National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Mapping Wilderness Character in Death Valley National Park

Natural Resource Report NPS/DEVA/NRR—2012/503

ON THE COVER
Author James Tricker overlooking the Racetrack Playa from the Grandstand
Photograph by: Peter Landres

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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.

This report is available from Death Valley National Park http://www.nps.gov/deva, and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/).

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Executive Summary

The recent development of an interagency strategy to monitor wilderness character allows on-the-ground managers and decision-makers to assess whether stewardship actions for an individual wilderness are fulfilling the mandate to “preserve wilderness character.” By using credible data that are consistently collected, one can assess how wilderness character changes over time and evaluate how stewardship actions affect trends in wilderness character. As most of these data depict spatial features in wilderness, this study investigates whether a wilderness character map can be developed to provide a spatially explicit understanding of these changes and trends over time.

A GIS-based approach was developed to identify the state of wilderness character in Death Valley National Park (DEVA). A set of indicators and measures were identified by DEVA staff to be used as the basis for selecting data inputs and assigning them to a relevant quality of wilderness character. These data inputs were derived from a variety of spatial datasets and were formatted onto a common relative scale. Each data input was “weighted” by DEVA staff to reflect its importance in relation to other data inputs. Maps were generated for each of the four qualities of wilderness character, which were added together to produce the wilderness character map for DEVA.

The wilderness character map delineates the range in quality of wilderness character in the DEVA wilderness. A histogram of the map reveals that the majority of wilderness character in DEVA is of high quality, with the top 10 percent areas to be found mostly in the northern section of the park. Using this map as a baseline for wilderness character quality in DEVA, future reruns of the map with updated datasets will allow for identifying areas where wilderness character is changing over time. Furthermore, this map is intended to be used by DEVA staff to evaluate, on a pixel-by-pixel basis, the spatial impacts of different planning alternatives for the pending DEVA Wilderness and Backcountry Stewardship Plan.

In addition to this report, a technical report written for GIS specialists detailing these methodologies is available at http://wilderness.net/index.cfm?fuse=toolboxes&sec=WC.

Acknowledgements

Special thanks to S. Craighead (DEVA Superintendent) for encouraging and supporting this project. The passion and commitment of park staff to wilderness stewardship at DEVA made it the ideal location to conduct this study.

We also greatly appreciate the willingness of the following people to share their time and expertise to help develop the wilderness character map: D. Duriscoe and C. Moore (NPS Night Sky Team); M. Barna, E. Porter, and J. Vimont (NPS Air Resources Division); L. Marin (NPS Natural Sounds Program); J. Burke (NPS Mojave Desert Network); and A. Shandor (DEVA Assistant Chief Ranger).

Finally, a special thanks to the Timbisha Shoshone Tribe for the use of their facilities and participation in the project.

Introduction

The 1964 Wilderness Act (Public Law 88-577) established the National Wilderness Preservation System "for the protection of these areas, the preservation of their wilderness character" (Section 2a). In congressional testimony clarifying the intent of wilderness designation, Zahniser (1962) said, "The purpose of the Wilderness Act is to preserve the wilderness character of the areas to be included in the wilderness system, not to establish any particular use" (United States Congress 1983), and legal scholars (Rohlf and Honnold 1988, McCloskey 1999) subsequently confirmed that preserving wilderness character is the Act's primary legal mandate. Further, the policies of all four agencies that manage wilderness state that they are to preserve wilderness character in all areas designated as wilderness. For the purpose of wilderness stewardship, a tangible definition of wilderness character was developed (Landres et al. 2005, Landres et al. 2008).

As described in these publications, wilderness character is an inherent part of an entire wilderness and varies across a landscape just as landscape features vary from one place to the next. Wilderness attributes have been previously mapped at a variety of different scales: globally (Sanderson et al. 2002), continentally (Carver 2010), nationally (Aplet et al. 2000), and locally (Carver et al. 2008), depicting how these attributes vary across the wilderness continuum from least to most wild. In the United States, however, a spatially explicit description of wilderness character for all lands falling within a designated wilderness area had not been previously attempted.

The purpose of this project was to develop an approach that depicts how the quality of wilderness character varies across the Death Valley Wilderness that is located within Death Valley National Park (DEVA) (Figure1). This map of wilderness character will:

- Show the current overall condition of wilderness character and how it varies across the 3.1 million acres of the Death Valley Wilderness.
- Allow analysis of different planning alternatives being considered in the Wilderness and Backcountry Stewardship Plan and their effects on wilderness character by varying different factors that affect the map. Similarly, this map could be used for project planning to analyze the effects of proposed actions on wilderness character.
- Provide a baseline from which future monitoring could show the trend in wilderness character over time.
- Allow park staff to evaluate existing park spatial data and consider whether new or better data would be needed for future planning and analyses of effects on wilderness character.

In addition to the four primary benefits described above, other potential benefits of the wilderness character map include identifying specific areas where actions could be taken inside the wilderness to improve wilderness character or areas where actions should not be taken because they would degrade wilderness character. In addition, the map would help identify specific areas outside the wilderness where actions might pose a significant risk of degrading wilderness character inside wilderness.

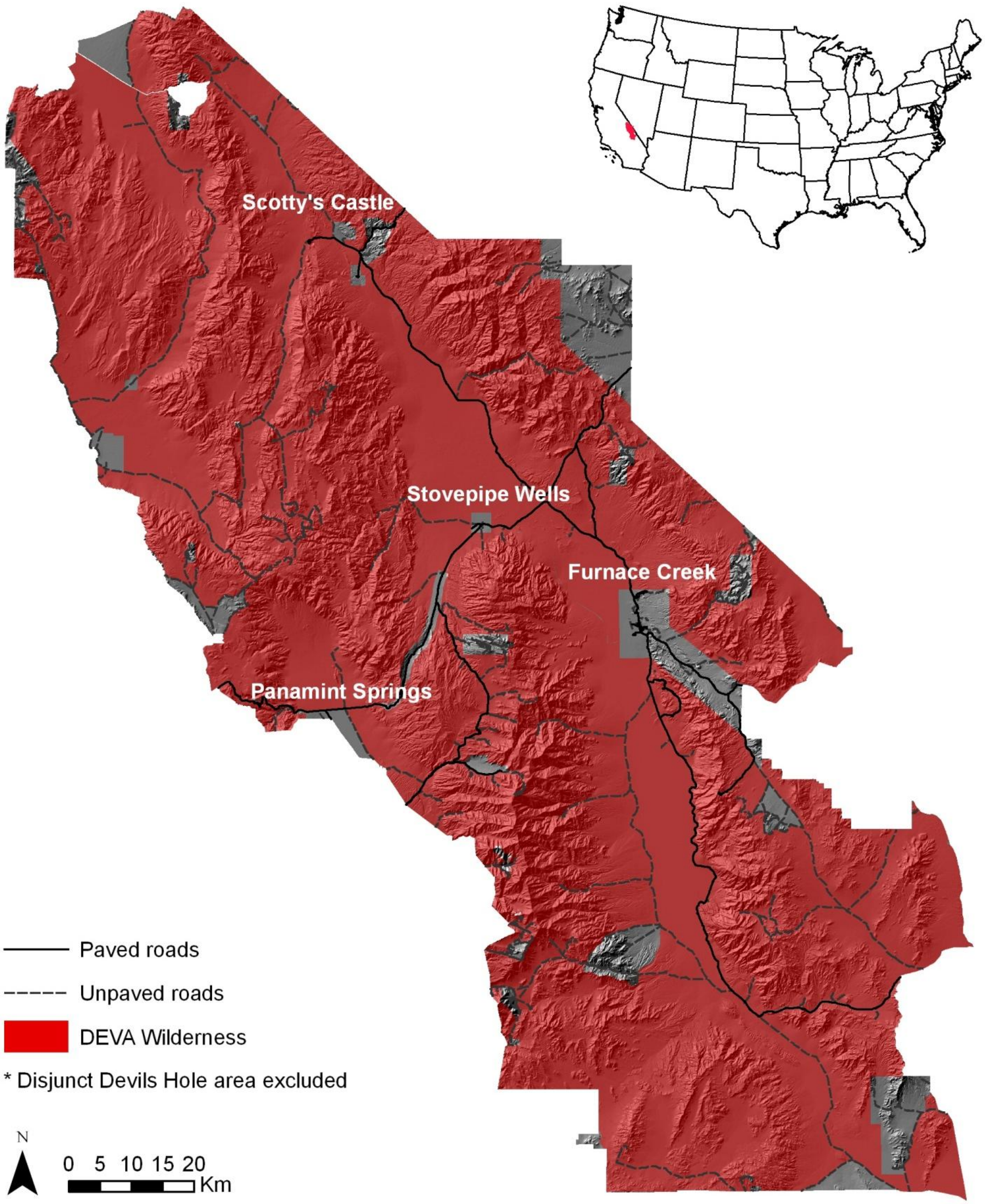

Figure 1. *Death Valley National Park.*

There are a number of concerns and cautions about producing the wilderness character map. Specific cautions are described under each of the data inputs. Major cautions about this overall effort include:

- *Creating sacrifice zones* - the map may facilitate inappropriate creation of "sacrifice zones" within the wilderness, directly contravening Congressional and agency mandates to preserve wilderness character across an entire wilderness. For example, if the map shows that some areas are "better" or of "higher quality" than others, the tendency may be to focus efforts on preserving wilderness character only in these specific areas while allowing wilderness character to degrade in "lower quality" areas. By showing the current condition of wilderness character and how it varies across the entire wilderness, the intent of the map is to help staff maintain high quality areas while raising the quality of wilderness character in other areas.
- *Comparing the condition of wilderness character between wildernesses* - the map may facilitate inappropriate comparison of wilderness character among different wildernesses, if or when this approach is repeated for other wilderness areas. The maps will show the current status or trend of wilderness character in different colors, and it will be easy for users to compare the quantity of a given color among different wildernesses. Comparing these maps among different wildernesses, however, is neither valid nor appropriate because each map is built with data from the unique context of a particular wilderness.
- *Assuming that the resulting maps accurately and precisely describe wilderness character* - the variety of map products can be misconstrued as an accurate and precise description of wilderness character. These maps are instead only an estimate of selected aspects of wilderness character for which spatial data were available for this particular wilderness. In addition, these maps do not portray in any way the symbolic, intangible, spiritual, or experiential values of wilderness character. In short, while these maps are useful for the purposes described in this report, they do not describe the complexity, richness, or depth of wilderness character.

A team approach was used to develop the wilderness character map for the Death Valley Wilderness, tapping the experience and knowledge of the staff that work at the park. Together, this team has approximately 50 person-years of on-the-ground experience in the Death Valley Wilderness. This team conducted four face-to-face meetings and had several phone and email conversations in developing the map products described in this report. All decisions about developing the map were made by team consensus.

This report provides an in-depth discussion of how the wilderness character map was developed. It is divided into three major sections:

- Overview of developing the wilderness character map – describes the conceptual foundation for how the map was developed.
- Methods – describes the measures used to represent the degradation of wilderness character, along with different data sources, data processing, rationale for weighting, and cautions when interpreting results.
- The Wilderness Character Map – discusses some of the patterns revealed in the wilderness character map, uncertainty in the map products, , approaches to improving map development, and final concerns about the overall process.

In this report we have kept the use of technical terms to a minimum and provide technical explanations for several terms with footnotes. In addition to this report, a technical report written for GIS specialists is available at http://wilderness.net/index.cfm?fuse=toolboxes&sec=WC.

Overview of Wilderness Character Map Development

Our objective is to develop a GIS-based approach to spatially depict the quality of wilderness character in DEVA. The interagency strategy for monitoring wilderness character, as described in *Keeping it Wild* (Landres et al. 2008), is used as the basis for developing this approach. This document identifies four qualities of wilderness character: natural, untrammeled, undeveloped, and opportunities for solitude or a primitive and unconfined type of recreation, as well as a set of indicators and measures to evaluate their condition. Spatial datasets, which are obtained from a variety of sources, are processed into “data inputs” and assigned and weighted under an appropriate indicator. The indicators for each quality are combined together to produce a map for that quality, and the four maps, one for each quality, are in turn combined to create an overall map of wilderness character in DEVA (Figure 2).

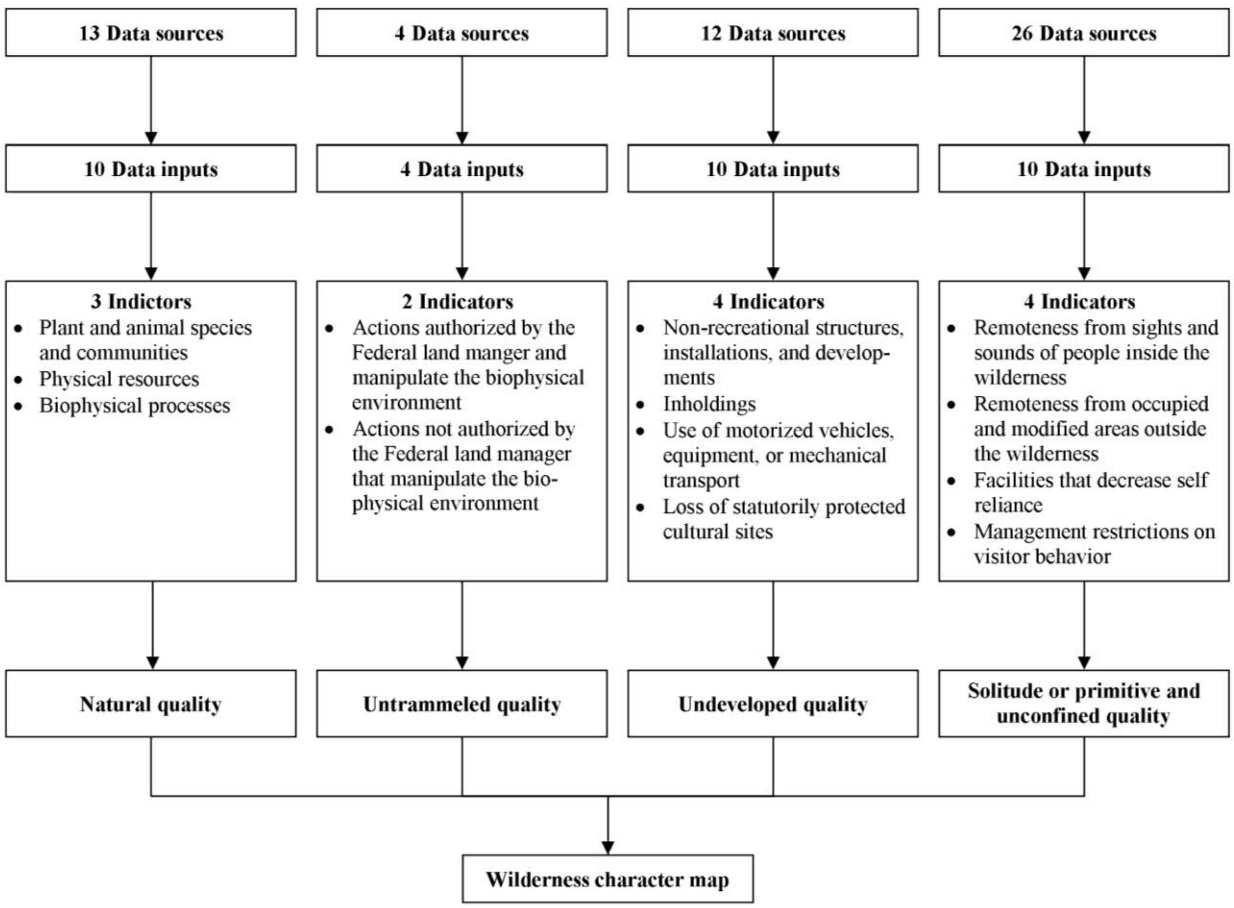

Figure 2. *Flow chart for developing the wilderness character map.*

A total of 51 datasets[1] are used for delineating wilderness character in DEVA and comprise local, regional, and national spatial data at varying scales, accuracy, and completeness (as is often the case with geospatial datasets). This variation may reduce the integrity of the map products, however, initial dataset quality is identified and recorded, and as improved data become available these can replace older data. This procedure builds in flexibility and adaptability to differences in data quality and availability.

The datasets from the various sources are processed, converted to raster grids, and standardized[2] into data inputs. These represent features, conditions, and actions that degrade the quality of wilderness character. Maps of the DEVA wilderness begin from a baseline condition of optimal wilderness character and data inputs record where each quality has been degraded. For example, the exotic species data input records (under the plant and animal species and communities indicator) where the natural quality has been degraded. Each data input is formatted to depict the spatial extent of degradation on a standardized scale. Creating a standardized range of values for all data inputs allows them to be evaluated together on a common relative scale (Carver et al. 2008). For example, the soundscape and night sky maps are each depicted using different units of measure (decibel vs. millilux), and so cannot be directly compared without standardization. Higher values of standardized data inputs represent “degraded” conditions and lower values represent “optimal” conditions.

The resolution of data inputs are set at 100 m, albeit some datasets such as air quality and night sky have a significantly lower native resolution. Although using a 100 x 100 m pixel size may be deemed too coarse for many features in DEVA (e.g. springs), the sheer size of the DEVA wilderness means that choosing a lower resolution would make these features impossible to see when viewing the wilderness character maps in their entirety.

A hierarchical framework of measures and indicators taken from *Keeping it Wild* (Landres et al. 2008), is used to sort each data input under an appropriate wilderness quality. For example, under the natural quality of wilderness character, the exotic species data input informs the measure “abundance, distribution and, or number of invasive non-indigenous species” of the “plant and animal species communities” indicator. The natural quality also includes “physical resources” and “biophysical processes” indicators and related measures.

The data inputs under each indicator are added together using a weighting regime determined by the DEVA staff. These weights reflect the importance of a data input in relation to the others under a particular indicator. The indicators are added together under their respective qualities to produce four maps, one for each quality of wilderness character. These four maps are then added together to produce a single map of wilderness character for DEVA.

A number of cautions are presented for each data input in the methods section, which are necessary for creating and interpreting the wilderness character maps. These cautions describe

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[1] This total is smaller than the sum of the data sources in Figure 2 because some datasets are used to map wilderness character for more than one quality.

[2] Standardization of data inputs is achieved using a linear rescaling of the input values onto a 0-255 scale on an equal interval basis.

and qualify the decisions made when formatting the datasets into inputs and explain the calibration of the parameters for the travel time and viewshed models.

Methods

The four qualities of wilderness character, as defined in *Keeping it Wild* (Landres et al. 2008), are mapped using a combination of readily available datasets and the latest GIS-based techniques. The maps are produced for all lands within the Death Valley National Park boundary (excluding the disjunct Devils Hole Unit), with additional buffer zones extending beyond the park boundaries to 15 and 30 km respectively for running the travel time and viewshed models. These buffer zones are necessary to account for edge effects from visible human features and points of access immediately outside the park. The data sources, notes on processing, and associated cautions are described for all the data inputs that inform the four wilderness qualities. Notes for relevant technical GIS terms and processes are included as footnotes.

