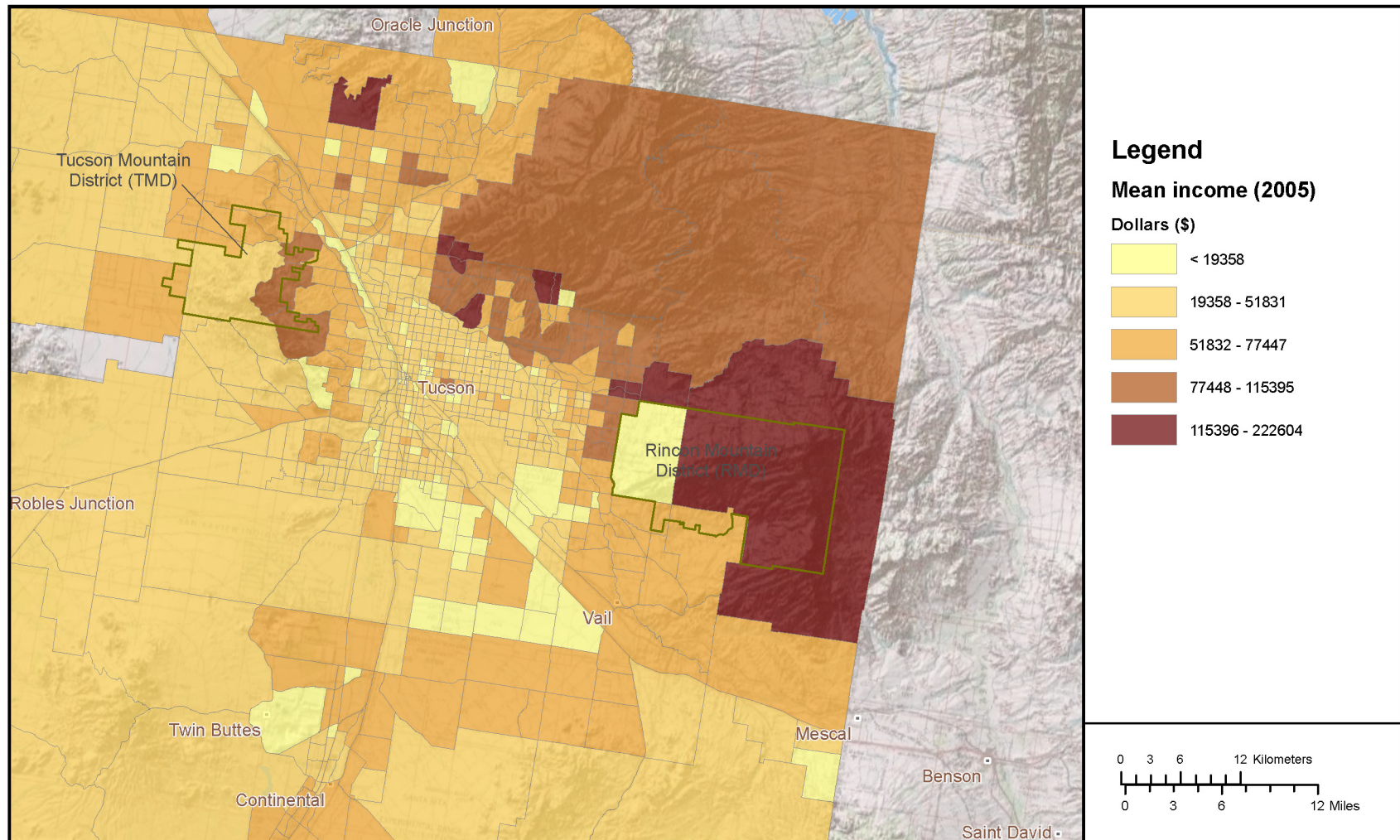
Map 184. Number of people employed (year 2005) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