Selecting data inputs was an iterative, group decision-making process that began by first identifying possible measures, then reviewing these for relevance to the indicator, and determining data availability and data quality. In general, only measures that were relevant and data that were available and of sufficient quality were included. However, some measures that were important in DEVA had insufficient or non-existent data. DEVA staff acknowledged these "missing" measures under each applicable indicator, and as data improves or becomes available, the wilderness character map can be rerun to include these data.

A number of basic processing tasks are performed for datasets in ArcGIS before they can be used as data inputs to create the wilderness character map. Values are assigned to the vector datasets to represent their spatial impact in DEVA. These vectors are then converted to grids at 100 m resolution, whereby their extent is represented by the above values and the rest of the park is reclassed as 0. Some of the vector datasets may have a range of values depending on the data they represent. For example, the data input "mines" has a value of 1 assigned to smaller mining sites and a value of 2 to larger open pit mines (to represent their respective impact on the natural quality), and the rest of the park is classed as 0. The raster datasets, namely land cover, air quality, night sky, soundscape, and the travel time and viewshed models, retain their native resolution and are clipped at the park boundary. All the grids are stretched to a standardized range of values and these data inputs are then projected in ArcGIS using the NAD 1983 UTM Zone 11N coordinate system. Unless stated otherwise, all point data were assumed to affect only the location of where those points occur.

Each data input is "weighted" (or assigned a percentage) out of a total of 100 under each indicator to reflect its importance in relation to other data inputs. For example, springs are an important resource in a desert environment and their condition will affect other features such as vegetation and animal presence. Therefore, the springs input is assigned a relatively high weight as their modification or degradation has a significant impact on the natural quality of wilderness character in DEVA. An iterative process is used to refine all weightings by asking park staff to review the map outputs, modifying the weighting scheme as needed, and then rerunning and reviewing the maps until results are satisfactory. Weights were also provided for "missing" measures should they become available in the future. These weights, and their impact to existing data input weights, are indicated in brackets in Tables 2 and 4.

All maps are displayed using the "minimum – maximum" stretch method[3] unless otherwise stated. The color ramp depicts areas of intact, high quality wilderness character as green and degraded or deteriorated areas of wilderness character as brown.

Natural Quality

The natural quality defines wilderness as containing ecological systems that are substantially free from the effects of modern civilization. This quality is degraded by the intended or unintended effects of modern people on the ecological systems inside the wilderness since it was designated (Landres et al. 2008).

Indicators and Data Inputs

Data inputs were selected for each of the three indicators recommended in *Keeping it Wild* (Landres et al. 2008). The following indicators, with their data inputs and relevance to the natural quality, were used:

Indicator: Plant and animal species and communities

- Land cover type – this is a direct measure of degradation to the natural quality because some cover types are known to be unnatural in DEVA.
- Exotic plant and animal species – this is a direct measure of the degradation of the natural quality because the presence of these species is unnatural in DEVA.

Indicator: Physical resources

- Ozone (Air quality) – this is a direct measure of the degradation of the natural quality because ozone, recorded as annual average ozone concentration (ppm), is known to affect sensitive plants.
- Wet deposited nitrate and ammonium (Air quality) – this is a direct measure of the degradation of the natural quality because this input, recorded as the total annual wet deposition (grams N/hectare) of particulate and nitrate, is primarily due to urban influences in the region and is known to affect water, soils, and plants.
- Mining sites – mining sites, which include shafts, adits, prospects, and pits, are unnatural features of the landscape.
- Springs – springs are important natural features but many have been manipulated by humans to increase, divert, or impound natural flows for consumptive purposes. Such alterations are a degradation of the natural quality.
- Sky brightness above natural levels (Night sky) – this is an interpolated surface based on actual observations of the total light pollution as a fraction above what would be the natural level.

Indicator: Biophysical processes

- Grazing – there is one remaining cattle grazing allotment within the park and it has been grazed continuously for over 140 years. This data input represents the unnatural effects of long-term vegetation trampling, hoof impacts to soil resources, and herbivory in the area

[3] The stretch method defines the type of histogram stretching that will be applied to raster datasets to enhance their appearance. The minimum – maximum stretch applies a linear stretch on the output minimum and output maximum pixel values, which are used as endpoints for the histogram (ESRI Inc. 2008).

that has been grazed (and although grazing appears in *Keeping it Wild* as a measure of the plant and animal species and communities indicator, this data input is recorded under biophysical processes due to the pervasive and intense nature of impacts from domestic grazing in desert landscapes).

- Guzzlers – these are artificial water sources built and maintained by modern humans for the purpose of augmenting water for wildlife use, most typically to increase the population size of game species. These were all pre-existent on lands that were added to the park in 1994. Their presence causes an unnatural distribution of animals, potentially unsustainable population sizes, and they serve as a potential vector for disease.
- Fire regime – this is the departure from the natural fire regime, which is a general classification of the role fire would play across a landscape in the absence of modern human intervention, but including the influence of aboriginal burning.
- Climate change – this data is not currently available, but ideally would measure the influence of anthropogenic climate change as a deviation from natural conditions.

Data Sources, Processing, and Cautions

A wide variety of data were used to create the natural quality map, including data on plants, animals, air and water quality, mining features, night sky, and artificial water features. These data sources are both vector and raster data and exhibit high variation in scale, mostly high levels of accuracy, and differing levels of completeness (Table 1). Two additional data inputs: fire regime and climate change, were identified but because data is inadequate or currently unavailable, were not included.

Table 1. *Natural quality datasets.*

Dataset	Source	Type	Scale	Accuracy	Completeness
Landcover	Central Mojave Mapping Project/USGS NVC	Raster	5 ha/ 30 m	High	Medium
Exotic plants	NPS APCAM	Polygon	100 m	High	Medium
Burros	DEVA	Polgon	100 m	High	Low
Air Quality - Ozone and wet desposited NO3 and NH4	Air Resources Division, NPS	Raster	12 km	Medium	High
Mining sites	NPS AML/USGS/DEVA	Point	100 m	High	Low
Open pits	DEVA	Polygon	100 m	High	High
Springs	DEVA	Point	10 m	High	High
Nightsky - deviation from natural	Night Sky Team, NPS	Raster	1 km	High	Medium
Grazing	DEVA	Polygon	100 m	High	High
Guzzlers	DEVA	Polygon	100 m	High	High
Fire regime*	FRCC	n/a	n/a	Unsuitable	n/a
Climate change*	n/a	n/a	n/a	n/a	n/a

*No data

Land cover

- *Sources*: Raster datasets from Central Mojave Mapping Project (CMMP) (Thomas et al. 2004) and USGS National Vegetation Classification Standard (NVCS).
- *Processing*: The CMMP data covers 95% of the park and is used as the primary land cover map. This map is used in combination with the USGS NVCS dataset to provide a complete land cover map for DEVA. Land cover classes are ranked on a scale of 1-5 according to their natural condition. Classes such as urban, agricultural, and developed areas receive high rankings as they show high deviation from natural conditions. Shrubland, high elevation woodland, and sparsely vegetated areas receive low rankings as they show minimal deviation from an original natural state. A table with these rankings is included in Appendix A.
- *Cautions*: Of the two data sources, the CMMP provides the most recent and accurate land cover map for DEVA. Although data gaps occur in small areas to the north of the park and in all lands located in Nevada, this map is considered most representative of current land cover by park staff.

Exotic species - plants

- *Sources*: Polygon dataset from the NPS Alien Plant Control and Monitoring Database (APCAM) based on GPS data collection and North American Weed Management Association data standards.
- *Processing*: Locations where exotic plant species occur in DEVA are given a value of 1.
- *Cautions*: None.

Exotic species - animals

- *Sources*: Polygon dataset created by Linda Manning, DEVA wildlife biologist.
- *Processing*: This dataset depicts known burro and feral horse ranges in DEVA. A value of 1 is given to locations where these animals are present yet dispersed and a value of 2 to locations where these animals are concentrated (due to features such as water sources, vegetation and topography). These values reflect the impact the animals have through trampling, droppings, and grazing. Grids are created for both species and weighted together as follows: burros = 75% because they are more prevalent and concentrated than feral horses in DEVA, and feral horses = 25%. A multi-criteria evaluation model was developed and considered as an alternate input but was deemed unsuitable by the wildlife biologist because it did not accurately represent her experience and knowledge of the distribution of these species.
- *Cautions*: Areas of high and low impact by exotic animal species are based on the experience and knowledge of the park wildlife biologist, whereas a different person may identify different areas and/or different impacts.

Ozone and wet deposited nitrate and ammonium (Air Quality)

- *Sources*: Raster datasets from the NPS Air Resource Program. Although there is data available from the park's single air quality monitoring station, it was not possible to use this data in conjunction with other air quality monitoring stations in the region to extrapolate values for the rest of the park. Instead, the air quality rasters were obtained from the national dataset of modeled air quality values at a low resolution of 12 km.
- *Processing*: Re-project raster to NAD 1983 UTM Zone 11N coordinate system.
- *Cautions*: Despite the low resolution of these grids (Figure 3), it was considered important to include these data to acknowledge how processes outside the park impact natural conditions within the park.

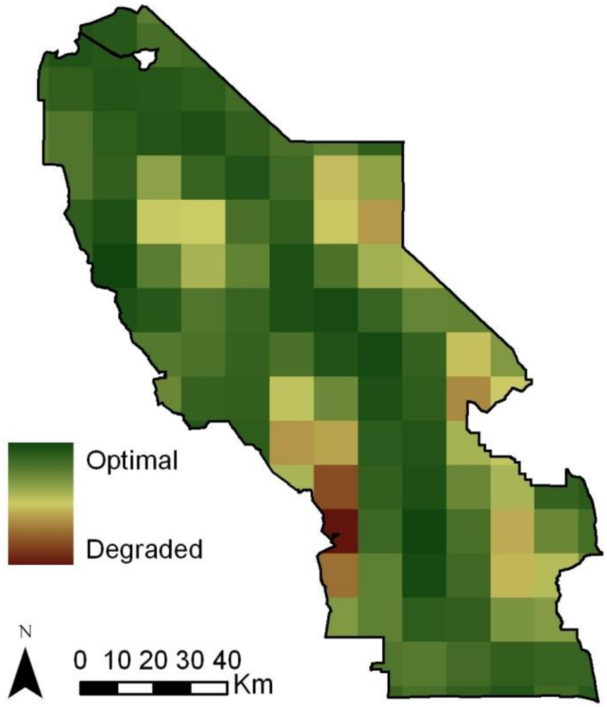


Figure 3. *Wet deposited nitrate and ammonium in DEVA. Green depicts optimal quality and brown depicts degraded quality.*

Mining sites

- *Sources*: NPS Abandoned Mineral Lands (AML) point dataset, USGS mining point dataset (the name and source of this data is unknown as is no longer available for download), DEVA GIS polygon dataset (open pits).
- *Processing*: Three data sources and two vector types are combined into one input. The point data (depicting the locations of the numerous small mining features occurring in DEVA) are assigned a value of 1 and the polygon data (depicting the locations of the large open pit mines) are assigned a value of 2. These values represent the different impacts of mining features on the natural quality in DEVA.
- *Cautions*: Converting the mining point data to a grid at 100 m resolution may appear to overestimate the effects of a number of small and inconspicuous mining features on the natural quality. The majority of these mining features, however, are clustered together and do have considerable local impact on the natural quality. Therefore, 100 m resolution was considered an appropriate scale in the context of the park. It must also be acknowledged that the AML dataset is a work in progress and represents only a quarter of all mining features in DEVA. The USGS mining dataset has no metadata or additional information supplied with the GIS layer, however, this dataset accurately depicts mining sites that were not present in the incomplete AML dataset.

Springs

- *Sources*: The DEVA springs database, created by the Mojave Network Inventory and Monitoring Program in 2007, provided point data for spring locations in DEVA. However, the interpretation of spring manipulations or impacts was determined to be inadequate for use because of a lack of sufficient reporting about what data were collected and how they were collected. Descriptions of spring manipulations and impacts were therefore developed by Charlie Callagan, DEVA Wilderness Coordinator, based on his personal knowledge of the sites.
- *Processing*: Locations of springs with a known high deviation from natural condition occurring in DEVA are given a value of 1.
- *Cautions*: The springs data only include sites that are known by park staff to have a very high deviation from their natural condition. Although the majority of springs within DEVA have been manipulated to some extent from their natural condition, current data on spring conditions is incomplete.

Sky brightness above natural levels (Night sky)

- *Sources*: Raster dataset created by Dan Duriscoe, NPS Night Sky Team. The grid is a spline surface model interpolated from 13 observation points.
- *Processing*: Re-project raster to NAD 1983 UTM Zone 11N coordinate system.
- *Cautions*: This data input represents temporal impacts to the natural quality that are only noticeable at night. In contrast to night sky data inputs described under the solitude quality of wilderness character, this data input represents all sky brightness above natural levels, as such deviations may impact various natural processes or activities of nocturnal species regardless of whether such unnatural brightness is detectable to the human eye. DEVA staff decided to use a different night sky metric under the solitude quality.

Grazing

- *Sources*: DEVA GIS polygon dataset of allotment boundaries for Hunter Mountain Allotment.
- *Processing*: The location of the grazing area occurring in DEVA is given a value of 1.
- *Cautions*: This data input assumes every hectare of wilderness within the grazing allotment has been used by cattle and therefore degraded. The degree of degradation, however, likely varies over space and time due to changes in concentrations and dispersal of animals. As data necessary to articulate these variations into accurate geospatial data is unavailable, the entire allotment was assigned the same value. Given the 140+ year grazing history of this allotment, it is likely the entire area has been degraded to some degree from natural conditions.

Guzzlers (artificial water sources previously installed for game species)

- *Sources*: Point data based on communication with Linda Manning and a 2004 Sheep Guzzlers Condition and Use Assessment.
- *Processing*: Five concentric 1 km buffer zones are extended from the location of each guzzler occurring in DEVA, which are in turn assigned a decreasing range of values from the center of the guzzler (a value of 5 for the closest zone, and a value of 1 for the zone furthest from the center). These values represent the impact to the natural quality caused by animals being drawn unnaturally to this artificial water source. The different zones

emphasize different concentrations of impacts from animal grazing, droppings, and trampling, based on distance from the guzzler.
- *Cautions*: The different zones were created through consultation with park staff who observed impacts on natural conditions due to the presence of guzzlers. The concentric buffer zones are a coarse estimate of impacts and were not quantified on the ground.

Fire regime
- *Sources*: Fire Regime Condition Class (FRCC) dataset (Rollins 2009).
- *Processing*: None.
- *Cautions*: The FRCC dataset has been developed as an interagency tool for determining the degree of departure from reference condition vegetation, fuels, and disturbance regimes. However, park staff consider this data source unsuitable as a data input because it does not accurately represent desert environments in general, or known conditions in DEVA.

Climate change
- *Sources*: Data not sourced.
- *Processing*: None.
- *Cautions*: A climate change data input is not included because this would require a complex amalgamation of climate data from a variety of sources and models, and the level of certainty about these analyses is currently unknown.

Weighting
The first page of the methods section describes the underlying principle for using a weighting system. A rationale is provided for the assigned weight of each data input (Table 2). The "weighted" data inputs under each indicator total 100. Although data for fire regime and climate change are unsuitable or unavailable, these "missing" data inputs are still assigned weights. In the future, should the data improve or become available, these data inputs can be added to a rerun of the wilderness character map. The revised weights for indicators with missing data are recorded in brackets in Table 2.

Table 2. *Indicators and data inputs for the natural quality with weights and rationale.*

Indicator	Input	Weight	Rationale
Plant and animal species and communities	Land cover	50	Overriding descriptor of the landscape
	Exotic plants	25	Equal weighting because both plant and animal exotic species degrade habitat quality
	Exotic animals	25	
Physical resources	Ozone (Air quality)	5	Minor issue due to relatively low ozone concentrations and a lack of ozone-sensitive species
	Wet deposited nitrate and ammonium (Air quality)	10	Important due to correlation with increased red brome invasion and altered fire regimes
	Mining sites	30	Pervasive impacts across park
	Springs	35	Very important resource for sustaining desert life
	Night sky – deviation from natural	20	Important as degradation may impact nocturnal species
Biophysical processes	Grazing	67 [30]	Important and long term issue that has known detrimental impacts to desert soils and plants
	Guzzlers	33 [15]	Localized impacts
	Fire regime (FRCC)*	[25]	Important in the desert due to recent and widespread increases in fire frequency and fire size
	Climate change*	[30]	Very important in the desert due to effects of hotter temperatures and unresolved changes to timing and amount of precipitation
	* No data	300	

Maps

The weighted data inputs for each indicator are added together using a raster calculator to create separate maps for plant and animal species and communities, physical resources, and biophysical processes (Figure 4). After these indicator maps are created, the raster calculator is used to add the three indicator maps together to create the natural quality map (Figure 5).

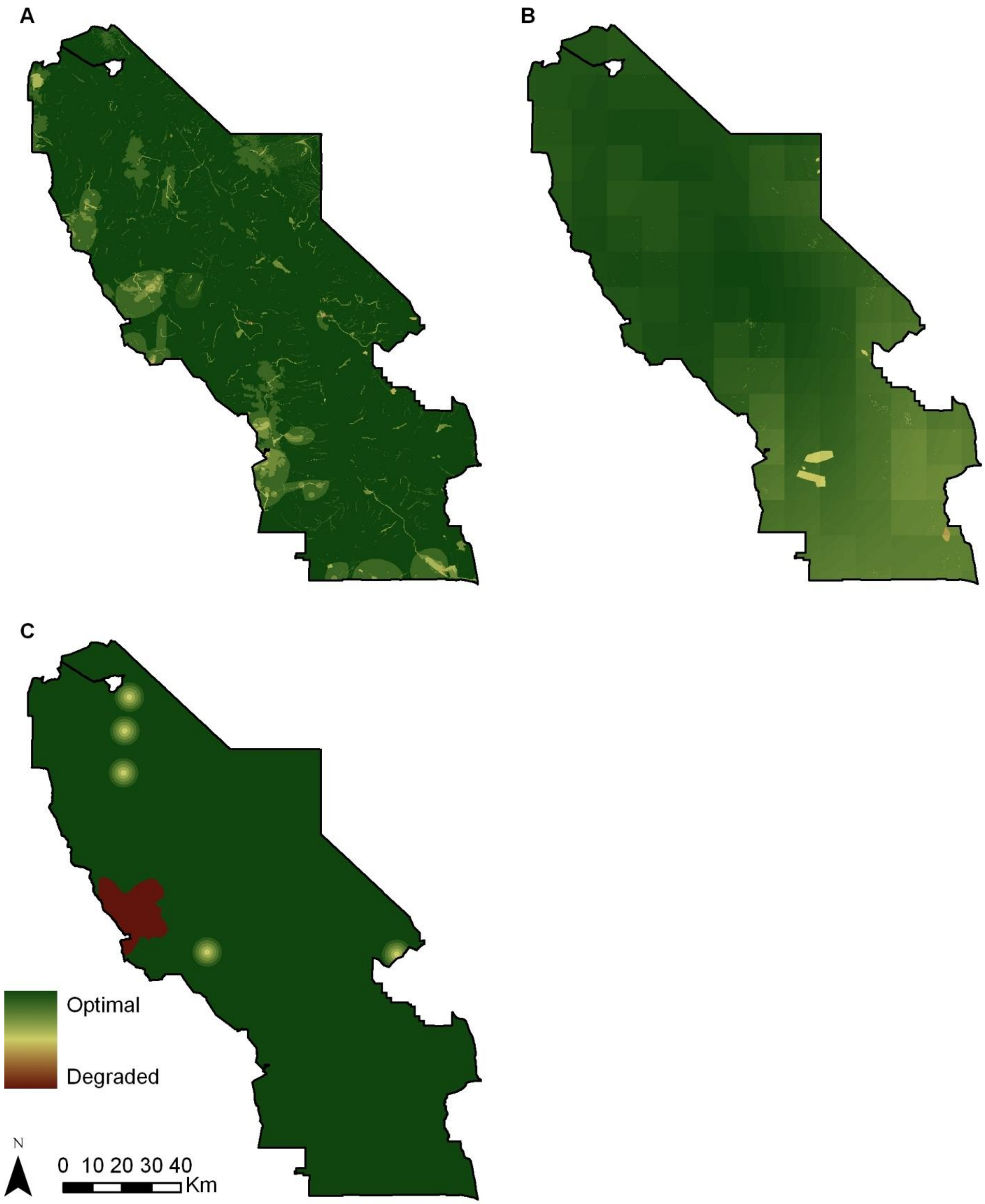


Figure 4. *Indicator maps for (A) plant and animal species and communities, (B) physical resources, and (C) biophysical processes. Green depicts optimal quality and brown depicts degraded quality.*

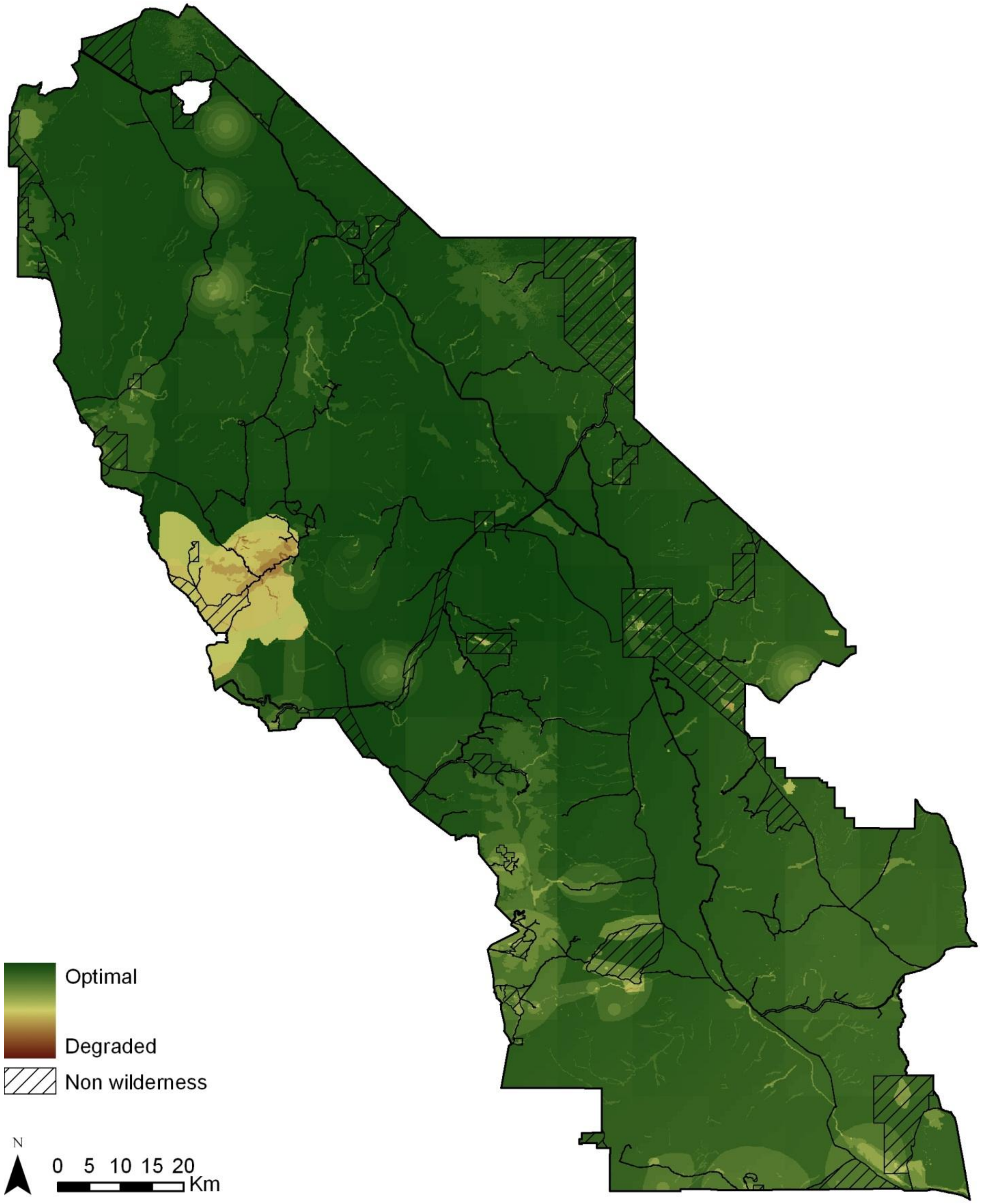


Figure 5. *Natural quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.*

Untrammeled Quality

The untrammeled quality defines wilderness as essentially unhindered and free from modern human control or manipulation. The untrammeled quality is degraded by actions that intentionally manipulate or control ecological systems, whereas the natural quality is degraded by the intentional and unintentional effects from actions taken inside wilderness, as well as from external forces on these systems (Landres et al. 2008).

There are important temporal questions to consider when developing a map of this quality. DEVA staff decided that the baseline for including management actions would be 1994, the year DEVA was designated wilderness. This decision implies that all management actions that occurred in the past 17 years will be included in the current wilderness character map, even though the action no longer occurs. This captures the spatial dimension of actions that occurred in the past, however, the protocol in *Keeping It Wild* only counts actions during the year in which they occur. Other parks may choose to follow this protocol or devise a more appropriate method for counting management actions.

Indicators and Data Inputs

Data inputs were selected for each of the two indicators recommended in *Keeping it Wild*. The following indicators, with their data inputs and relevance to the untrammeled quality, were used:

Indicator: Actions authorized by the Federal land manager that manipulate the biophysical environment

- Fire suppressions (natural ignitions) – fire perimeters of natural ignitions that were actively suppressed for protection of some other value at risk. The suppression of natural ignitions represents deliberate interference with natural processes and thus degrades the untrammeled quality.
- Weed treatments – locations where weeds have been treated using chemical, mechanical, or manual methods. Such treatments, regardless of method, represent a deliberate manipulation of plant communities and thus degrade the untrammeled quality.
- Burro removals – locations where burros were gathered and removed from the park, including actual loading locations as well as areas where they were captured. Similar to weed treatments, actions to remove feral animals from the park represent a deliberate manipulation of the park's fauna and thus degrade the untrammeled quality.
- Mine closure/bat gate installations – locations where gates, cupolas, or other structures were installed on mine openings for the purpose of mitigating mine hazards while accommodating wildlife use. The location and design of such structures alters the suitability of the site for use by bats, rodents, ringtails, and other wildlife, and thus degrades the untrammeled quality.
- Landscape manipulations that alter water flow – locations where natural water flows have been deliberately diverted through engineered structures in order to mitigate a risk to downstream infrastructure. The design and location of such water diversions deliberately alters natural surface flows as well as groundwater recharge and thus degrades the untrammeled quality.

Indicator: Actions not authorized by the Federal land manager that manipulate the biophysical environment

- Poaching incidents – known and recorded law enforcement incidents where plants or animals were illegally removed. The illegal removal of plants or animals degrades the untrammeled quality.

Data Sources, Processing, and Cautions

The untrammeled quality map is composed of four data inputs, reflecting the small number of modern human actions impacting the untrammeled quality of the DEVA wilderness (Table 3). Two additional data inputs: manipulation of water flows and poaching incidents, were identified but not included due to a lack of relevant data.

Table 3. *Untrammeled quality datasets.*

Dataset	Source	Type	Scale	Accuracy	Completeness
Fire suppressions (natural ignitions)	DEVA	Polygon	100 m	High	High
Weed treatments	NPS APCAM	Polygon	100 m	High	High
Burro removals	DEVA	Point	100 m	High	Low
Mine closure/bat gate installations	DEVA	Point	100 m	High	Moderate
Landscape manipulations that alter water flow*	n/a	n/a	n/a	n/a	n/a
Poaching incidents*	n/a	n/a	n/a	n/a	n/a

* No data

Fire suppressions

- *Sources*: GPS fire perimeters as recorded in the DEVA fire history database.
- *Processing*: Locations where fire suppression has occurred in DEVA are given a value of 1.
- *Cautions*: These actions are recorded as trammeling for a period of only one year, as these management decisions are seen as a short-term tradeoff for a long-term benefit to the natural quality. For this initial map, however, all recorded trammeling events from 2000 onwards are included.

Weed treatments

- *Sources*: Polygon dataset from the NPS APCAM database.
- *Processing*: Locations where weed treatments have occurred in DEVA are given a value of 1.
- *Cautions*: None.

Burro removals

- *Sources*: Point dataset providing approximate locations of burro removal sites as recorded in the 1999, 2000, and 2001 Burro Capture Summary Reports of DEVA.
- *Processing*: Locations where burro removals have occurred in DEVA are given a value of 1.
- *Cautions*: Uncertain locations of known removals have not been placed.

Mine closure/bat gate installations

- *Sources*: DEVA GIS point dataset.
- *Processing*: Locations where mine closures/bat gates have been installed in DEVA are given a value of 1.
- *Cautions*: None.

Landscape manipulations that alter water flow

- *Sources*: Data not sourced.
- *Processing*: None.
- *Cautions*: There are currently no data available for these types of manipulations, however, consequent high surface run-off from infrequent yet intense rain storms have a significant impact on the natural quality. Further investigation using modeling techniques may help identify where manipulated land surfaces (e.g., adjacent road corridors and their attendant culverts and ditches) alter the natural water flow.

Poaching incidents

- *Sources*: Incidents of poaching are known to have occurred in DEVA in recent years, but no precise location data exists.
- *Processing*: None.
- *Cautions*: None.

Weighting

The first page of the methods section describes the underlying principle for using a weighting system. A rationale is provided for the weight of each data input (Table 4). The “weighted” data inputs under each indicator total 100. Although data for landscape manipulations that alter water flow and poaching incidents are unsuitable or unavailable, these “missing” data inputs are still assigned weights. In the future, should the data improve or become available, these data inputs can be added to a rerun of the wilderness character map. The revised weights for indicators with missing data are recorded in brackets in Table 4.

Table 4. *Indicators and data inputs for the untrammeled quality with weights and rationale.*

Indicators	Input	Weight	Rationale
Authorized actions	Fire suppressions (natural ignitions)	25 [20]	Equal weights for all data inputs because all trammeling actions have the same effect on the untrammeled quality.
	Weed treatments	25 [20]	
	Burro removals	25 [20]	
	Mine closure/bat gate installations	25 [20]	
	Landscape manipulations that alter water flow*	[20]	
Unauthorized actions	Poaching incidents*	[100]	
	* No data	100 [200]	

Maps

The weighted data inputs are added together using a raster calculator to create the authorized actions indicator map. As there are currently no data for unauthorized actions, this map also serves as the untrammeled quality map (Figure 6).

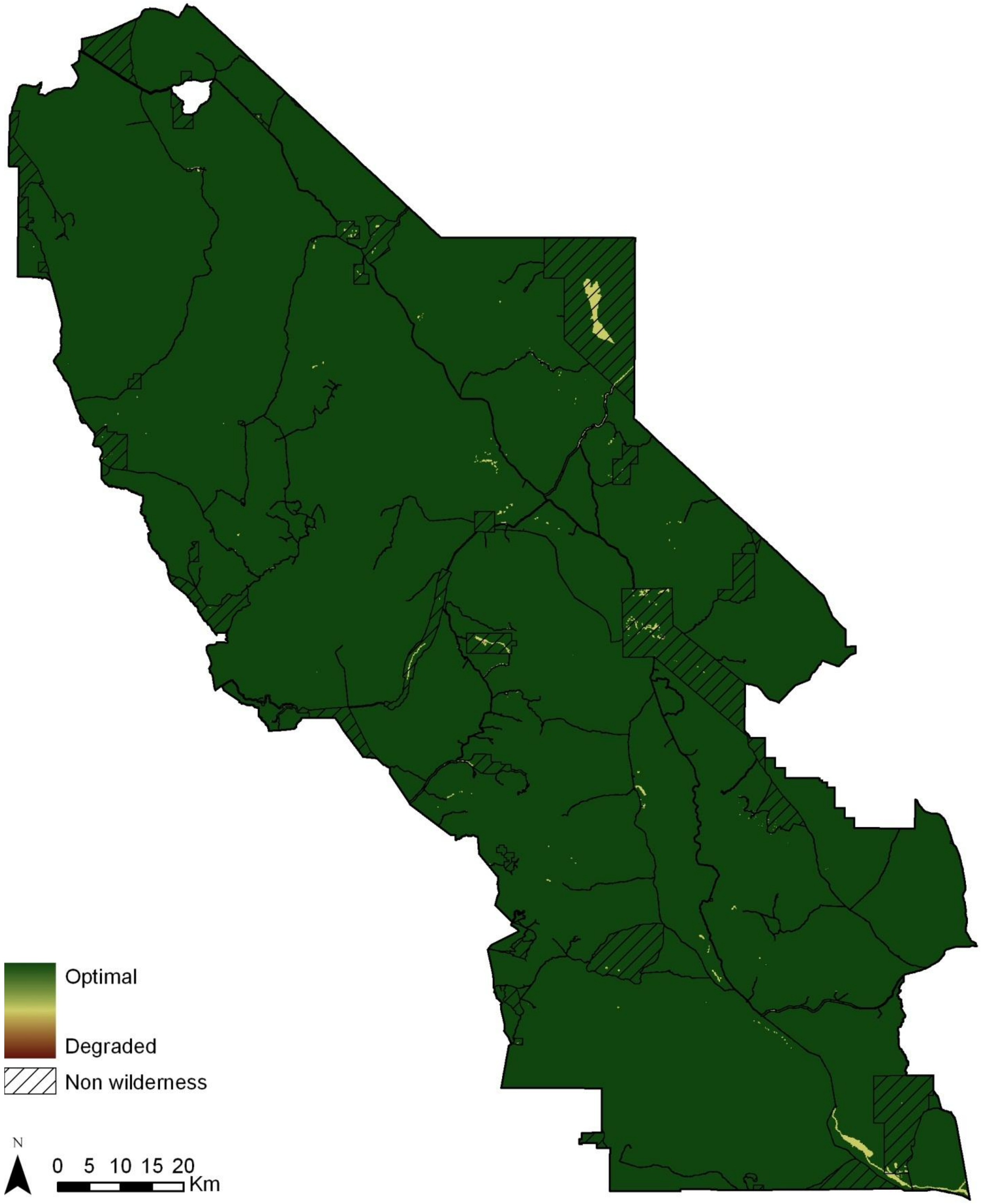


Figure 6. *Untrammeled quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality. Please note that this is also the map for the authorized actions indicator.*

Undeveloped Quality

The undeveloped quality defines wilderness as an area without permanent improvements or modern human occupation. This quality is degraded by the presence of non-recreational structures and installations, habitations, and by the use of motor vehicles, motorized equipment, or mechanical transport, because these increase people's ability to occupy or modify the environment (Landres et al. 2008a).

Indicators and Data Inputs

Data inputs were selected for each of the four indicators recommended in *Keeping it Wild*. The following indicators, with their data inputs and relevance to the undeveloped quality, were used:

Indicator: Non-recreational structures, installations, and developments

- Installations (including guzzlers and fences) – locations of guzzlers, fences, and utility and communication systems. These are more or less permanent installations whose presence degrades the undeveloped quality.
- Unauthorized installations/debris – locations of junk piles, trash dumps, abandoned vehicles, etc. The presence of such detritus is an obvious sign of modern human occupation and activity, and thus degrades the undeveloped quality. If such material is determined to be a significant cultural resource then it would not be included here.
- Borrow pits – locations of large excavated pits associated with industrial mining activities and road building. These pits are an obvious sign of modern human occupation and thus degrade the undeveloped quality.

Indicator: Inholdings, lands not owned or that contain mineral rights not wholly owned by the NPS. Such lands have the potential to be developed by non-NPS interests, which would degrade the undeveloped quality, although the location and magnitude of such impacts are hard to pinpoint because future development is speculative.

- State inholdings with road access – state-owned land parcels that can be accessed by open roads.
- State inholdings with no road access or held for wildlife – state-owned land parcels that have no direct road access or are specifically managed for wildlife.
- Private inholdings – privately-owned land parcels.
- Unpatented inholdings – a parcel for which an individual has asserted a legal right of possession to develop a mineral deposit in the future (subject to additional policies and procedures), although no land ownership is conveyed.

Indicator: Use of motor vehicles, motorized equipment, or mechanical transport

- Off-road vehicle (ORV) trespass – known locations where off-road vehicle trespass has occurred in the recent past. Such incidents of motorized vehicle trespass, as well as the often long-lasting visual effects of such trespass, degrade the undeveloped quality.
- Administrative uses – authorized use of motorized equipment, such as chainsaws, for specific purposes at specific times and locations during either emergency incidents or following a minimum requirements decision analysis for non-emergency uses. The authorized use of motor vehicles, motorized equipment, or mechanical transport degrades the undeveloped quality.

Indicator: Loss of statutorily protected cultural resources

- Damaged or destroyed cabins – cabins that are eligible or potentially eligible for listing on the National Register of Historic Places that have been damaged or destroyed as indicated by condition assessments and staff reports.

Data Sources, Processing and Cautions

The undeveloped quality datasets are all vector data, of high scale, and generally of moderate to high accuracy and completeness (Table 5).