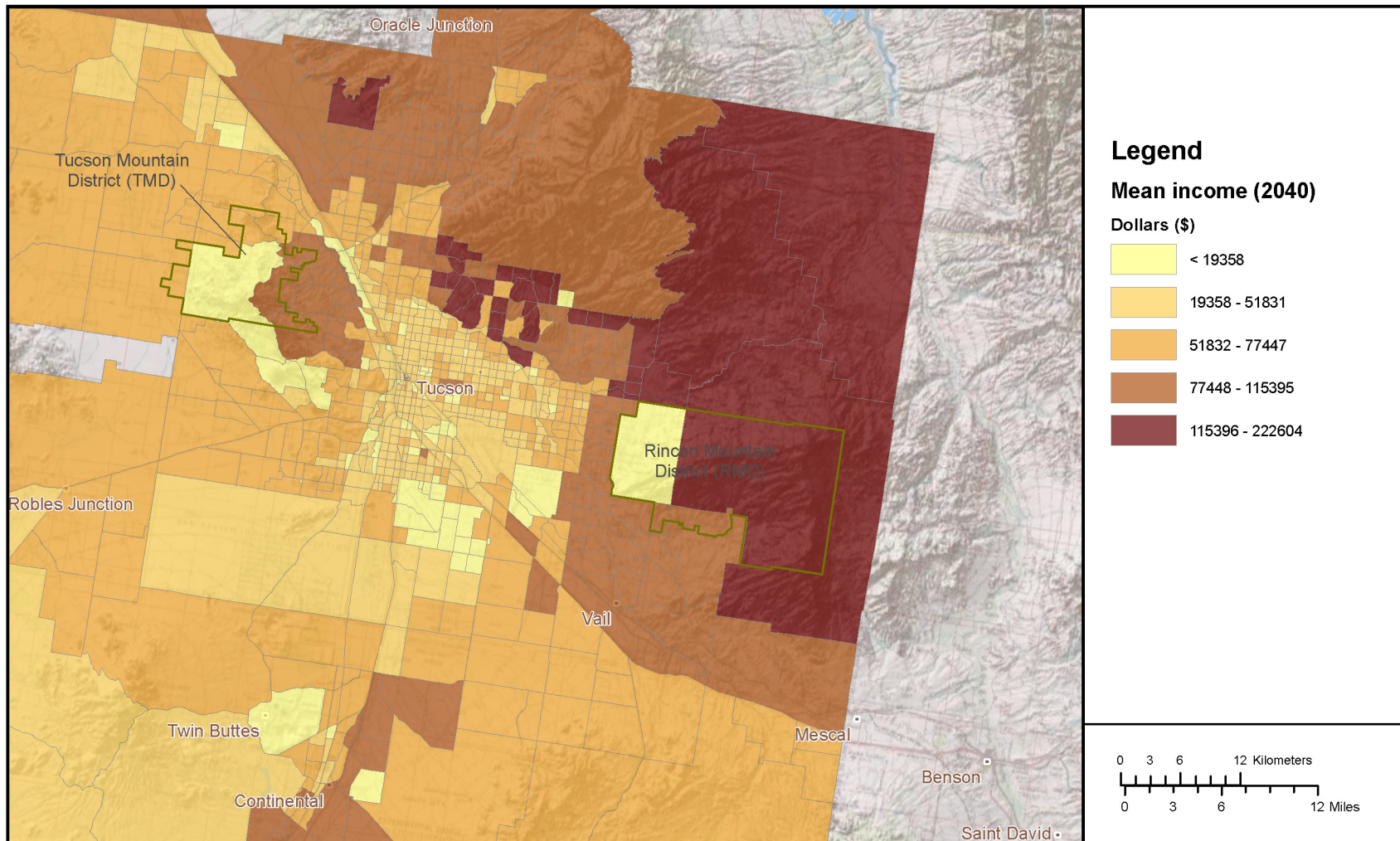
Map 185. Number of people employed (projected to the year 2040) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