Table 5. *Undeveloped quality datasets.*

Dataset	Source	Type	Scale	Accuracy	Completeness
Installations	DEVA	Point	100 m	Moderate	Low
Guzzlers	DEVA	Point	100 m	High	High
Fences	NPS ASMIS	Polyline	100 m	Moderate	Moderate
Unauthorized installations/debris	DEVA	Point	100 m	Moderate	Low
Borrow pits	DEVA	Point	100 m	High	Moderate
Inholdings	BLM GCDB	Polygon	100 m	High	High
ORV trespass	DEVA	Polygon	100 m	Moderate	Low
Administration uses	DEVA	Point	100 m	Moderate	Moderate
Damaged or destroyed cabins	NPS ASMIS	Point	100 m	High	High

Installations (including guzzlers and fences)

- *Sources*: DEVA generated datasets. Installation point data was created using topographic maps or aerial photographs. Guzzler point data is based on communication with Linda Manning and a 2004 Sheep Guzzlers Condition and Use Assessment. Fence polyline data is from the NPS Archeological Sites Management Information System (ASMIS).
- *Processing*: Locations where installations occur in DEVA are given a value of 1.
- *Cautions*: The guzzler data input for the natural quality depicts the impact guzzlers have on ecosystems from grazing, trampling, and droppings by animals attracted to the artificial water source. For the undeveloped quality, the guzzler data input only records the location of the guzzler, which is considered a development or installation in wilderness.

Unauthorized installations/debris

- *Sources*: Point dataset created by Charlie Callagan, Wilderness Coordinator.
- *Processing*: Locations where unauthorized installations and debris occur in DEVA are given a value of 1.
- *Cautions*: The debris data input is largely incomplete and only records particular objects that have been selected for removal by wilderness managers. Using a single pixel point to represent debris that may be scattered over the land may also underestimate the total impact of this dataset on the wilderness character map. As this data source is updated, it will more accurately represent the undeveloped quality.

Borrow pits

- *Sources*: DEVA polygon dataset.

- *Processing*: Locations where borrow pits areas occur in DEVA are given a value of 1.
- *Cautions*: None.

Inholdings

- *Sources*: Bureau of Land Management's Geographic Coordinate Database (GCDB).
- *Processing*: The dataset was queried to create polygons for state, private, and unpatented inholdings. State inholdings and road data were analyzed (using the "Select By Location" tool in ArcGIS) to determine which polygons were accessible by roads. Locations where all types of inholdings occur in DEVA are given a value of 1.
- *Cautions*: This data delineates areas in the wilderness where development may occur. These inholdings typically pre-date wilderness designation and have different likelihoods of development as depicted in the weighting table. However, it is important to acknowledge that at present these parcels of land are not developed and will appear no different from undeveloped wilderness.

ORV trespass

- *Sources*: Polygon dataset heads-up digitized[4] by Charlie Callagan, DEVA Wilderness Coordinator, using National Agriculture Imagery Program (NAIP) imagery.
- *Processing*: Locations where ORV trespasses have occurred in DEVA are given a value of 1.
- *Cautions*: None.

Administrative uses

- *Sources*: Point dataset created by Charlie Callagan, DEVA Wilderness Coordinator.
- *Processing*: Locations where administration uses have occurred in DEVA are given a value of 1.
- *Cautions*: None.

Damaged or destroyed cabins

- *Sources*: Point dataset created by Leah Bonstead, DEVA Archeologist, using the ASMIS dataset.
- *Processing*: Locations of damaged cabins in DEVA are given a value of 1 and locations of destroyed cabins in DEVA are given a value of 2.
- *Cautions*: None.

Weighting

The first page of the methods section describes the underlying principle for using a weighting system. A rationale is provided for the weight of each data input (Table 6). The "weighted" data inputs under each indicator total 100.

[4] Digitizing directly onto a map on the computer screen using the mouse cursor.

Table 6. *Indicators and data inputs for the undeveloped quality with weights and rationale.*

Indicator	Input	Weight	Rationale
Non-recreational structures, installations, and developments	Installations (including guzzlers and fences)	55	Big footprints and large areas of impact
	Unauthorized installations/debris	10	Small footprints, scattered
	Borrow pits	35	Big footprints, but few
Inholdings	State inholdings with road access	15	Limited potential for development
	State inholdings with no road access or held for wildlife	5	Least likely to be developed
	Private inholdings	60	Most likely to be developed
	Unpatented inholdings	20	Limited potential for development, but more than state inholdings with road access
Use of motor vehicles, motorized equipment, or mechanical transport	ORV trespass	60	Frequent occurrence with potential for long lasting impacts
	Administrative uses	40	Limited in space, time, and effect on land
Loss of statutorily protected cultural resources	Damaged or destroyed cabins	100	Important cultural resource valued by park visitors. Destroyed ranked higher than damaged cabins
		400	

Maps

The weighted data inputs for each indicator are added together using a raster calculator to create maps for non-recreational structures, installations, and developments; inholdings; use of motor vehicles, motorized equipment, or mechanical transport; and loss of statutorily protected cultural resources (Figure 8). After these indicator maps are created, the raster calculator is used to add the four indicator maps together to create the undeveloped quality map (Figure 9).

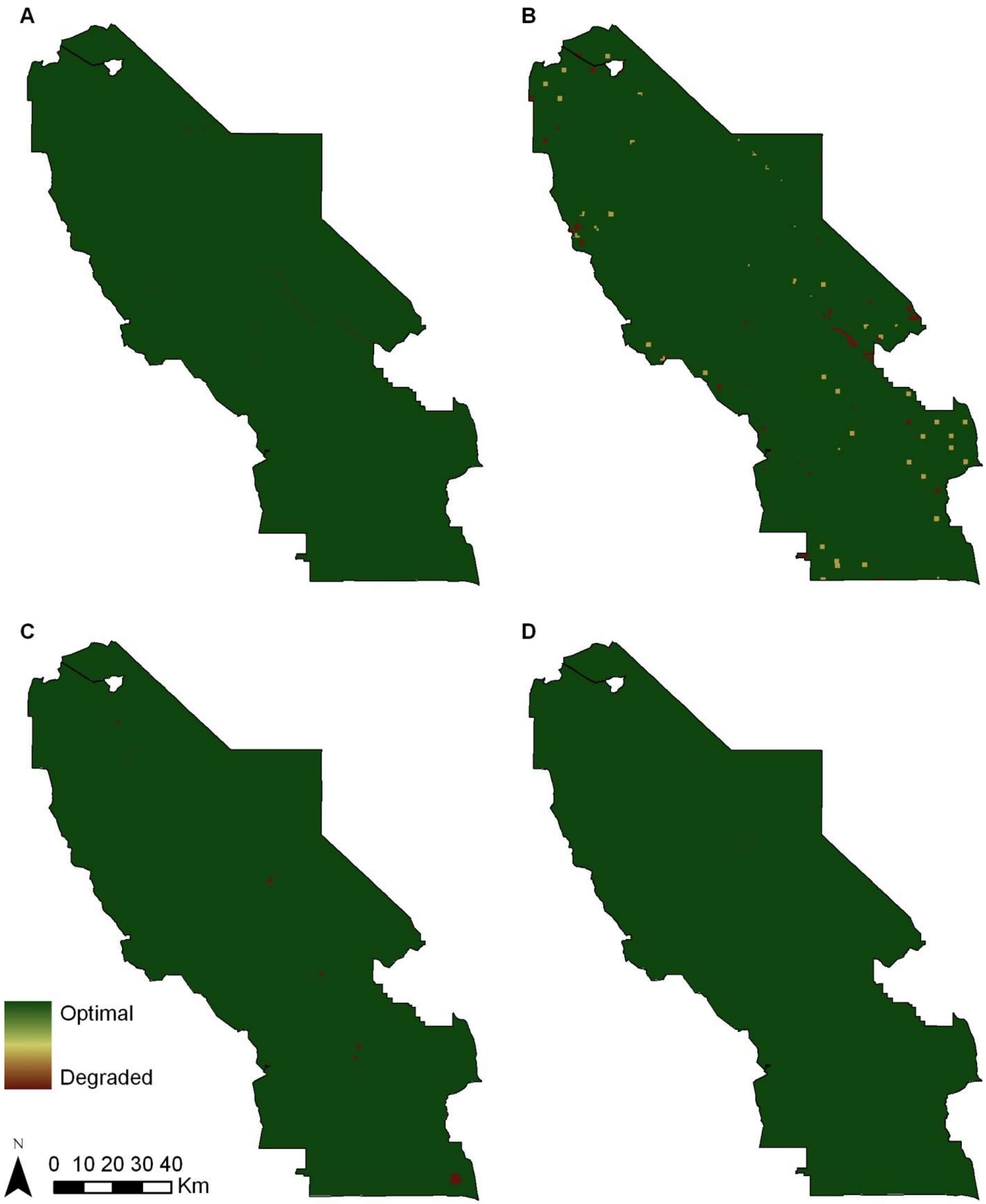


Figure 7. *Indicator maps for (A) non-recreational structures, installations, and developments; (B) inholdings; (C) use of motor vehicles, motorized equipment, or mechanical transport; and (D) loss of statutorily protected cultural resources (all maps in this figure are displayed using a standard deviation stretch to emphasize map data). Green depicts optimal quality and brown depicts degraded quality.*

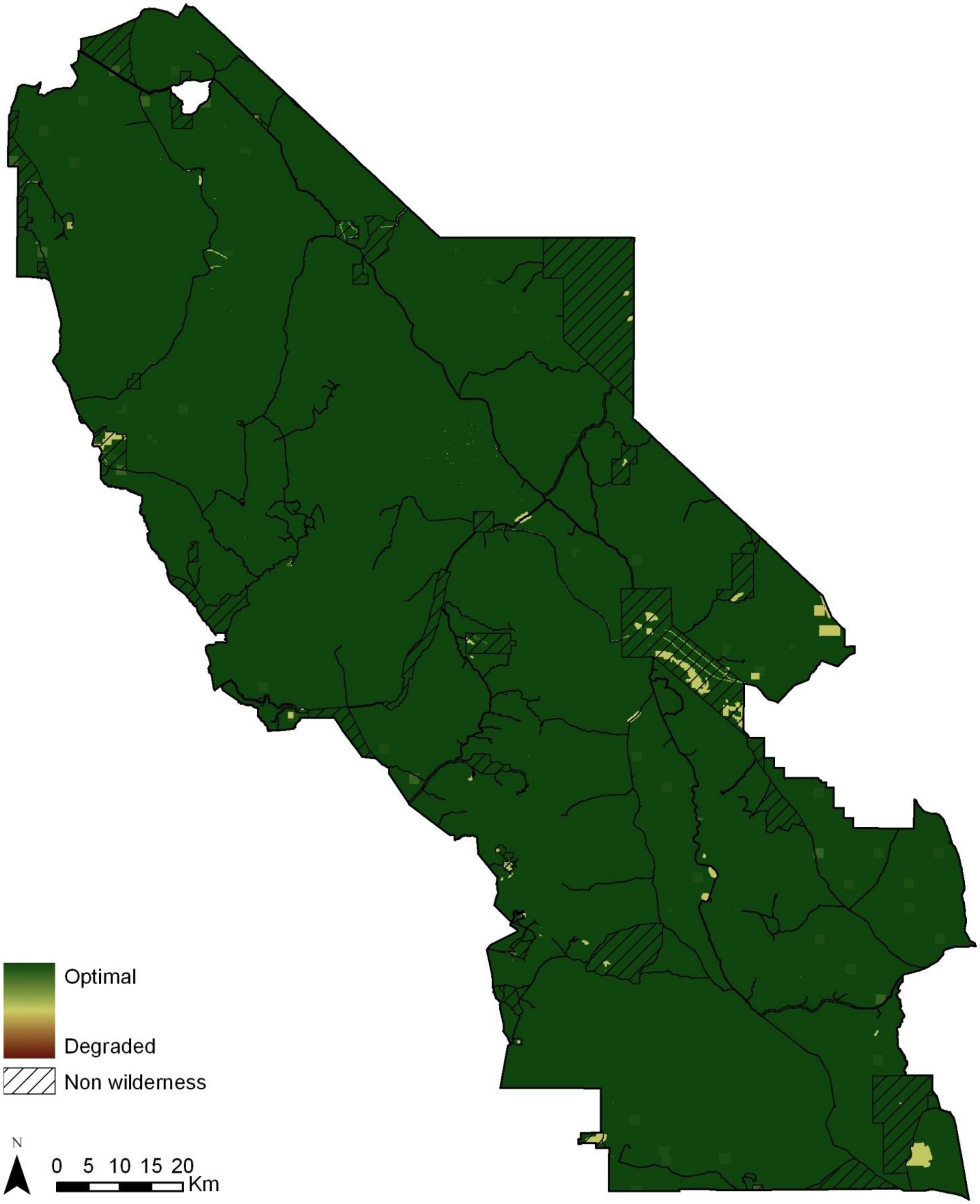


Figure 8. *Undeveloped quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.*

Solitude or Primitive and Unconfined Quality

The solitude or primitive and unconfined quality defines wilderness as containing outstanding opportunities to experience solitude, remoteness, and primitive recreation free from the constraints of modern society. This quality is degraded by settings that reduce these opportunities, such as visitor encounters, signs of modern civilization, recreation facilities, and management restriction on visitor behavior (Landres et al. 2008a).

Indicators and Data Inputs

Data inputs were selected for each of the four indicators recommended in *Keeping it Wild*. The following indicators, with their data inputs and relevance to the solitude or primitive and unconfined quality, were used:

Indicator: Remoteness from sights and sounds of people inside the wilderness

- Travel time model –calculates the time it takes a person of average fitness to travel across the landscape from various access points (paved roads), taking into account cost surfaces[5] (elevation and land cover) and barrier features (steep ground and closed to visitor use).
- Viewshed model – calculates the line-of-sight impacts (using distance decay) of modern human features both inside and outside the wilderness.

Indicator: Remoteness from occupied and modified areas outside the wilderness

- Over-flights – aircraft landing and taking off at DEVA airstrips, proposed air tour routes, and low military flight floors all degrade the opportunity for solitude.
- Soundscape – this is a direct measure of audible unnatural sounds above ambient natural conditions as recorded in Death Valley National Park at 7 locations in 2009. These audible unnatural sounds degrade the opportunity for solitude.
- Dark sky index (Night sky) – this is an interpolated surface based on numerous direct observation points taken in Death Valley over the last decade. It is a synthetic index from 0 (lightest) to 100 (darkest) tailored to match the response of the human eye. The overall loss of visual acuity and ability to detect distant astronomical features degrades the opportunity for solitude and primitive recreation associated with enjoyment of night skies.
- Visibility (Air quality) – this is modeled visibility or average light extinction (deciview) from particulate matter as calculated using the IMPROVE[6] equation, and is the sum of the extinction values for particulate sulfate, particulate nitrate, particulate organics, light-absorbing carbon, fine particulate soil, and coarse particulates. The overall loss of visual acuity and ability to detect the details of distant features of the landscape degrades the opportunity for solitude and primitive recreation.

Indicator: Facilities that decrease self-reliant recreation

- Trails – location of designated trails or routes managed by the NPS. Developed and maintained trails degrade the opportunity for solitude by concentrating visitor presence

[5] Cost surfaces are used in surface modeling to establish the impedance for crossing each individual cell.
[6] The Interagency Monitoring of Protected Visual Environments (IMPROVE) protocols are used for reconstructing ambient light extinction from measured aerosol species.

and degrade the opportunity for primitive and unconfined recreation by providing explicit direction for travel.
- Visitor facilities – location of facilities installed and maintained by the NPS for use by park visitors, such as toilets and fire pits. Developed and maintained facilities degrade the opportunity for solitude by concentrating visitor presence and degrade the opportunity for primitive and unconfined recreation by explicitly providing visitor amenities.

Indicator: Management restrictions on visitor behavior
- Camping restrictions – locations that forbid camping as per Superintendent's Compendium. Such restrictions degrade the opportunity for unconfined recreation because they impose agency control on visitor behavior and constrain free choice.
- Closed to visitor use – locations closed to visitor access temporarily or permanently for protection of sensitive resources (Copper Canyon) or due to extreme safety hazards (Keane Wonder Mine). Such closures degrade the opportunity for unconfined recreation because they deny visitors the opportunity to access those sites.

Travel time and viewshed modeling
Two models are employed to depict remoteness from the sights and sounds of people in wilderness. The travel time model is used to delineate areas of DEVA that may be considered more remote than others due to the considerable time and distance required to reach these places. The viewshed model is used to delineate the line of sight impacts of modern human features existing inside and outside wilderness. Both models use a variety of data at a higher resolution of 30 m for more precise analysis. This analysis is extended into a buffer zone 15 km outside the wilderness boundary for the travel time model and up to 30 km for the viewshed model to allow for edge effects occurring outside the park. These models analyze a variety of inputs, including road networks, land cover, and all modern human developments occurring in and around the park.

Travel time
Travel time is modeled in DEVA based on a GIS implementation of Naismith's Rule[7], with Langmuir's correction[8]. Terrain and land cover information are used to delineate the relative time necessary to walk into a roadless area from the nearest point of legal motorized access taking into account the effects of distance, relative slope, ground cover, and barrier features such as very steep ground. The travel time (or "remoteness") model, developed by Carver and Fritz (1999), assumes a person can walk at a speed of 5 km/hr over flat terrain and adds a time penalty of 30 minutes for every 300 m of ascent and 10 minutes for every 300 m of descent for slopes greater than 12 degrees. When descending slopes between 5 and 12 degrees, a time bonus of 10 minutes is subtracted for every 300 m of descent. Slopes between 0 and 5 degrees are assumed to be flat. Ancillary data layers are used to modify walking speeds according to ground cover (e.g.,

[7] Naismith's Rule is a simple formula that helps to plan a hiking expedition by calculating how long it will take to walk the route, including ascents. Devised by Scottish mountaineer, William Naismith, the basic rule states: "Allow…an hour for every three miles on the map, with an additional hour for every 2,000 feet of ascent" (1892: 136).
[8] Langmuir's correction acknowledges the need to descend slowly in steep terrain as it is necessary to take shorter steps, or reduce slope angle and extend path length by zig-zagging.

Naismith's 5 km per hour on the map can be reduced to 2 km per hour or less when walking across the Devil's Golf Course), and include barrier features that force a detour as "null" values[9].

- *Sources*: Calculating travel time based on Naismith's rule requires a range of data including a detailed terrain model, land cover data, and information on the location of barrier features, roads, and other access features. The USGS 30 m Digital Elevation Model (DEM) provides terrain elevation data, the combined Mojave Vegetation Mapping Project and USGS National Vegetation Classification provide land cover data, and a combination of the DEVA road dataset and heads-up digitized roads from the NAIP imagery is used to create the road classes. Additional inputs are derived from trails, fences, areas closed to visitor use, and heads-up digitized data from ranger knowledge detailing unique land cover features such as the Devil's Golf Course and Badwater Basin.
- *Processing*: A macro program implementing the PATHDISTANCE function in ArcGIS is used to model Naismith's rule. This estimates walking speeds based on relative horizontal and vertical moving angles across the terrain surface together with appropriate cost or weight factors incurred by crossing different land cover types and the effects of barrier features. The model is applied using the following conditions:
    1. *Source grid:* This is taken to be the paved road network that provides vehicular access.
    2. *Cost surface:* This is assumed to be 5 km/hr for the majority of land cover types in DEVA. However, certain land cover types such as sagebrush are estimated at 4 km/hr, high elevation pine woodlands at 3 km/hr, chaparral at 2 km/hr, and sand dunes at 1 km/hr (for a full list of land cover impendence values that represent off-trail travel, see Appendix A). Additional features not found in the land cover data are used to amend the base cost surface for a more accurate depiction of the cost surface. Trails are overlaid onto the cost surface at 5km/hr, due to their low resistance to movement. Fences are overlaid at 1km/hr to represent the time it takes to climb over them. The unique land cover areas of the Devils golf course and Badwater Basin supersede the land cover values at 2km/hr and 4km/hr respectively. Lastly, the backcountry roads are "hardwired" onto the cost surface to represent the different speeds a vehicle can travel in the back country. The roads are split into two categories: dirt roads suitable for low clearance, non-4x4 vehicles traveling at an average speed of 40km/hr and dirt roads only suitable for high clearance, 4x4 vehicles traveling at an average speed of 20km/hr.
    3. *Barriers to movement:* These include areas that are closed to visitor use and slope angles that are greater than 40 degrees.

The standardized travel time data input needs to be inverted to reflect high degradation of solitude values near access points, and lower degradation further away from these features (Figure 10).

Cautions: Naismiths's Rule and the model used to implement it here assumes the person "travelling the landscape" is a fit and healthy individual and does not make allowances for load carried, weather conditions (such as extreme heat or strong headwinds), or navigational skills.

---

[9] NoData or null values in a raster grid contain no data and so are disregarded in most calculations unless the model explicitly references these. NoData values are useful in building access models in that they can be used to describe the location of barrier features that cannot be crossed.

The model does, however, take barrier features and conditions underfoot into account. Steep slopes and areas closed to visitor use are considered impassable on foot and are included as barrier features by coding these as NoData (null values) in the model inputs. This forces the model to seek a solution that involves walking around the obstacle. The model also uses a cost or friction surface that controls walking speed according to the land cover or conditions underfoot. A speed of 5 km/hr (1.389 m/s) is assumed for most land cover types, but some fall within a range of 4 km/hr (1.112 m/s) to 1 km/hr (0.278 m/s). The angle at which terrain is crossed (i.e., the horizontal and vertical relative moving angles[10]) is used to determine the relative slope and height lost/gained. These values are input into the model using a simple lookup table as shown in Table 7. The paved road network, both within and outside the DEVA boundary, is used as the access points from which to calculate remoteness of non-road areas. The road network outside DEVA is included in the analysis to avoid any possible edge effects in the travel time calculation.

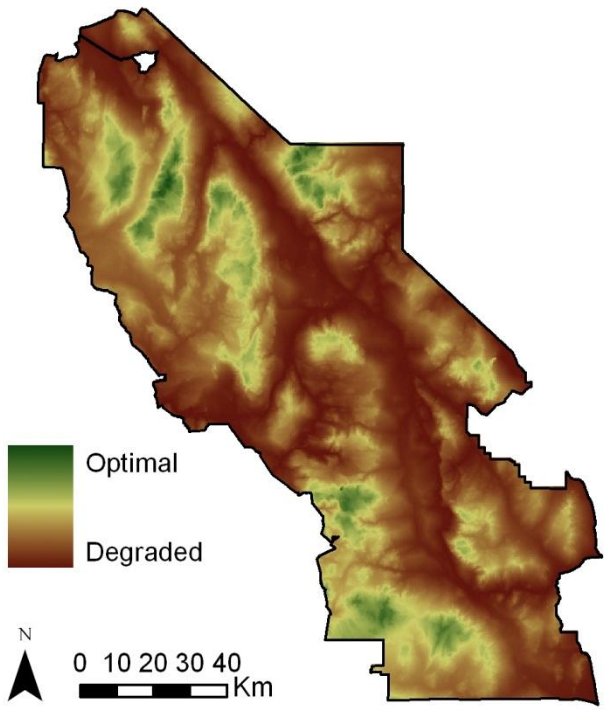


Figure 9. *Travel time model. This map depicts the fastest route it would take a person to walk to every pixel in DEVA from the source grid (paved road network). Brown indicates the pixels that are within quicker reach and therefore we assume that these pixels represent a lower opportunity for solitude, and green represents pixels that will take longer to reach and therefore represent greater opportunity for solitude.*

[10] Vertical and horizontal factors determine the difficulty of moving from one cell to another while accounting for vertical or horizontal elements that affect movement. These include slope and aspect as they determine the relative angle of the slope in the direction traveled and hence the elevation gained or lost.

Table 7. Naismith's Rule expressed in the Vertical Relative Moving Angle field.

VRMA (Degrees)	Vertical Factor
-40	2.4
-30	1.87
-20	1.45
-12	0.29
-11	0.33
-10	0.37
-9	0.44
-8	0.47
-6	0.51
-5	0.72
0	0.72
10	1.78
20	2.9
30	4.19
40	5.75

Viewshed

The visual impacts of modern anthropogenic features in the DEVA wilderness are modeled using a custom-built software tool that has been designed to work directly with GIS data. The presence of these artificial features, which may be located within or adjacent to the wilderness, are assumed to detract from a sense of solitude. Previous work on the effects of human features on perceptions of wilderness, carried out at national and global scales, has tended to focus on simple distance measures (Lesslie 1993, Carver 1996, Sanderson et al. 2002). More recent work has used measures of visibility of anthropogenic features in 3D landscapes described using digital terrain models (Fritz et al. 2000, Carver and Wrightham 2003). This is feasible at the landscape scale utilizing viewshed algorithms and land cover datasets to calculate the area from which a given feature can be seen[11].

- *Sources*: Visibility analysis and viewshed calculations rely on the ability to calculate "line-of-sight" from one point on a landscape to another. It has been shown that the accuracy of viewsheds produced in GIS is strongly dependent on the accuracy of the terrain model used and the inclusion of intervening features or "terrain clutter" in the analysis (Fisher 1993). While previous studies have made use of a digital surface model (DSM) for obtaining "terrain clutter" (Carver et al. 2008), the extent of DEVA and relative lack of features allows feature information to be collated and formatted manually (Table 8). A resolution of 30 m for feature inputs was considered adequate for this analysis. Viewshed distance and height information were determined for each feature by the working group. The USGS 30 m DEM was used to provide terrain elevation data.

[11] Viewshed algorithms are used with digital terrain models to calculate where a particular feature, for example a building or radio antennae, can be seen by a person standing anywhere on a landscape. These algorithms calculate line-of-sight between the viewer and the feature, accounting for areas where line-of-sight is interrupted by intervening higher ground.

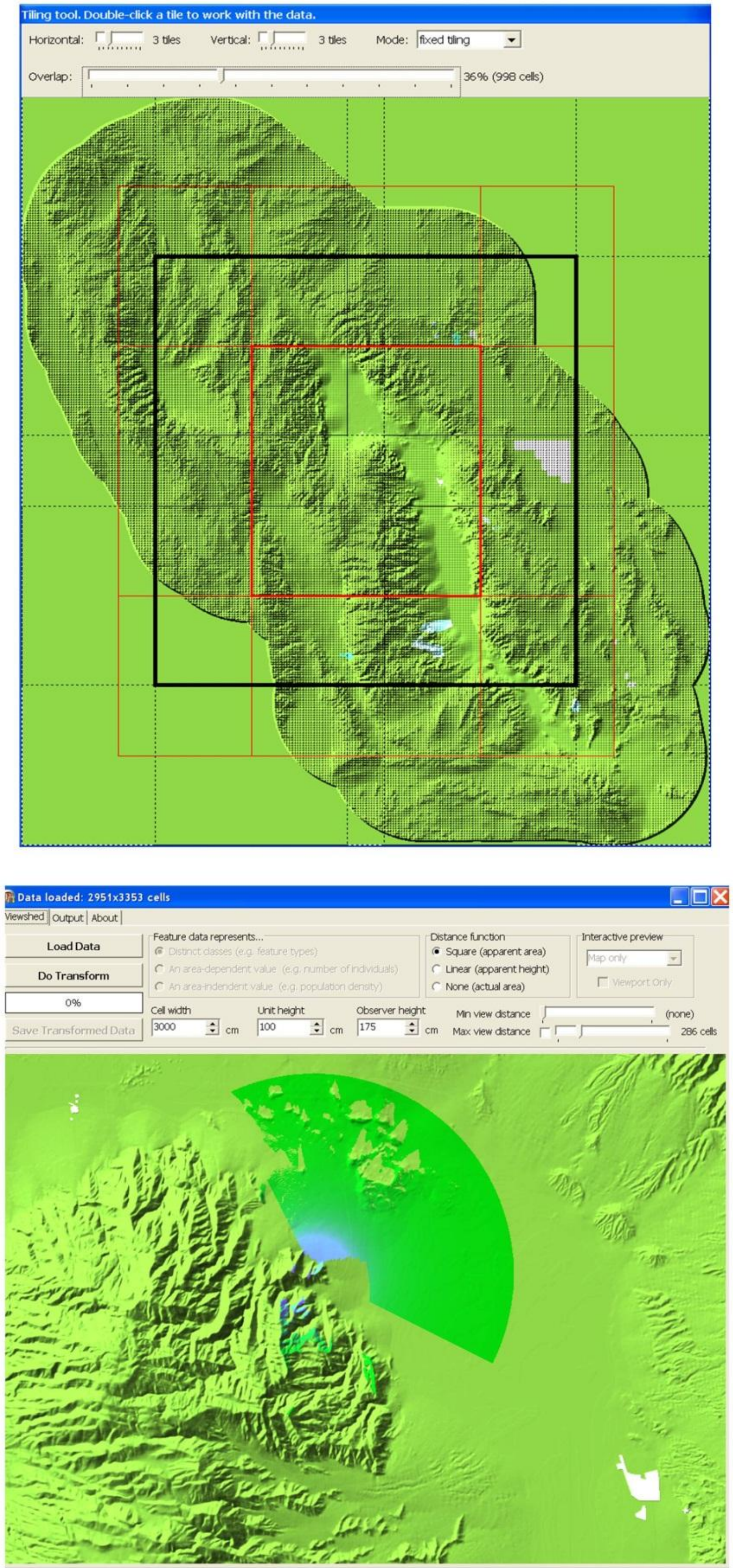
Table 8. *Human features impacting viewshed.*

Feature	Source	Viewshed distance	Height	Accuracy	Completeness
Small installations	DEVA	1 km	5 m	Moderate	Moderate
Mines	NPS AML/ USGS/DEVA	1 km	2 m	High	Low
Utilities	DEVA	1 km	5 m	Moderate	High
Fences	NPS ASMIS	1 km	1 m	High	High
Dirt roads	DEVA	1 km	2 m	High	High
Debris	DEVA	1 km	2 m	Moderate	Low
Cabins	NPS ASMIS	10 km	3 m	High	High
Structures - isolated	DEVA	10 km	5 m	Moderate	Moderate
Structures - clustered	DEVA	10 km	7 m	High	High
Large mines	DEVA	10 km	10 m	High	High
Mormon Peak installation	DEVA	15 km	10 m	High	High
Paved roads	DEVA	15 km	5 m	High	High
Large clustered buildings	DEVA	30 km	10 m	Moderate	High
Open pits and Ryan, Briggs and Barrack Mines	DEVA	30 km	5 m	High	High
Rogers Peak installation	DEVA	30 km	10 m	High	High
Amargosa farming area	DEVA	30 km	10 m	Moderate	High

- *Processing*: Viewshed analyses such as these are extremely costly in terms of computer processing time. Detailed analyses can take weeks, months, or even years to process depending on the number of anthropogenic features in the database. Recent work by Washtell (2007), however, has shown that it is possible to both dramatically decrease these processing times and improve their overall accuracy through judicious use of a voxel-based landscape model[12] and a highly optimized ray-casting algorithm. The algorithm, which is similar to those used in real-time rendering applications and in some computer games, was designed to perform hundreds of traditional point viewshed operations per second. By incorporating this into a custom-built software tool that has been designed to work directly with GIS data (Figure 11), it is possible to estimate the visibility between every pair of cells in a high-resolution landscape model utilizing only moderate computing resources. This "viewshed transform" approach represents a maturation of traditional cumulative viewshed techniques (Carver et al. 2008) and is used to:
    1. calculate the viewshed for every single feature;
    2. incorporate estimates of the proportional area of each visible feature; and
    3. run separate viewshed calculations for each of the different categories of features listed in Table 8, which can then be combined together to create the viewshed map.

[12] A voxel is a volumetric pixel.

An inverse square distance function is used in calculating the significance of visible cells. Put simply, the viewshed transform determines the relative viewshed value for each cell by calculating what proportion of the features can be seen and the distance between the cell and the particular features. Thus, the smaller the proportion of the feature in view and the further away it is, the lower the viewshed value for the particular cell. The greater the proportion of the feature in view and the closer it is, the higher the viewshed value of the particular cell.



A

B

Figure 10. *The viewshed tool interface demonstrating (A) the tiling tool and (B) sample DEM and feature tiles loaded into the model.*

For this analysis, certain compromises and customizations were necessary to make the task manageable. These included:

1. The cell resolution was limited to 30 m for all features;
2. A "pessimistic" re-sampling was done to generate the 30 m feature inputs guaranteeing that features smaller than this area were included[13] and that the viewsheds produced an accurate representation of the visual impacts of these features;
3. The landscape was split into a number of overlapping tiles such that they could be simultaneously analyzed by a cluster of desktop computers;
4. The viewshed analysis was run for both 15 km and 30 km maximum viewshed distances. Features with a maximum viewshed distance listed as 15 km or less in Table 8 are run in the 15 km batch, and the 30 km features run in the latter batch. Smaller features with viewshed distances less than 15 km are clipped to their respective pre-determined distances on completion of the analysis.

The two batched outputs are combined together using the MINIMUM function in ArcGIS to provide an overall viewshed grid for DEVA. The normalized viewshed data input needs to be inverted to reflect high degradation of solitude values near human features and lower degradation further away from these features (Figure 12).

- *Cautions*: Categorizing the anthropogenic features in DEVA into specific viewshed distances requires careful consideration as to how well each type of feature blends into the desert background. For example, the majority of utility lines in DEVA are largely unnoticeable from close distances because they are difficult to pick out against a desert backdrop, and thus are assigned a maximum viewshed distance of 1 km. Isolated and clustered structures that have larger surface areas stand out when viewed against a desert backdrop and are assigned a maximum viewshed distance of 10 km. Some features in the wilderness were excluded from this analysis because they have little to no impact on the DEVA viewshed. For example, borrow pits were excluded because they are relatively small, ground-level depressions that blend in well with the surrounding landscape.

  Depending on the angle of view, an unpaved road in the backcountry can be largely unnoticeable from distances as close as 50 m. However, if a vehicle is on the road and is creating a dust plume, the road quickly becomes apparent. Thus, this particular feature is calibrated negatively at a height of 2 m in anticipation of traffic on the road.

  Another issue that exists in modeling is the realistic representation of re-sampled feature inputs in the viewshed analysis. Utility lines in the model are represented as a solid 5 m high "wall" when in reality these features only consist of poles and powerlines. These are limitations of the model and should be considered when analyzing viewshed results.

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[13] Re-sampling of feature layers in GIS is normally carried out on a "majority class" basis wherein the value of a grid cell takes on the value of the largest feature by area that it contains. Using this rule, a 10 x 10 m building in a 30 x 30 m grid cell that was otherwise not classified as a feature would not be recorded on re-sampling. The "pessimistic" re-sampling used here operates on presence/absence basis such that any grid cell containing a human feature will be classified as such even though the actual area or footprint of the feature may not cover the majority of the grid cell.

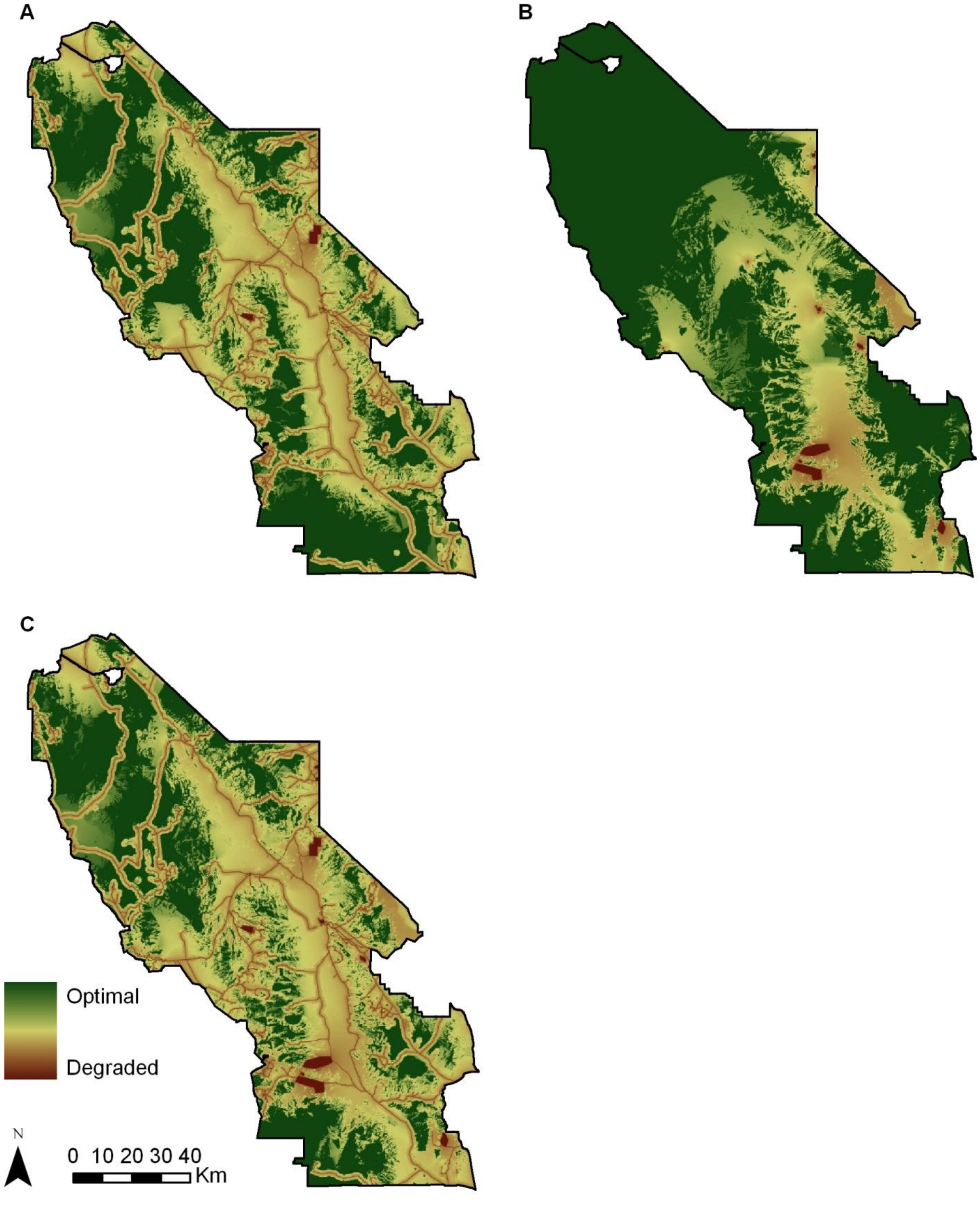

Figure 11. *Viewshed impacts in DEVA: (A) 15 km viewshed impacts, (B) 30 km viewshed impacts, (C) combined viewshed impacts (using the MINIMUM function). Green depicts optimal quality viewshed and brown depicts degraded quality viewshed. Note that there are no viewshed impacts in the north of the 30 km map because no features with a 30 km viewshed distance exist in this area.*

Data Sources, Processing and Cautions

A wide variety of data sources are used for the solitude or primitive and unconfined type of recreation map (Table 9), which encompass a range of different scales, variability in accuracy and completeness, and both vector and raster data.

Table 9. *Solitude and primitive and unconfined quality datasets.*

Dataset	Source	Type	Scale	Accuracy	Completeness
Travel time model	USGS, Central Mojave Mapping Project, DEVA	Raster/Polyline	30 m	High	High
Viewshed model	See Table 8	Raster/Polygon	30 m	Moderate	High
Over-flights	DEVA	Polygon	100 m	High/Moderate	High/Moderate
Soundscape	NPS Natural Sounds Program	Raster		Moderate	Low
Nightsky - dark sky index	Night Sky Team, NPS	Raster	1 km	High	Moderate
Air quality - visibilty	Air Resources Division, NPS	Raster	12 km	High	High
Trails	DEVA	Polyline	100 m	Moderate	Moderate
Visitor facilities	DEVA	Point	100 m	High	High
Camping restrictions	DEVA	Polygon	100 m	High	High
Closed to visitor use	DEVA	Polygon	100 m	High	High

Travel time & Viewshed models – see previous section

Over-flights

- *Sources*: This data input is a composite of three data sources. The first is polyline data depicting proposed air tour routes from the draft Air Tour Management Plan – heads-up digitized by Charlie Callagan using the DEVA road data (the proposed routes will follow the road network on the eastern side of the park). The second is polygon data depicting several existing airstrips inside of DEVA – heads-up digitized using NAIP imagery. The final data source depicts the impact of military over-flights occurring over DEVA (the park is near several major military installations). The Air Force and Navy both use the airspace above and near the park for training exercises. Airspace to the west of the original monument boundary has a significantly lower legal "flight floor" thus causing greater impacts on solitude over the western side of the park with more audible and visible air traffic.
- *Processing*: A numerical scale of 1 through 10 was used to represent these impacts, with 1 being the least impact and 10 being the greatest. The proposed air tour routes are buffered by 2 km to represent the visual and noise impact of this air traffic. The airstrips are buffered in the style of commercial runway noise maps to represent the visual and noise impacts of aircraft landing and taking off. The military over-flights polygon is buffered twice, by 1 km and 4 km respectively, to represent less impact further away from this area. The proposed air tour routes are given a value of 1 as the routes are correlated to the road network in DEVA, which makes their noise and visual impact less noticeable. The impact of the airstrips is more localized and flights landing and taking off are less frequent, so this data is given a value of 3. Military over-flights are given a value of 10 because they have the highest noise impact and are most frequent. The buffer zones of reduced values (9 for the 1 km buffer and 6 for the 4 km buffer) signify less impact

further away from the over-flight area. These three datasets are then added together to create the over-flights data input (Figure 13).

- C*autions*: This data input represents temporary impacts to solitude and assumes a worst case scenario.

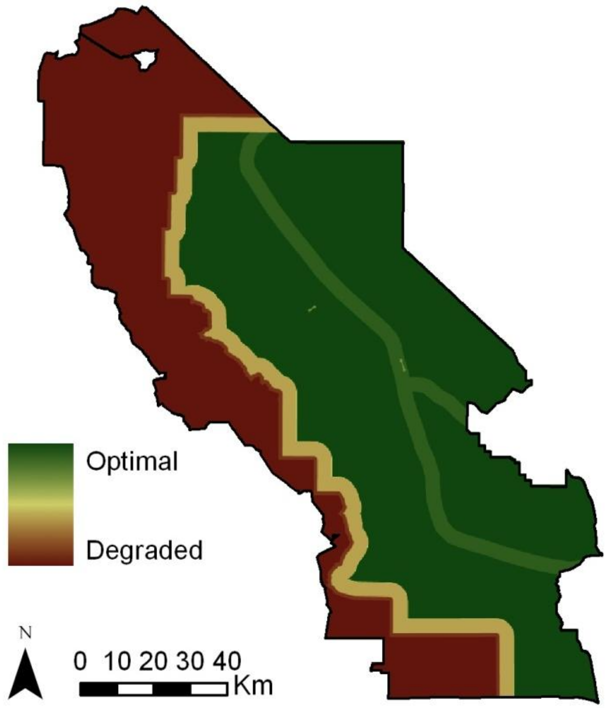

Figure 12. *Over-flights data input for DEVA. Green depicts optimal quality and brown depicts degraded quality.*

Soundscape

- *Sources*: Raster datasets provided by the NPS Natural Sounds Program. These data are collected from strategically-placed sites throughout DEVA to generalize acoustic data for the entire park. Computer modeling is used to then estimate and logarithmically add contributing effects of other mechanical sound sources, such as roads, to the measured ambient sound to create "combined" ambient sound. Road sound sources are estimated based on data gathered from Federal Highway Administration (FHWA) sources and represent traffic that would occur on an average day during peak seasonal visitation.
- *Processing*: The "natural measured sound" raster was subtracted from the "existing combined sound" raster to produce a raster depicting non-natural sound.
- *Cautions*: The Natural Sounds Program data is produced for the entire park using certain estimations of natural measured (ambient) sound based on a small number of sampling points and a very limited sampling period. This data input represents temporary impacts to solitude and assumes a worst case scenario.

Dark sky index (Night sky)

- *Sources*: Raster dataset created by Dan Duriscoe, NPS Night Sky Team. The grid is a spline surface model interpolated from 13 observation points.
- *Processing*: Re-project raster to NAD 1983 UTM Zone 11N coordinate system.
- *Cautions*: This data input represents temporal impacts to solitude that are only noticeable at night.

Visibility (Air Quality)

- *Sources*: Raster dataset from NPS Air Resource Program.
- *Processing*: Re-project raster to NAD 1983 UTM Zone 11N coordinate system.
- *Cautions*: None.

Trails

- *Sources*: Polyline dataset created by Leah Bonstead, DEVA Archaeologist, from topographic maps, aerial photographs, and GPS tracking. Three types of trails were recorded: route – a cross country path with no signage; informal trail – a use-worn path but not designated as a trail by park management; and formal trail – a managed trail with interpretative and directional signage. Each trail type will cause different levels of impact on opportunities for solitude from visitor encounters and on primitive and unconfined recreation from the presence of different trail amenities.
- *Processing*: Different trails types are processed according to what park staff perceive as the overall level of impact on visitors seeking opportunities for a wilderness experience. Locations where these features occur in DEVA are given the following values: routes = 1, informal trails = 2, and formal trails = 4.
- *Cautions*: None.

Visitor facilities

- *Sources*: Polygon dataset created by Leah Bonstead, DEVA Archaeologist, from aerial photographs and heads-up digitizing based on input from park staff. Three types of existing visitor facilities were recorded: frontcountry (formal campsites located along paved roads), backcountry (formal campsites located along backcountry corridors), and wilderness (‘ad hoc’ campsites that are not managed by DEVA but have regular use). The DEVA staff determined that the presence of other people using these campsites would decrease opportunities for solitude in the nearby wilderness, and features associated with campsites, such as toilets, fire rings, and leveled tent sites would decrease opportunities for self-reliant recreation in the vicinity of the camping area. Each type of campsite will have different levels of use and associated impacts to surrounding areas (e.g., presence of litter and human feces, evidence of fire and/or illegal firewood collection, and soil compaction and vegetation trampling due to increased foot traffic).
- *Processing*: Different types of visitor facilities are processed according to their perceived impact by park staff on visitors seeking opportunities for a wilderness experience in the vicinity (through potential encounters, noise, impacts to the landscape, and the facilities themselves degrading a true wilderness experience). Designated and backcountry campsites were buffered by 500 m and wilderness campsites by 100 m to represent noticeable impacts. Locations where all the sites occur in DEVA are given a value of 1.
- *Cautions*: Even though frontcountry and backcountry campsites are not in wilderness, their proximity to wilderness may affect a visitor seeking a wilderness experience.

Camping restrictions

- *Sources*: A polygon dataset derived from the DEVA road network and information from Charlie Callagan, DEVA Wilderness Coordinator. Camping is restricted in areas within 2 miles of all paved roads in DEVA except for specific designated camping areas. Additionally, specific areas such as the Valley floor, the Racetrack, and Saratoga Spring are included as no camping zones. These specific areas were heads-up digitized using NAIP imagery.
- *Processing*: Locations where paved roads and specific sites occur in DEVA are buffered by 2 miles and given a value of 1.
- *Cautions*: Camping restrictions don't adversely affect visitors seeking a wilderness experience during the day, but the knowledge that these areas cannot be occupied overnight represents a loss of unconfined recreation.

Closed to visitor use

- *Sources*: Polygon data created by Charlie Callagan, DEVA Wilderness Coordinator.
- *Processing*: Locations where closed areas occur in DEVA are given a value of 1.
- *Cautions*: None.

Weighting

The first page of the methods section describes the underlying principle for using a weighting system. A rationale is provided for the weight of each data input (Table 10). The "weighted" data inputs under each indicator total 100.

Table 10. *Indicators and data inputs for the solitude or primitive and unconfined quality with weights and rationale.*

Indicator	Input	Weight	Rationale
Remoteness from sights and sounds of people inside the wilderness	Travel time model	70	Remoteness is highlighted in the General Management Plan (GMP) as a park value to be preserved
	Viewshed model	30	Scenic quality is mentioned in GMP as a park value to be preserved
Remoteness from occupied and modified areas outside the wilderness	Over-flights	25	Issue of concern identified by the public during public scoping for the DEVA Wilderness Plan
	Soundscape	20	Issue of concern identified by the public during public scoping for the DEVA Wilderness Plan
	Night sky – dark sky index	35	Important resource identified in the GMP as a park value to be preserved
	Visibility (Air quality)	20	As a component of scenic vistas, this is a park value identified in the GMP to be preserved
Facilities that decrease self-reliant recreation	Trails	20	Less influential on self-reliance
	Visitor facilities	80	More influential on self-reliance
Management restrictions on visitor behavior	Camping restrictions	20	Less impact on visitor use
	Closed to visitor use	80	High impact on visitor use
		400	

Maps

The weighted data inputs for each indicator are added together using a raster calculator to create separate maps for remoteness from sights and sounds of people inside the wilderness, remoteness from occupied and modified areas outside the wilderness, facilities that decrease self-reliant recreation, and management restrictions on visitor behavior (Figure 14). The first two indicators are added together to depict opportunities for solitude inside wilderness and the latter two indicators are added together to depict opportunities for primitive and unconfined recreation inside wilderness (Figure 15). Finally, the raster calculator is used to add the four indicator maps together to create the solitude or primitive and unconfined quality map (Figure 16).

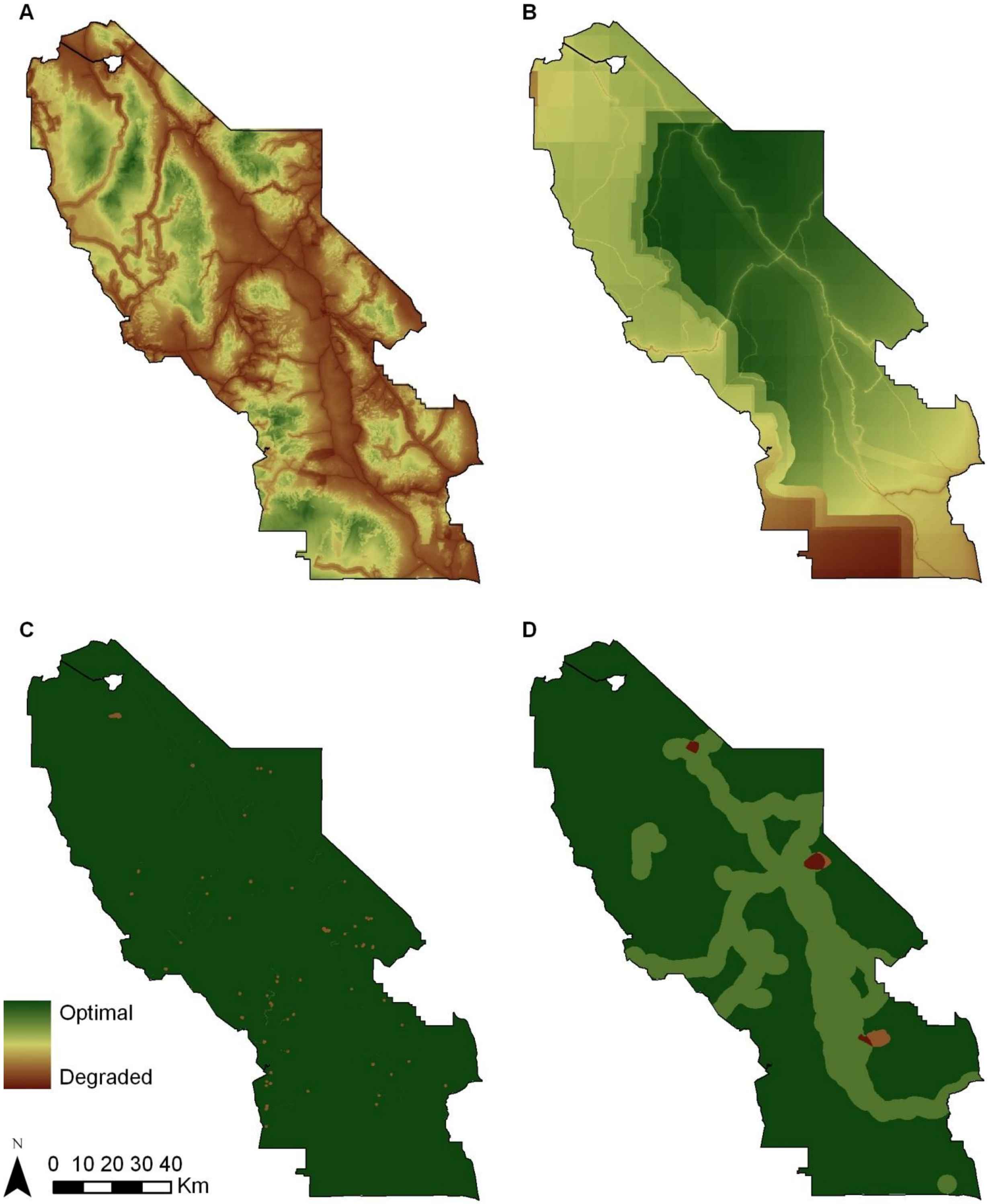

Figure 13. *Indicator maps for (A) remoteness from sights and sounds of people inside the wilderness, (B) remoteness from occupied and modified areas outside the wilderness, (C) facilities that decrease self-reliant recreation, and (D) management restrictions on visitor behavior. Green depicts optimal quality and brown depicts degraded quality.*

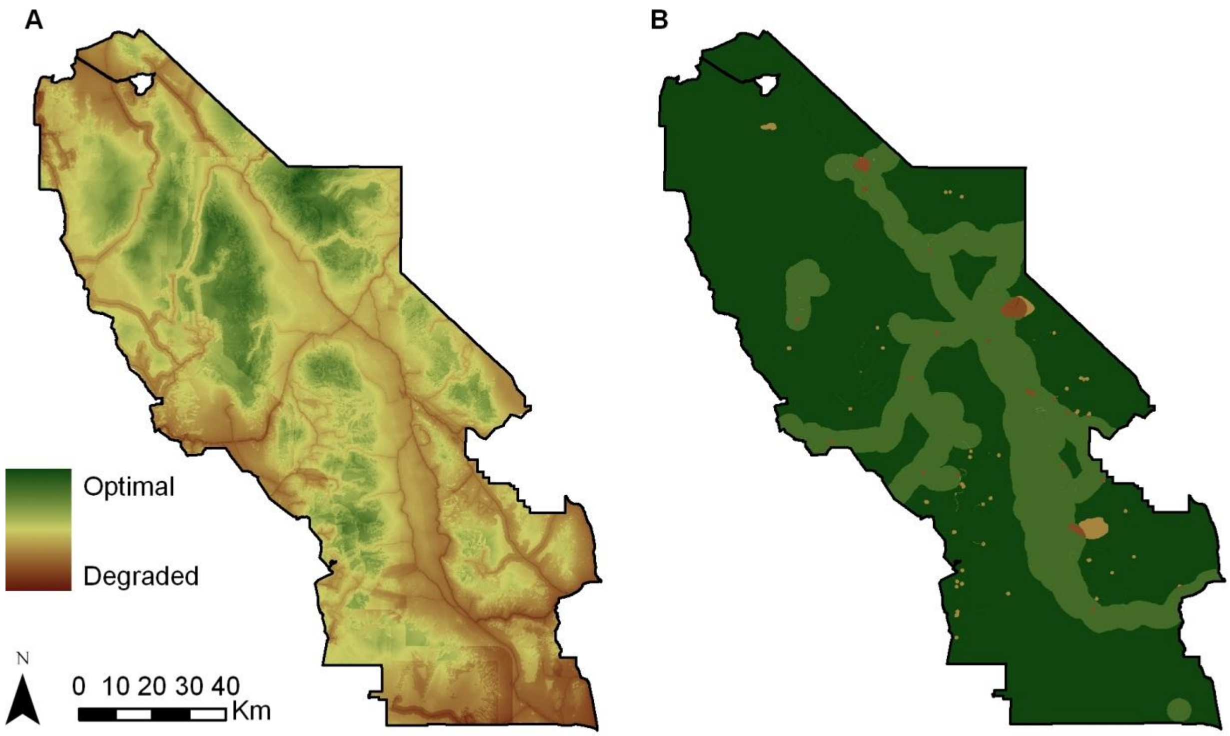

Figure 14. *Combined indicator maps for (A) opportunities for solitude inside wilderness, and (B) opportunities for primitive and unconfined recreation inside wilderness. Green depicts optimal quality and brown depicts degraded quality.*

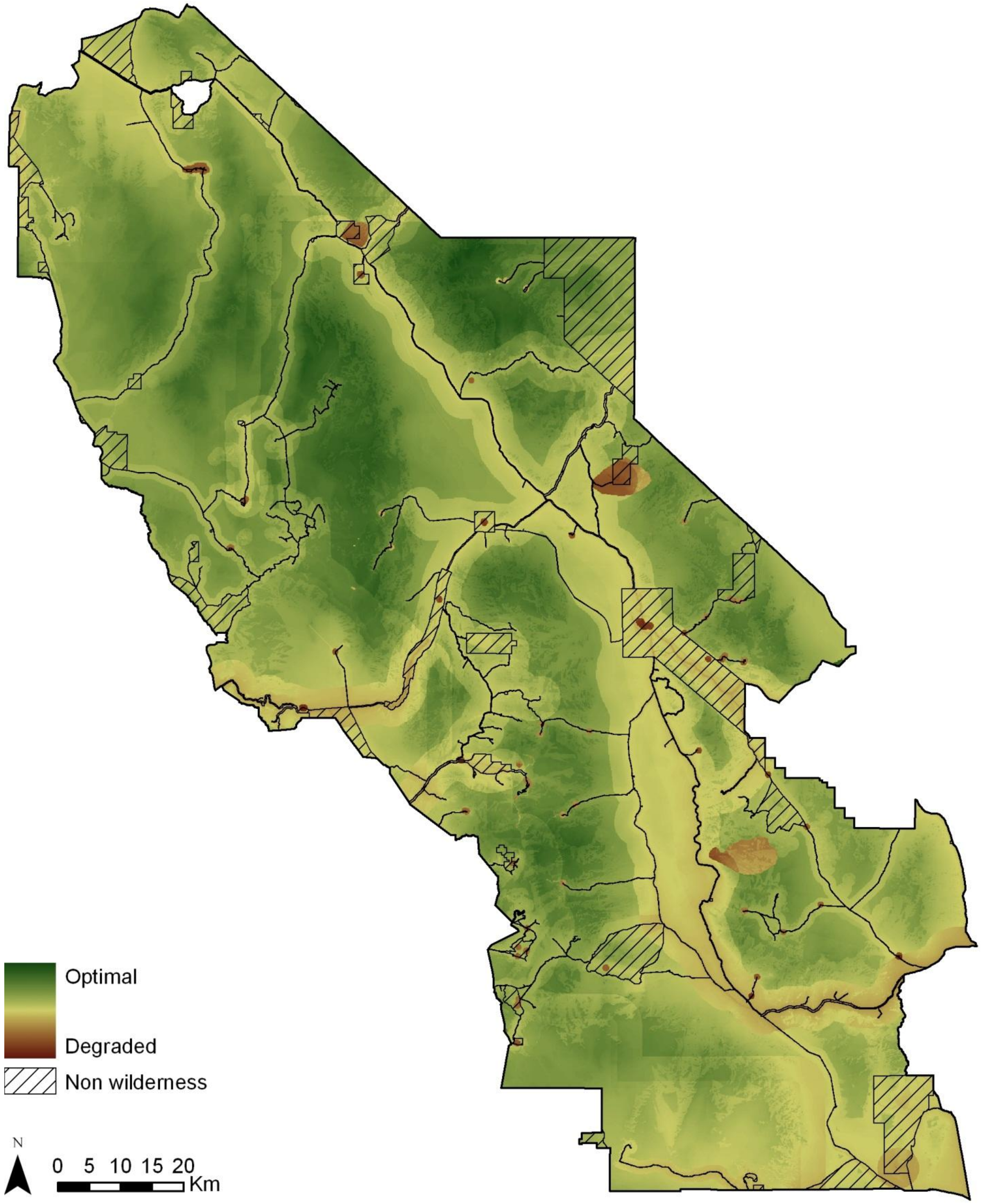

Figure 15. *Solitude or primitive and unconfined quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.*

Cultural Resources

Cultural qualities of wilderness character are both significant and important in DEVA as provided for generally by NPS policy and federal law, and specifically in the California Desert Protection Act of 1994 and the Timbisha Homeland Act of 2000. The park is richly endowed with ethnographic and archeological resources, and is part of the ancestral homeland of the Timbisha Shoshone. However, because the wilderness character map is based on attributes that degrade wilderness character and these cultural resources add value to wilderness character in DEVA, they were not included in the final map. In addition, these resources are extremely sensitive and after consultation with the Tribe it was decided to not include data on these resources in the map products. Park staff will, however, use these data “in-house” to inform and support DEVA wilderness stewardship, and to ensure that the park does not compromise the integrity of these cultural resources.

The Wilderness Character Map

The methodology described produces four maps, one for each of the qualities of wilderness character (Figure 17). These maps are then combined to produce a single map of overall wilderness character quality in DEVA. Because all four qualities are equally important and none is held in higher or lower regard than the other, the four qualities are added together equally. It is then necessary to clip out the non-wilderness areas of DEVA (as the analysis was run for the entire park) when presenting the maps (Figure 18).

Interpreting and discussing these maps requires a clear understanding of the methods used and the many limitations when creating the map products. For example, it is noticeable in Figure 17 that the natural and solitude maps are distinctly different in appearance to the untrammeled and undeveloped maps. This is because the undeveloped and untrammeled maps only use vector data sources, as opposed to a combination of vector and continuous raster data sources used for the other two maps. Furthermore, it is important to emphasize that the maps represent a grid of values (approximately 1.2 million pixels). The maps are presented using a color ramp and the "minimum – maximum" stretching technique to best represent these values for display and discussion. In addition, the user should bear in mind that the degraded areas in the overall wilderness character map are generated through the analysis of a multitude of inputs: to understand why these areas are degraded one must "drill down" into the individual qualities, indicators, and data inputs.

An equal interval reclassification[14] of the wilderness character map splits the range of values of all the pixels into a scale of 1-100%. These percentages are then split into ten equal categories (i.e., 0-10%, 11-20%, 21-30%, and so on) to identify the current status of wilderness character at DEVA (Figure 19). Most of the high quality wilderness character occurs in the northern section of the park. Large areas of the highest quality category (91-100%) are found in the Cottonwood Mountains, the Grapevine Mountains and Tucki Mountain. The next highest category (81-90%) covers large swathes of landscape in the north of the park, particularly over the Saline Range, the Grapevine Mountains, and much of the Panamint Range. The top two categories are noticeable for their general absence in the southern part of the park. The bottom three categories contain very small pockets of low quality wilderness character. These are typically found near campsite areas, visitor facilities, and the edges of old mining sites.

Looking at the histogram of the distribution of pixel values (Figure 20), it is clear that the majority of the park has mostly high quality wilderness character. However, due to the number of impacts, especially from factors outside the park such as air and light pollution, the two dominant categories are from 61-70% and 71-80%.

[14] This reclassification scheme divides the range of attribute values into equal-sized sub-ranges, allowing the user to specify the number of intervals while ArcMap determines where the breaks should occur (ESRI Inc. 2008)

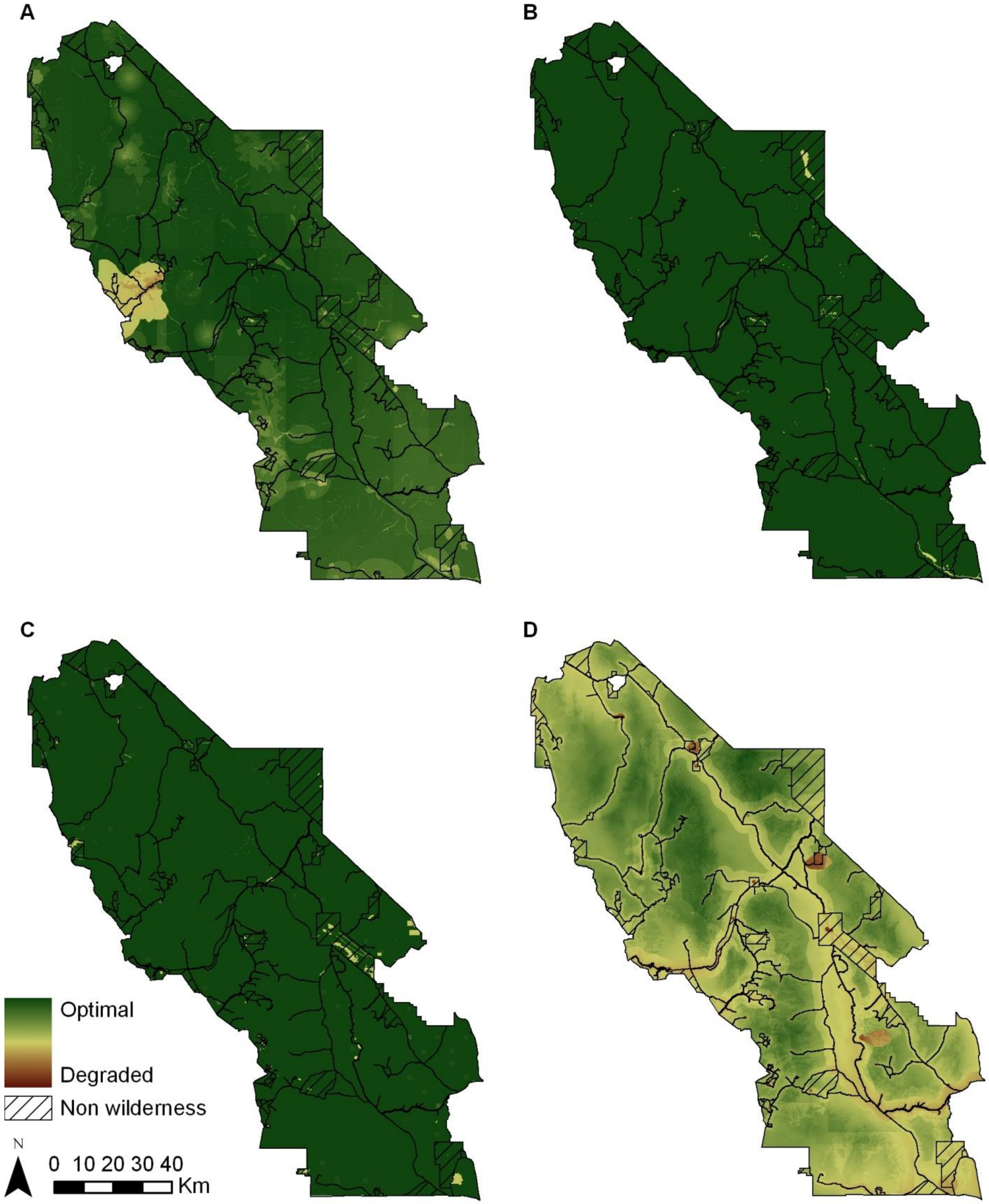

Figure 16. *Four qualities of wilderness character: (A) natural, (B) untrammeled, (C) undeveloped, and (D) opportunities for solitude or primitive and unconfined recreation. Green depicts optimal quality and brown depicts degraded quality.*

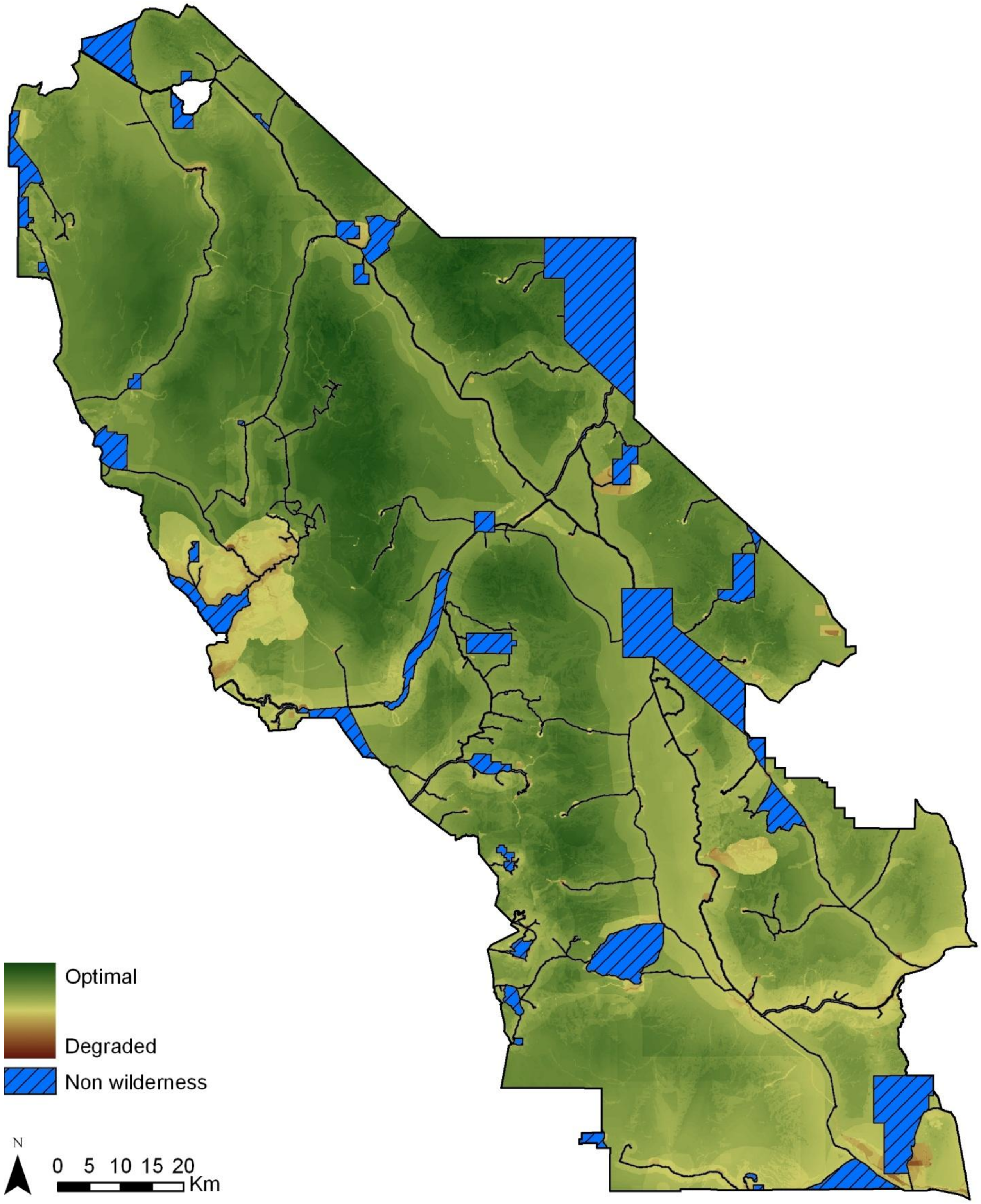

Figure 17. *Map of wilderness character in DEVA. Green depicts optimal quality and brown depicts degraded quality.*

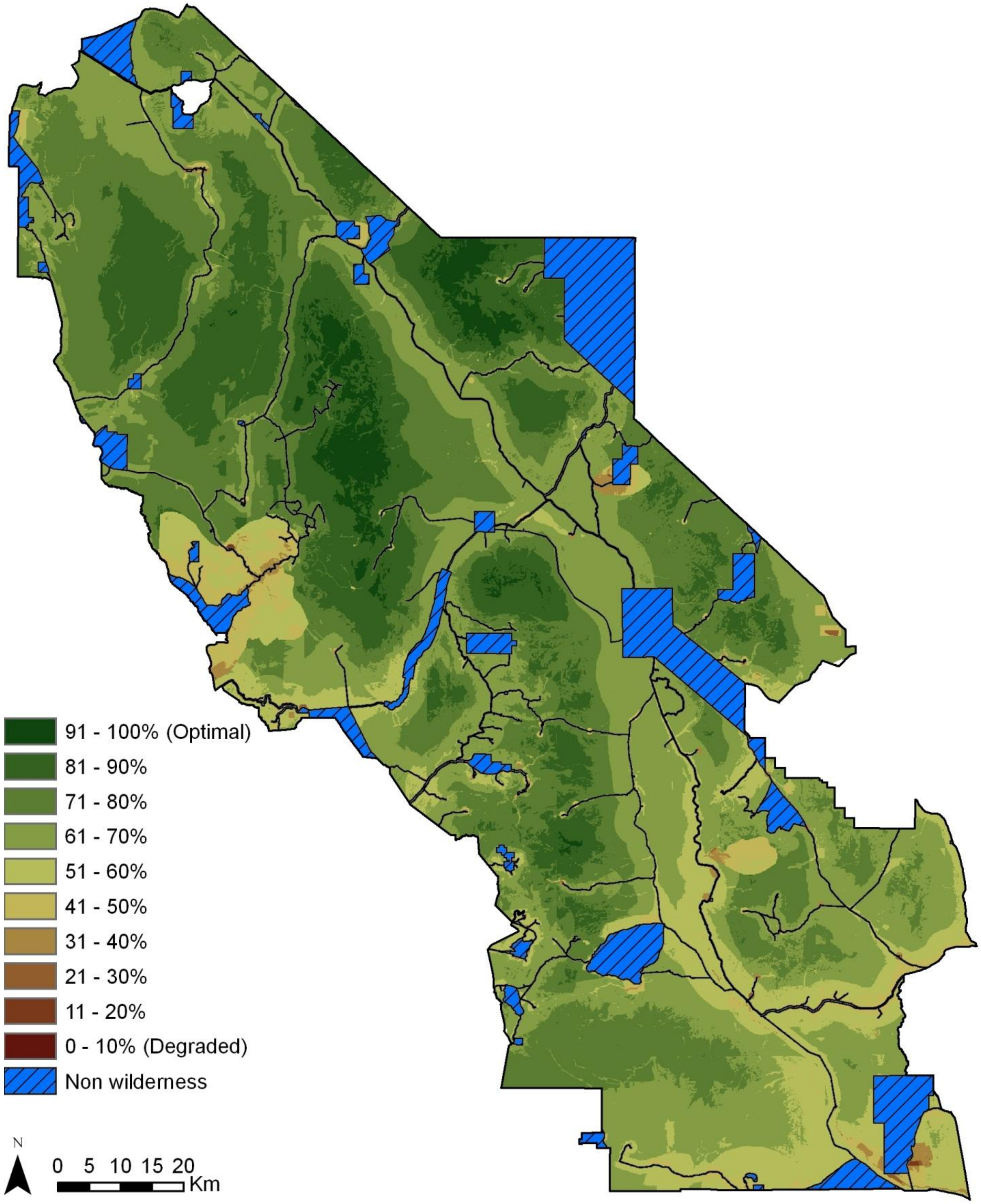

Figure 18. *Map of wilderness character in DEVA reclassed into ten equal categories. Green depicts optimal quality and brown depicts degraded quality.*

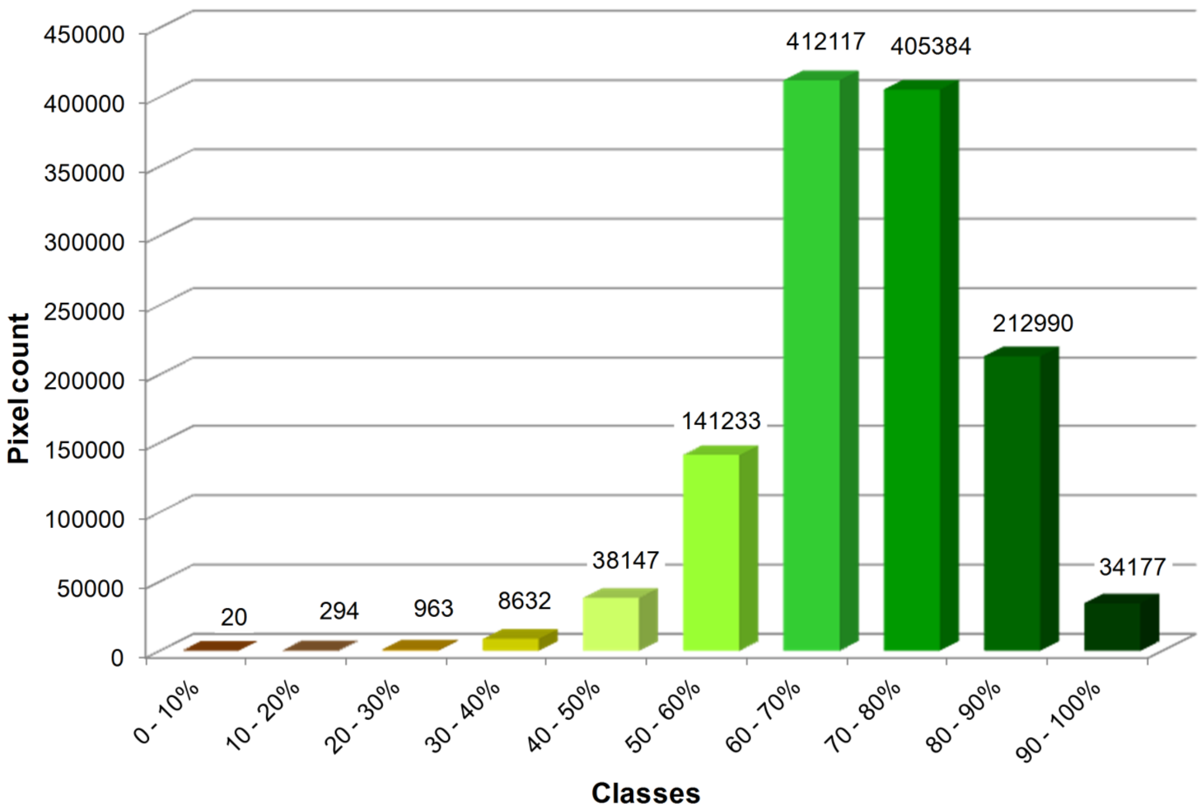

Figure 19. *Histogram of the wilderness character map values.*

Uncertainty in the Wilderness Character Map

The wilderness character map is sensitive to two main sources of uncertainty: the accuracy of the data that comprise the data inputs, and the weights assigned to the data inputs. To model data accuracy uncertainty, error models were created to generate random noise to the continuous and discrete datasets. However, adding these results together to form the wilderness character map proved inconclusive (due to the variety and scale of data). Thus, whilst it is difficult to evaluate how and where data error propagates through the map, we can establish that the map will be sensitive to data error at a local level.

For uncertainty associated with the assigned weights, we can assume that the weights are correct as they were chosen by the park staff. However, the process of defining these weights was subject to small adjustments until the staff were satisfied with how the various assigned weights influence the map products. To investigate which areas in the wilderness character map would be most sensitive to these small adjustments, a Monte Carlo simulation (bootstrapping) approach was applied to model the effects of this uncertainty. The data input weights were randomized within their indicators by ±10% and rescaled before generating the wilderness character map. This process was repeated 100 times and a composite map created (Figure 20). Mean and standard deviation of these 100 iterations were calculated to determine the overall sensitivity of the model and identify any areas of localized sensitivity.

The results indicate that some areas of the park are more sensitive to weighting uncertainty then others. For example, in Figure 20 the blue areas indicate where the map is most robust to changes in weights, whereas the yellow to red areas are more sensitive to changes. This map can be used to help inform decisions made in these more sensitive areas by recommending extra caution when using the wilderness character map for supporting particular management decisions.

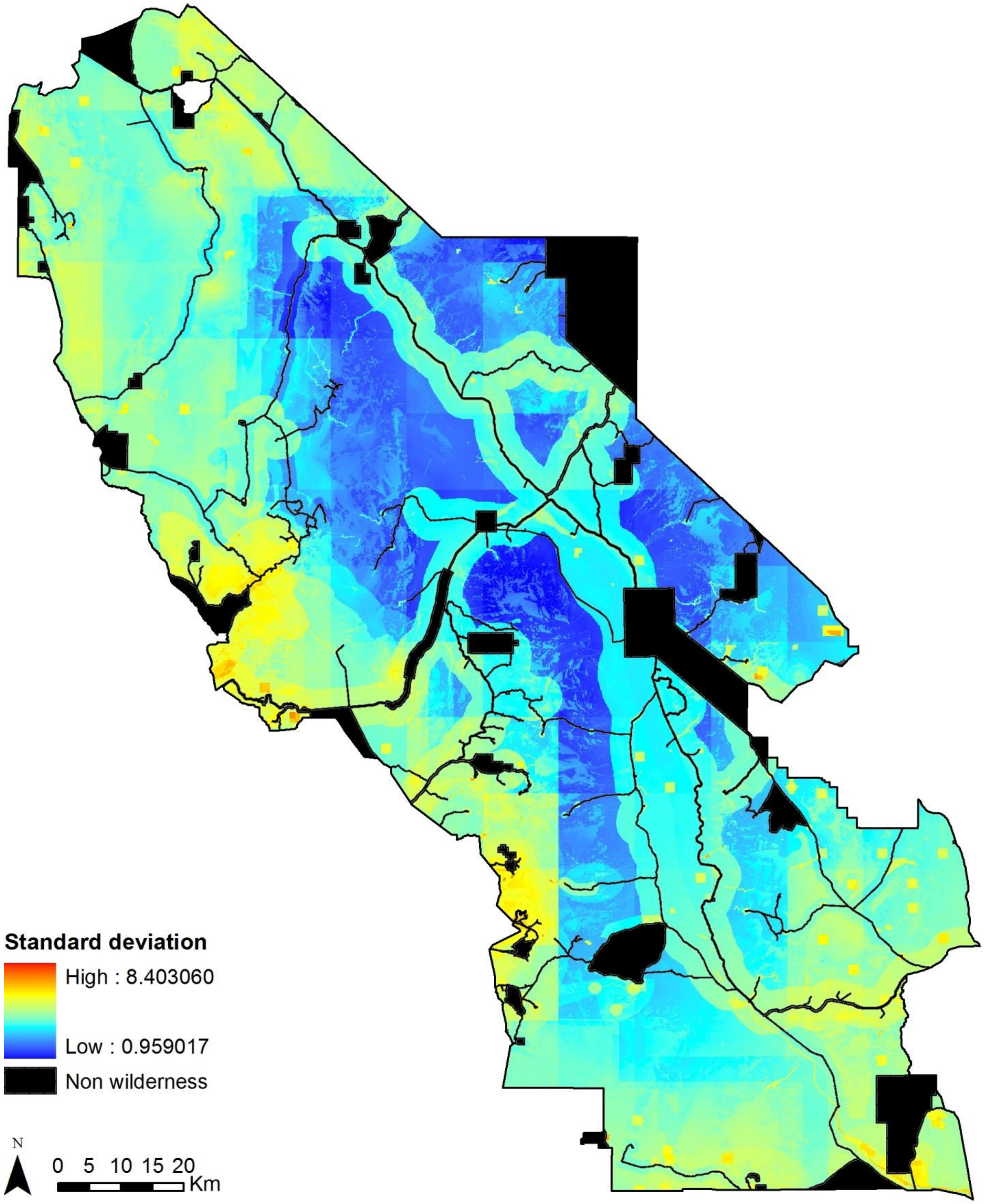

Figure 20. *Sensitivity to data input weights. Blue indicates areas that are more robust to weight uncertainty and red indicates areas that are more sensitive to the weight uncertainty.*

Improvements

The map products presented in this document have much room for improvement. The maps are highly dependent on the wide range of spatial datasets that define wilderness character. As the data quality becomes more accurate and complete and the missing data gaps are filled, the maps will improve. Again, the availability of improved land cover maps and a high resolution Digital Surface Model would increase the accuracy and effectiveness of the travel time and viewshed models.

The issue of data quality also highlights the need for the NPS to manage its spatial database more effectively. Clear communication is required to ensure that contractors providing GIS products for the park submit comprehensive datasets and easy-to-understand metadata. Again, clear communication with scientists conducting research in DEVA can allow for the generation of spatial datasets that can be used to inform the map products. An example of this communication is the night sky raster data: discussion with night sky researchers facilitated the development of data inputs for use in this study by interpolating data from the various survey points to create a set of informative, useable rasters.

The database can be further improved by creating awareness among park staff to correctly record spatial information gathered in the field. Field staff should be encouraged to learn how to operate GPS units and download data into spatial datasets. Park staff with backcountry experience should be encouraged to meet regularly with GIS technicians to transfer their knowledge into spatial datasets. Field staff can also be used to ground-truth the accuracy of spatial datasets used in the wilderness character map. In particular, it would be useful to test the output of the travel time and viewshed models against observations in the field.

Considering the extremely high summer temperatures in DEVA, maps could be produced to emphasize the impact of seasonality on the different wilderness qualities. In particular, the hot summer months have a significant impact on visitor use. The travel time model could be recalibrated to depict the effects of having to carry more water, walking slower to prevent over-heating, and taking more rest stops. Similarly, there are sections of road that are routinely closed due to snow and mud during winter months, which would eliminate them as travel routes or points of access in the travel time model during those months. These modifications would result in noticeable changes to the map of the solitude or primitive and unconfined recreation quality.

This mapping approach also highlighted the difficulties in accounting for “value added” features of the landscape. While the concepts of wilderness character are positive, most of the measures identified in *Keeping it Wild* are measures of loss or degradation from an ideal condition. However, conceptually there are some features that add value to wilderness character. For example, it is logical to consider the extirpation of a species as a degradation of the natural quality of wilderness character and the persistence of an imperiled species as a positive value. However, under the mathematical construct of the map and the wilderness character monitoring framework, to add value to pixels in which desert tortoise (a federally listed threatened species) exist would mean that all the other pixels would be devalued for that same data input, even though they might not even be suitable for desert tortoise. A similar paradox exists for paleontological resources and some cultural resources. In many cases, these value added features are a focal point for management actions, such as a paleontological site that is closed to public entry due to the sensitive nature of the resources at that location (e.g., Copper Canyon). In that case, the map depicts a loss of unconfined recreation and thus a degradation of the solitude quality of wilderness character without accounting for the value added to wilderness character by the presence and persistence of the paleontological resources. A future improvement to this mapping approach would be to find a way to include "value added" situations rather than just degradations of wilderness character.

Final Concerns about Mapping Wilderness Character

A major concern of this work common to all GIS analyses is the tendency for end-users to ascribe false levels of reliability and precision to the maps because they look accurate. Therefore, it is important to emphasize that these map products are only intended as an estimate of selected aspects of wilderness character and their relative spatial dimensions of variability and pattern. Another concern is that wilderness researchers and users may debate the merits of even attempting to map wilderness character. Some suggest that quantification of wilderness character does not reflect how wilderness affects each of us in different ways (e.g., Watson 2004), while others point to the need to develop indicators that can be used to aid monitoring and management (e.g., Landres 2004). Therefore, it is important to clarify that the maps do not in any way portray the symbolic, intangible, spiritual, and experiential values of wilderness character that are unique to the individual person, the location, and the moment.

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Appendix A. Deviation from Natural Condition and Travel Impedance for Land Cover Classes

The condition column ranks the land cover classes on a scale of 1-5 according to their deviation from natural condition (1 = least natural, 5 = natural). The impedance column ranks the land cover classes on a scale of 1-5 according to their perceived impedance when “walking” through the landscape (1 = easy, 5 = difficult).

Habitat - Central Mojave Mapping Project	**Condition**	**Justification**	**Impedance**
Mining	1	Highly altered landscape	4
Rural Development	1	Highly altered landscape	1
Urban	1	Highly altered landscape	1
Agricultural Land Use	2	Altered landscape	2
Mesquite Shrublands	4	Manipulated by traditional use	4
Pinyon Woodlands and Shrublands	4	Manipulated by traditional use	3
Big Sagebrush Shrubland	5	Unmanipulated and unaltered	1
Blackbrush Shrubland	5	Unmanipulated and unaltered	2
Creosote Bush Shrubland	5	Unmanipulated and unaltered	2
Creosote Bush/Brittlebush Mosaic	5	Unmanipulated and unaltered	2
Desert Holly Shrubland	5	Unmanipulated and unaltered	1
Dunes	5	Unmanipulated and unaltered	5
Galleta Grasslands	5	Unmanipulated and unaltered	1
High Elevation Pine Woodlands	5	Unmanipulated and unaltered	3
High Elevation Wash System	4	Corridor frequently used for human foot travel, some impacts	1
Hopsage Shrubland	5	Unmanipulated and unaltered	1
Iodine Bush-Bush Seepweed Complex	5	Unmanipulated and unaltered	2
Joshua Tree Wooded Shrubland	5	Unmanipulated and unaltered	2
Juniper Wooded Shrubland	5	Unmanipulated and unaltered	3
Lava Beds and Cinder Cones	5	Unmanipulated and unaltered	5
Low Elevation Wash System	4	Corridor frequently used for human foot travel, some impacts	1
Menodora Shrubland	5	Unmanipulated and unaltered	1
Mid Elevation Wash System	4	Corridor frequently used for human foot travel, some impacts	1
Mojave Yucca Shrubland	5	Unmanipulated and unaltered	1
Nevada Joint-fir Shrubland	5	Unmanipulated and unaltered	2
Playa	5	Unmanipulated and unaltered	1
Shadscale Shrubland	5	Unmanipulated and unaltered	1
Saltgrass	5	Unmanipulated and unaltered	1
Shadscale Shrubland	5	Unmanipulated and unaltered	1
Sparsely Vegetated	5	Unmanipulated and unaltered	1
White Burrobush Shrubland	5	Unmanipulated and unaltered	1
Habitat - USGS NVCS	**Condition**	**Justification**	**Impedance**
Developed-Open Space	2	Altered landscape	1
Developed-High Intensity	1	Highly altered landscape	2
Developed-Medium Intensity	1	Highly altered landscape	1
Agriculture-Cultivated Crops and Irrigated Agriculture	2	Altered landscape	3
Developed-Low Intensity	2	Altered landscape	1
Agriculture - Pasture/Hay	2	Altered landscape	2

Habitat - USGS NVCS	Condition	Justification	Impedance
Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	5	Unmanipulated and unaltered	2
Introduced Riparian Vegetation	3	Unnatural veg type, but still has some natural habitat value	2
Introduced Upland Vegetation-Annual Grassland	3	Unnatural veg type, but still has some natural habitat value	1
Introduced Upland Vegetation-Perennial Grassland and Forbland	3	Unnatural veg type, but still has some natural habitat value	1
Introduced Upland Vegetation-Annual and Biennial Forbland	3	Unnatural veg type, but still has some natural habitat value	1
Rocky Mountain Aspen Forest and Woodland	5	Unmanipulated and unaltered	2
Great Basin Pinyon-Juniper Woodland	4	Manipulated by traditional use	2
Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	5	Unmanipulated and unaltered	2
California montane Jeffery Pine (Ponderosa Pine) woodland	5	Unmanipulated and unaltered	2
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	5	Unmanipulated and unaltered	2
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	5	Unmanipulated and unaltered	2
Southern Rocky Mountain Ponderosa Pine Woodland	5	Unmanipulated and unaltered	2
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Greasewood Flat	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Montane Riparian Systems	4	Corridor frequently used for human foot travel, some impacts	3
North American Warm Desert Riparian Systems	4	Corridor frequently used for human foot travel, some impacts	3
Rocky Mountain Montane Riparian Systems	4	Corridor frequently used for human foot travel, some impacts	3
Open Water	5	Unmanipulated and unaltered	barrier
Barren	5	Unmanipulated and unaltered	1
Inter-Mountain Basins Sparsely Vegetated Systems	5	Unmanipulated and unaltered	1
North American Warm Desert Sparsely Vegetated Systems	5	Unmanipulated and unaltered	1
Rocky Mountain Alpine/Montane Sparsely Vegetated Systems	5	Unmanipulated and unaltered	1
Great Basin Xeric Mixed Sagebrush Shrubland	5	Unmanipulated and unaltered	1
Inter-Mountain Basins Big Sagebrush Shrubland	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Mixed Salt Desert Scrub	5	Unmanipulated and unaltered	1
Mojave Mid-Elevation Mixed Desert Scrub	5	Unmanipulated and unaltered	1
Sonora-Mojave Creosotebush-White Bursage Desert Scrub	5	Unmanipulated and unaltered	2
Sonora-Mojave Mixed Salt Desert Scrub	5	Unmanipulated and unaltered	1
Great Basin Semi-Desert Chaparral	5	Unmanipulated and unaltered	4
Mogollon Chaparral	5	Unmanipulated and unaltered	4

Habitat - USGS NVCS	Condition	Justification	Impedance
Rocky Mountain Gambel Oak-Mixed Montane Shrubland	5	Unmanipulated and unaltered	2
Sonora-Mojave Semi-Desert Chaparral	5	Unmanipulated and unaltered	4
Southern Rocky Mountain Ponderosa Pine Savanna	5	Unmanipulated and unaltered	2
Columbia Plateau Low Sagebrush Steppe	5	Unmanipulated and unaltered	1
Inter-Mountain Basins Big Sagebrush Steppe	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Montane Sagebrush Steppe	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Semi-Desert Shrub-steppe	5	Unmanipulated and unaltered	2
Inter-Mountain Basins Semi-Desert Grassland	5	Unmanipulated and unaltered	1
Rocky Mountain Subalpine-Montane Mesic Meadow	5	Unmanipulated and unaltered	2
Coleogyne ramosissima Shrubland Alliance	5	Unmanipulated and unaltered	2
Grayia spinosa Shrubland Alliance	5	Unmanipulated and unaltered	1
Artemisia tridentata ssp. vaseyana Shrubland Alliance	5	Unmanipulated and unaltered	2

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