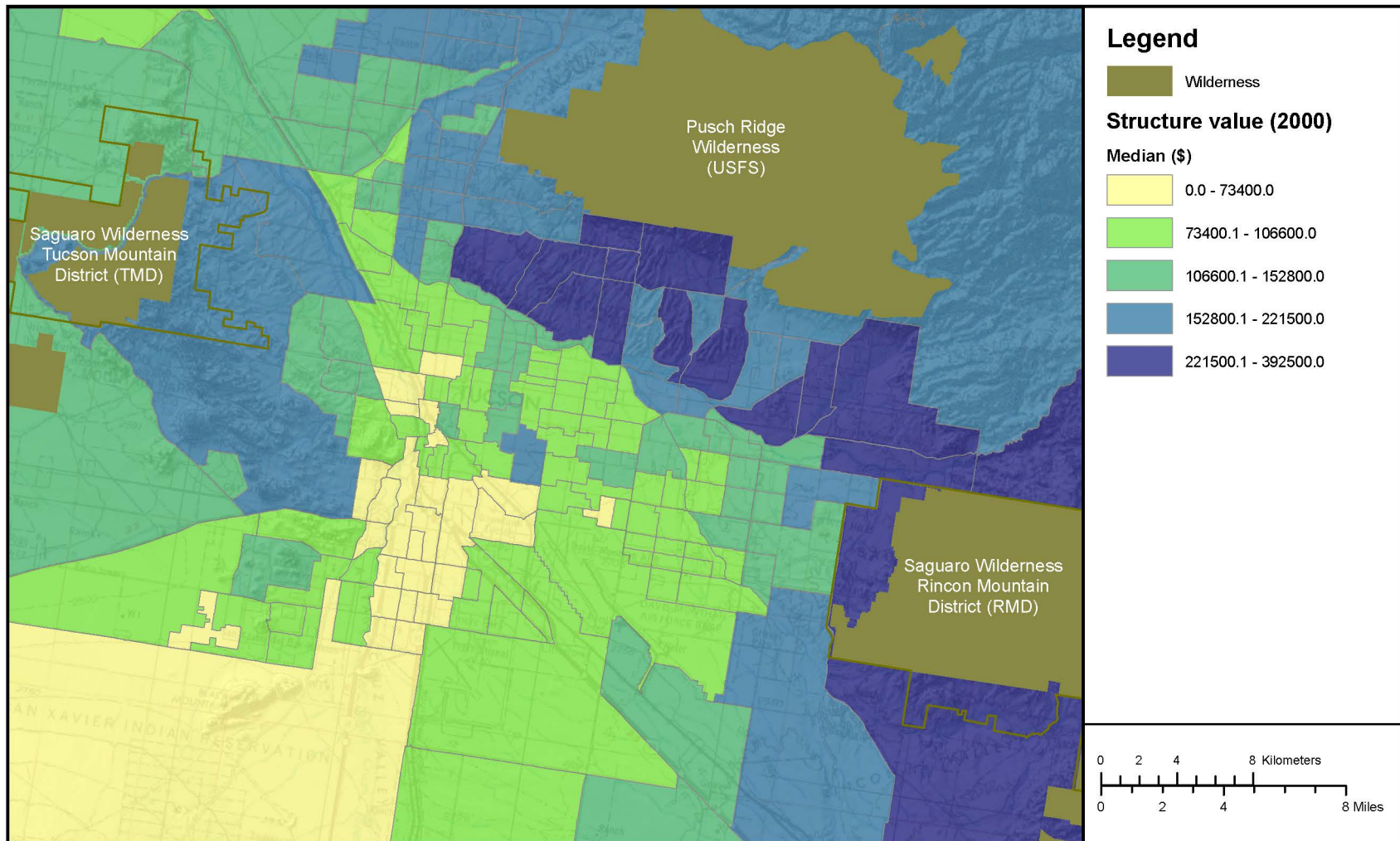
Map 186. Per capita income in the year 1999 (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



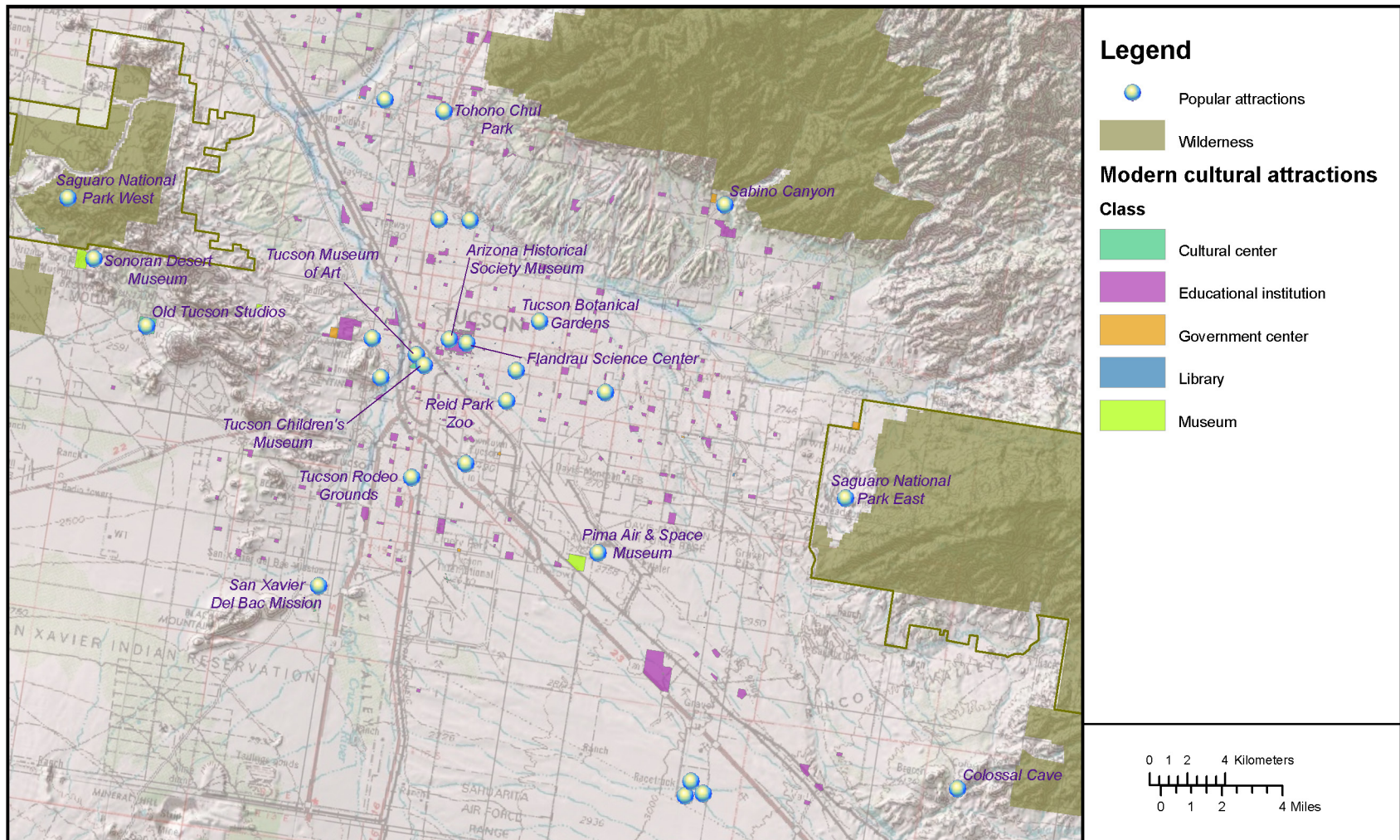
Map 187. Mean income (year 2005) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pag-net.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



Map 188. Mean income (projected to the year 2040) in the local area surrounding Saguaro National Park. Data obtained from the Pima Association of Governments (<http://www.pagnet.org/RegionalData/Maps/MapsandGISDownloads/tabid/902/Default.aspx>).



Map 189. Median structure value (US Census Bureau 2000) in the local area surrounding Saguaro National Park. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).



Map 190. Popular and modern cultural attractions in the Tucson area. Data obtained from the Pima County Information Technology Department (<http://gis.pima.gov/>).

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.

NPS 151/119539, January 2013

National Park Service
Department of the Interior



Natural Resource Stewardship and Science

1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA™