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Mapping Wilderness Character in Sequoia and Kings Canyon National Parks

Natural Resource Technical Report NPS/SEKI/NRTR—2014/872

ON THE COVER
Backpacker hikes through foxtail pine stand at Little Claire Lake, Sequoia National Park.
Photograph by: Linda Mutch

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Natural Resource Technical Report NPS/SEKI/NRTR—2014/872

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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 legislative 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 or geographic features in wilderness, a Geographic Information System (GIS) -based approach was developed to identify the state of wilderness character for the designated and proposed wilderness inside Sequoia and Kings Canyon National Parks (SEKI).

A set of indicators and measures was identified by SEKI staff to capture the impacts to the four qualities of wilderness character (natural, untrammeled, undeveloped and solitude or primitive and unconfined recreation). These measures were depicted using a variety of spatial datasets and were formatted to compare on a common relative scale. Each measure was “weighted” by SEKI staff to reflect its importance in relation to other measures. Maps were generated for each of the four qualities of wilderness character, which were added together to produce the composite wilderness character map for SEKI.

The SEKI wilderness character map delineates the range in condition of wilderness character, based on the measures that were identified and the datasets that were used. A histogram of the wilderness character map values reveals that the majority of wilderness character in SEKI is of high quality. This map will be used as a baseline representing wilderness character condition in SEKI, and future assessments of wilderness character can be updated with new and improved data as they become available. In addition, the map will be used by SEKI staff to evaluate spatial impacts of different planning alternatives during the development of the SEKI Wilderness Stewardship Plan.

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Special thanks to Karen Taylor-Goodrich and Woody Smeck (former and current Sequoia and Kings Canyon National Parks Superintendents) for encouraging and supporting this project. Additional thanks goes to Alex Eddy, Cartographic Technician, who brought together, processed, and mapped much of the data that contributed to the wilderness character map. Plus a big thanks to all the SEKI staff and other individuals involved with the project, for their passion and commitment to protecting the wilderness resource of Sequoia and Kings Canyon National Parks, and for supporting the wilderness ideal. Linda Mutch provided editing support, assisted with park response to peer review comments, and formatted the document. Finally, we would like to thank report reviewers Charlie Callagan, Sandee Dingman, David Graber, Pat Lineback, and Alison Steiner for improving the clarity and overall presentation of information in this report.

Acronyms and Abbreviations

AUN	Animal Unit Nights (relative to stock grazing)
CMAQ	Community Multi-scale Air Quality
DEM	Digital Elevation Model
DMSP	Defense Meteorological Satellite Program
DSM	Digital Surface Model
GIS	Geographic Information System
HSC	High Sierra Camp
IRMA	Integrated Resource Management Applications
MRA	Minimum Requirement Analysis
MYLF	Mountain yellow-legged frog
NAD	North American Datum
NPS	National Park Service
NRHP	National Register of Historic Places
NWPS	National Wilderness Preservation System
PCT	Pacific Crest Trail
SEKI	Sequoia and Kings Canyon National Parks
SIEN	Sierra Nevada Network (Inventory & Monitoring Program)
USFS	U.S. Forest Service
UTM	Universal Transverse Mercator
VRMA	Vertical Relative Moving Angle
WTZ	Wilderness Travel Zone

Introduction

The 1964 Wilderness Act (Public Law 88-577) established the National Wilderness Preservation System (NWPS) "for the protection of these areas, [and] the preservation of their wilderness character" (Section 2a). In congressional testimony clarifying the intent of wilderness designation, Howard 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," 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. 2008a).

As described in the publications referenced above, 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 mapped at a variety of scales: globally (Sanderson et al. 2002), continentally (Carver 2010), nationally (Aplet et al. 2000), and locally (Carver et al. 2008). These maps depict how these attributes vary across the landscape from least to most wild. Adding to this body of work, a recent study (Tricker et al. 2012, Carver et al. 2013) has provided a spatially explicit description of wilderness character for all lands falling within a particular NPS wilderness. SEKI is now part of a second wave of NPS wilderness areas that are developing a wilderness character map.

The Sequoia-Kings Canyon Wilderness was established in September of 1984 when President Ronald Reagan signed the California Wilderness Act (PL 98-425). In March 2009, President Barack Obama signed the Omnibus Public Land Management Act (PL 111-11) designating the John Krebs Wilderness and the Sequoia-Kings Canyon Wilderness Addition (all wholly contained within SEKI). Currently a total of 808,078 acres of SEKI are designated as wilderness and are a part of the National Wilderness Preservation System, wherein wilderness character is to be preserved. An additional 29,516 acres of these parks are proposed wilderness, and are managed as wilderness per NPS policy. Finally, 212 acres are classified as Designated Potential Wilderness Areas and would be designated as wilderness if the existing non-conforming uses (such as powerlines and inholdings) were no longer present. The 837,806 acres of SEKI designated and managed as wilderness comprise 96.7% of all lands within SEKI (Figure 1).

SEKI's wilderness abuts additional designated wilderness on the Inyo, Sierra, and Sequoia national forests (Figure 2). This puts the parks' wilderness at the heart of a contiguous area of wild lands that provide the highest level of natural-resource protection for roughly 25% of the Southern Sierra Nevada (Thorne et al. 2013). Together these areas comprise the largest continuous designated wilderness area in California. SEKI's wilderness stretches from foothills and canyons starting at 1,400 feet in elevation to Mount Whitney, the tallest peak in the contiguous United States at 14,494 feet. This represents the greatest elevation gradient range of any protected area in the lower 48 states. The wilderness contains the summits of 12 of the 15 peaks in California that are 14,000 feet or

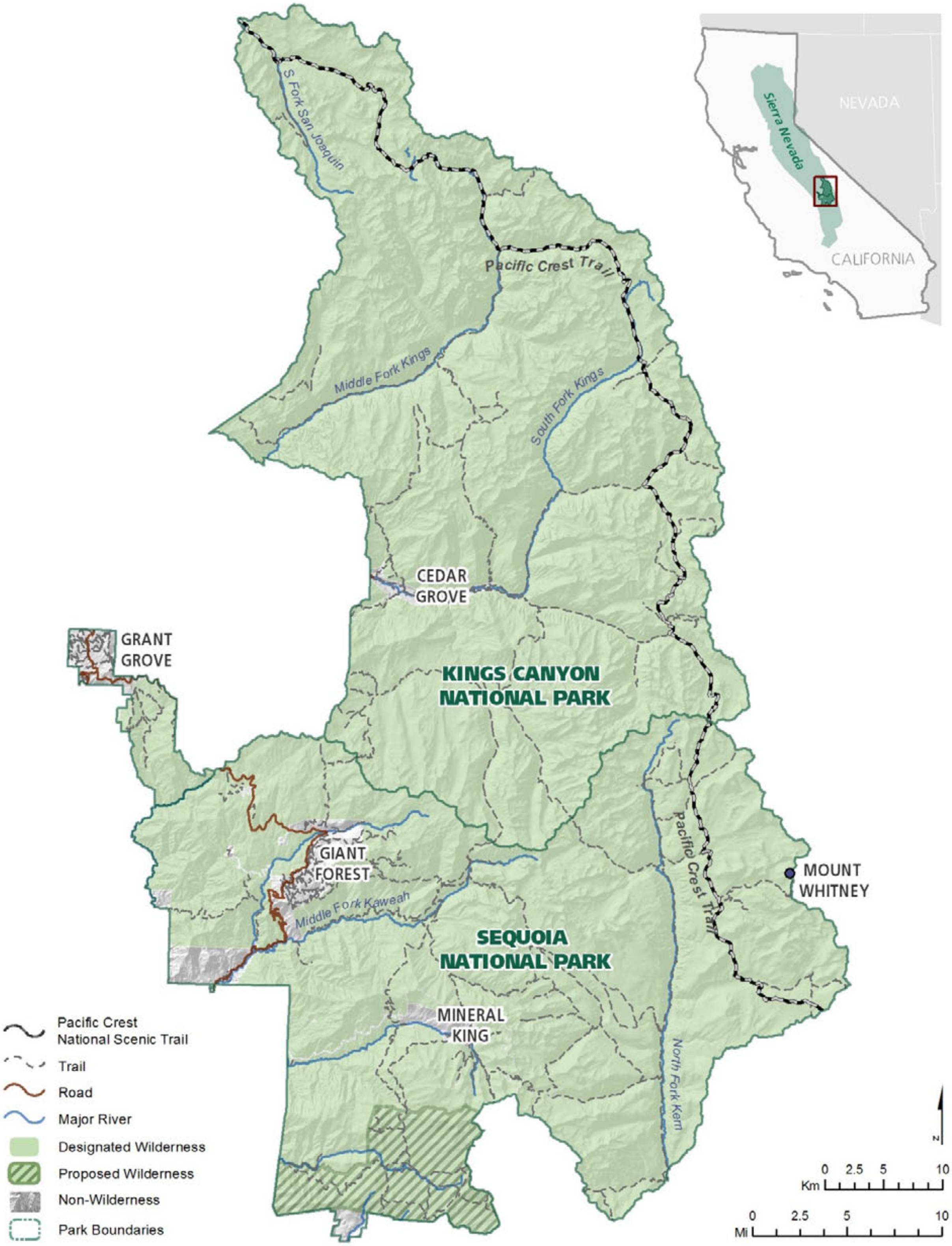


Figure 1. Sequoia and Kings Canyon National Parks.

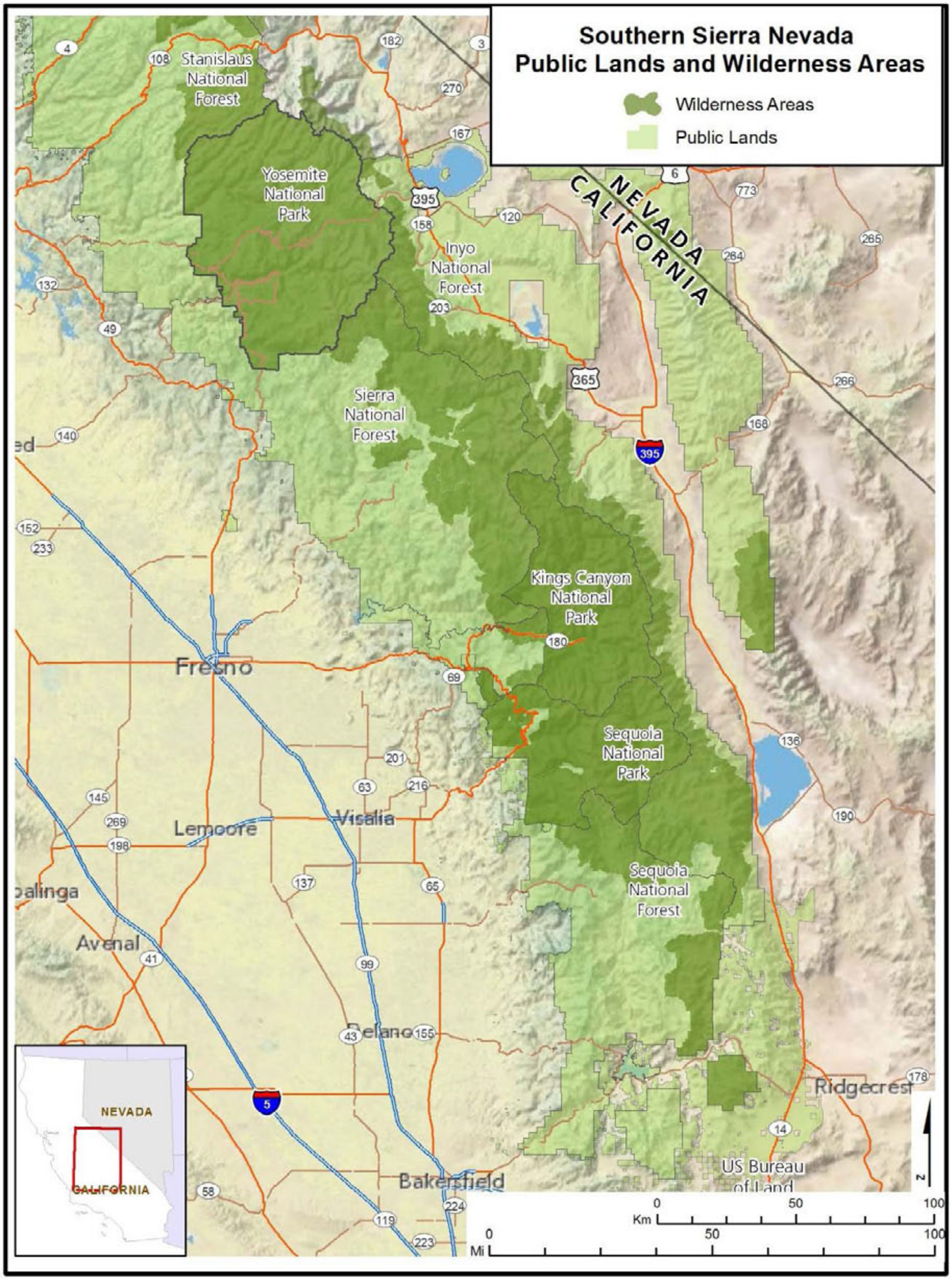


Figure 2. Wilderness areas in the Sierra Nevada.

higher, including Mount Whitney. The Pacific Crest National Scenic Trail and the John Muir Trail traverse SEKI's wilderness on a north-south trajectory.

The purpose of this project was to develop an approach that spatially depicts the condition of SEKI's wilderness character qualities and how they vary across the wilderness of these parks. This map of wilderness character will:

- Show the current overall condition of wilderness character and how it varies across the 837,806 acres of the wilderness of Sequoia and Kings Canyon National Parks.
- Provide a measurement baseline from which future monitoring can show spatial trends and changes in wilderness character over time.
- Allow the park to analyze the potential impacts of different management actions on wilderness character, such as those included in the current SEKI Wilderness Stewardship Plan. Similarly, this map can be used in the future to analyze the effects of site-specific projects on wilderness character.
- Identify areas within the wilderness where resource managers should make an effort to control or mitigate impacts. These efforts may include monitoring conditions, establishing thresholds, or taking direct action.
- Improve internal staff communication about wilderness and wilderness character; and improve external communication between the park and the public on related issues.

In addition to the five primary benefits described above, other potential benefits of the wilderness character map include identifying specific areas where actions can be taken inside the wilderness to improve wilderness character, or areas where actions should not be taken because they will degrade wilderness character. The map will also help identify specific activities or impacts outside the wilderness that may pose a substantial risk of degrading wilderness character inside wilderness. These could include permitting of power plants that worsen air quality, relaxation of regulations that reduce automobile emissions, or allowance of lighting in outside communities that degrades dark night sky.

There are a number of potential concerns and cautions about producing the wilderness character map. Despite these concerns, these maps are the best available metric. Specific cautions are described under each measure. 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 improving the quality of wilderness character in other areas.

- *Comparing the condition of wilderness character among wildernesses* – the map may facilitate inappropriate comparison of wilderness character among different wildernesses, as this approach is being repeated for other wilderness areas. The map will show the current status or trend of wilderness character in different colors (representing pixel values), 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 completely describe wilderness character* – the overall map of wilderness character 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. Map products are therefore a representation of wilderness character, and should not be considered as an absolute and complete description. 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.
- *Future wilderness character maps may not be directly comparable* – the map is a product of the spatial datasets that are available at the time the map was created. Future datasets may be more effective in representing impacts to wilderness character but the resulting map products may not be comparable to the current map. In addition, the rationale for assigning degradation values and weights to measures may change over time. The rationale used in making decisions for the current map was based on the working group's experience and understanding of a specific impact. With staff turnover over time, knowledge of the local area and its resources can change, potentially affecting the rationale used in making these decisions. Finally, this caution is similar to all long-term monitoring efforts, where changes in the quality and type of information used can make comparison of some of the original baseline datasets with subsequent ones invalid. Therefore, future changes to rationale and the availability of new datasets need to be handled carefully to allow comparability of map products over time.

A team approach was used to develop the wilderness character map for the wilderness of SEKI, tapping the experience and knowledge of the staff who work at the parks (see page viii & ix for a full list of staff involved). Together, the team and advisors have more than 300 person-years of on-the-ground experience in and with the wilderness of SEKI. The team and advisors conducted multiple face-to-face meetings and had numerous phone and email conversations while 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 that were used to represent the degradation of wilderness character, along with the data sources utilized, 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, approaches to improving map development in the future, and final concerns about the overall process.

Overview of Wilderness Character Map Development Process

The wilderness character mapping project used a Geographic Information System (GIS) to spatially describe and assess the quality of wilderness character in SEKI.[1] The interagency strategy for monitoring wilderness character, as described in *Keeping It Wild* (Landres et al. 2008a), was used as the basis for applying this approach. *Keeping It Wild* identifies four qualities of wilderness character that apply uniquely to every wilderness: natural, untrammeled, undeveloped, and opportunities for solitude or a primitive and unconfined type of recreation. It also identifies a set of indicators[2] and measures[3] to evaluate their condition.

We considered using a fifth quality, called "other features of value," in this project as well. This quality is based on the last clause of Section 2(c) in the 1964 Wilderness Act, which states that a wilderness "may also contain ecological, geological, or other features of scientific, educational, scenic or historical value" (Landres et al. 2012). We excluded the fifth quality because of the following: many of the features are intangible, highly subjective, difficult to describe, or unquantifiable; some features are represented in other qualities (e.g. scenic in *Natural*); and many features lack reliable spatial data sources.

Spatial datasets, which were obtained from a variety of sources, were processed into measures, i.e. raw data were converted into a standardized (normalized) project-specific format. They were then assigned and weighted under an appropriate indicator. The multiple indicators for each quality were combined to produce a map representing the condition of that quality. The four maps, one for each quality, were then combined together to create an overall map of the current condition of wilderness character in SEKI (Figure 3).

A total of 79 datasets were used for measuring and delineating wilderness character in SEKI and comprise local, regional, and national spatial data at varying scales, accuracy, and completeness. This variation places limitations on how the map products are developed. However, initial dataset quality was identified and recorded so that improved data can replace older data as they become available. This procedure builds in flexibility and adaptability to differences in data quality and availability.

The datasets represent features, conditions, and actions that degrade wilderness character. The baseline map of SEKI's wilderness represented optimal wilderness character. Measures were then used to record where each quality has been degraded. For example, the non-native plants measure records (under the plant and animal species and communities indicator) where the natural quality has been degraded. However, there are actions or features in wilderness that have a positive influence on

[1] The analysis was run for the entire park. The non-wilderness areas were clipped out of the final results.

[2] Indicators are distinct and important elements within each quality of wilderness character. They have measurable attributes that can be the focus of wilderness character monitoring efforts.

[3] Measures are a specific tangible aspect of an indicator that can be measured to gain insight into the status of the indicator and assess trends over time.

wilderness. Displaying positive and negative impacts simultaneously on a single map would make it difficult to discern the overall effect on wilderness character. Therefore, SEKI staff decided to adopt a negative mapping approach, in that the measures only record where wilderness character is degrading.

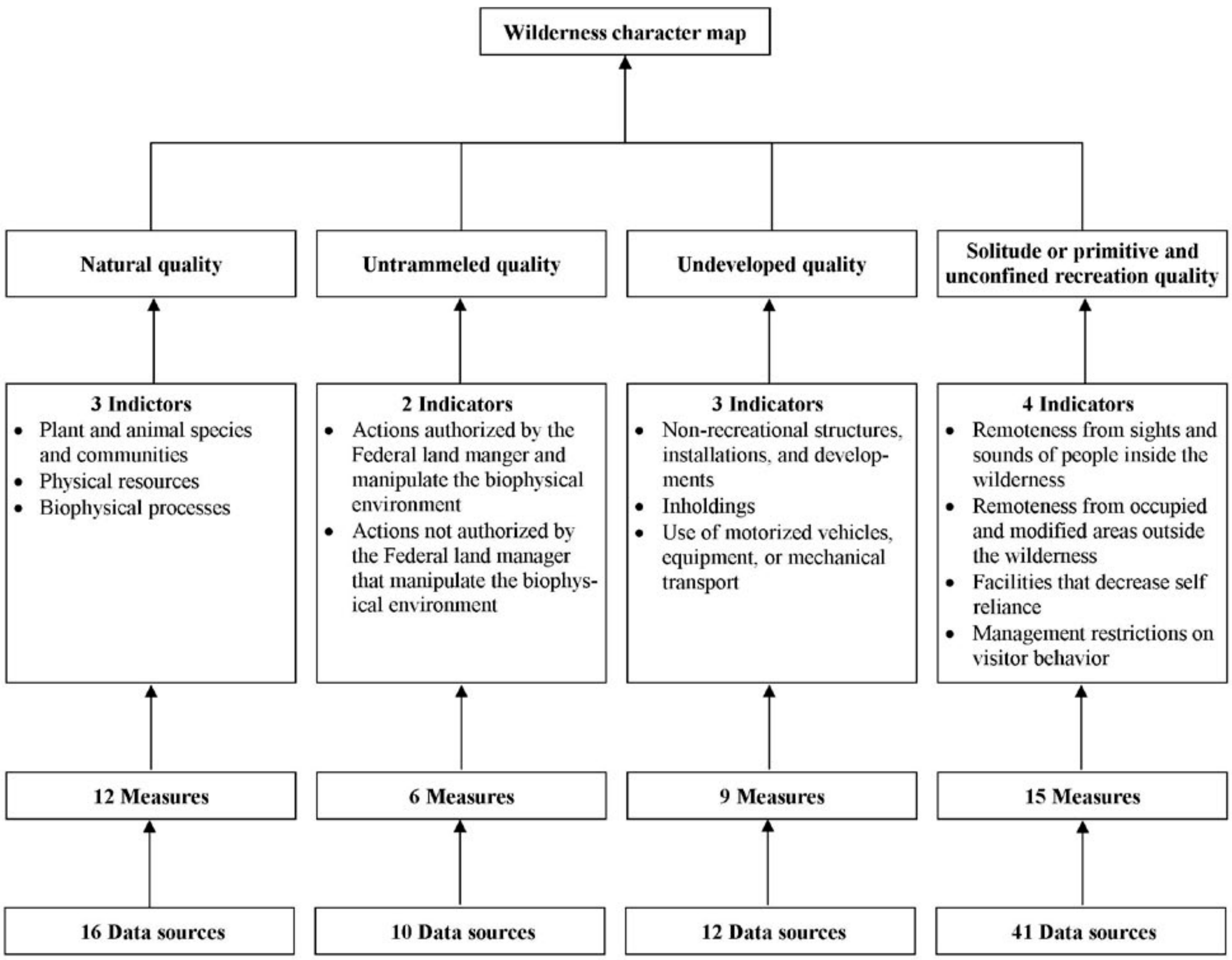


Figure 3. Flow chart for developing the wilderness character map.

The datasets from the various sources were processed, converted to raster grids[4], and normalized[5] into measures. The normalized range of values used for all measures allows them to be evaluated together on a common relative scale (Carver et al. 2008). For example, the soundscape and ozone concentrations maps use different units of measure (decibel vs. parts per billion) and cannot be directly compared without normalization. Higher values of normalized measures represent

[4] Raster data type consists of rows and columns of cells, with each cell storing a single value.

[5] Normalization of measures was achieved using a linear rescaling of the input values (slicing) onto a 0-255 scale on an equal interval basis.

“degraded” conditions and lower values represent “optimal” conditions (or as good a condition as can be expected).

The spatial resolution for all measures was set at 30 meters (m). However, some datasets such as soundscape and ozone concentrations had a significantly lower native resolution. Although using a 30 x 30m pixel size may be too coarse for many features in SEKI (e.g. trails, campsites), the sheer size of the SEKI wilderness meant that choosing a lower resolution would have made these features impossible to see when viewing the wilderness character maps in their entirety.

A hierarchical framework of wilderness character qualities, indicators, and measures taken from *Keeping It Wild* (Landres et al. 2008a and Figure 3) was used to sort each measure under its appropriate wilderness character quality. See Table 1 for examples of measures that were selected to provide information for one established indicator within each of the four qualities of wilderness character. Under the natural quality of wilderness character, the magnitude non-native plant invasion is informed by the “presence of non-native plant species” measure within the “plant and animal species communities” indicator. Each of these qualities has multiple additional indicators and measures that are discussed and displayed spatially in the subsequent sections of this report.

Table 1. Examples of one indicator and measure for each of the qualities of wilderness character addressed in this report.

Quality	Indicator	Measure
Natural— Wilderness ecological systems are substantially free from the effects of modern civilization	Plant and animal species and communities	Presence of non-native plant species
Untrammeled— Wilderness is essentially unhindered and free from modern human control or manipulation	Authorized actions	Suppressed fires
Undeveloped— Wilderness retains its primeval character and influence, and is essentially without permanent improvement or modern human occupation	Non-recreational structures, installations, and developments	Wilderness buildings
Solitude or Primitive and Unconfined Recreation— Wilderness provides outstanding opportunities for solitude or primitive and unconfined recreation	Remoteness from occupied and modified areas outside the wilderness	Dark skies

The assigned values of the measures under each indicator were weighted using a consensus-determined weighting regime based on expert judgments of SEKI staff. These weights reflect the impact of a measure in relation to the other measures under a particular indicator. Factors that were considered include the relationship of a measure to park mission; pervasiveness, intensity and persistence of a measure; the completeness and accuracy of the data sources; and whether data for this measure can continue to be collected. (Rationales for weights assigned to each measure can be found in Tables 3, 5, 7, and 11.) The weighted measures were combined to produce the indicator maps. The indicator maps were then added under their respective qualities to produce four maps showing the condition of each quality of wilderness character. These four maps were then added together to produce a single composite map of wilderness character for SEKI.

The above paragraph raises an important question about combining disparate measures. It could be argued that each measure captures a unique attribute of wilderness, and therefore it would be meaningless to combine different types of measures. For example, combining the areal extent of invasive plants with probability of trail encounters with other visitors may be counterintuitive to the average reader. However, both have an effect on wilderness character. For local management purposes, staff needs data for individual measures. However, the purpose of this mapping project is also to understand and report on the big picture – to represent the overall spatial pattern and variation of the impacts, and how wilderness character is changing over time. Carver et al. (2013) describe the rationale and methods for combining disparate measures to produce an overall map for wilderness character. This big picture is a powerful and effective tool for communicating wilderness issues within the agency and with external audiences (Landres et al. 2008b).

In the methods section, we present a number of cautions that are necessary for understanding and interpreting the wilderness character maps. These cautions describe and qualify the decisions made when formatting the datasets into numeric measures. They also explain the calibration or standardization of the parameters for models used in the solitude quality to depict travel time and viewshed.

Methods

The four qualities of wilderness character were mapped using a combination of available datasets and GIS-based techniques. Most of the datasets were produced for all lands within the Sequoia and Kings Canyon National Parks boundary[6]. Metadata were developed for each data layer used in the wilderness character assessment; documentation captured processing flows, quality/completeness, editing, development, and cautionary notes. All data and metadata are organized and stored on a network drive to ensure accessibility and facilitate use in future analyses. Datasets include:

- commonly-used data layers that are stored in the parks' Spatial Data Warehouse, a centrally-located geospatial repository that is accessible to park staff;
- existing data layers associated with previous or on-going park projects;
- existing datasets that were edited, combined, or refined as a prerequisite for use in this project; and
- original datasets that were developed from local sources - including records, reports, and expert knowledge - and converted into a geospatial format.

In the sections below that describe the analyses done for each wilderness quality, the data sources, processing, and cautions are described for all the included measures. All datasets were projected in ArcGIS using the NAD 1983 UTM Zone 11N coordinate system. Notes for relevant technical GIS terms and processes are included as footnotes.

Selecting measures was an iterative and collaborative decision-making process. The steps included: identifying possible measures, reviewing possible measures for relevance to the indicator, and determining data availability and data quality. In general, only measures that were relevant and data that were readily available and of sufficient quality were included. However, some measures that were important in SEKI had insufficient or non-existent data. SEKI staff acknowledged these measures as placeholders under each applicable indicator and noted data as missing or not useable for these analyses. As data improve or become available, wilderness character mapping can be repeated to include these data.

A number of basic processing tasks were performed for datasets using ArcGIS[7] before they were used as measures to create the wilderness character map. Values were assigned to the vector[8] datasets to represent their spatial impact in SEKI. The vectors were then converted to rasters at 30m resolution, whereby their extent was represented by the assigned values; the rest of the parks, where no degradation occurs, were set to a value of 0. Some of the vector datasets have a range of values because of the data they represent. For example, the measure "trails" has the value of 1 for minimally developed (Class 1) trails, a value of 2 for moderately developed (Class 2) trails, a value of 3 for

[6] Non-wilderness areas were clipped out of the final map products.

[7] GIS software developed by Environmental Systems Research Institute.

[8] Vector data type uses points, lines, and polygons to represent features.

developed (Class 3) trails , and a value of 0 for the remainder of the parks (US Forest Service 2008). The original raster datasets retained their native resolution and were clipped to the designated and proposed wilderness boundary. All the grids' layers were stretched to a standardized (normalized) range of values (0-255).

All measures were assigned a "weight" by the SEKI staff. The total weight of the measures within each indicator always equaled 100. A measure's weight reflects its impact to wilderness character in relation to the other measures within the indicator. For example, under the biophysical resources indicator the following weights were applied: stock grazing (25%), departure from fire regime (70%), and effects of human infrastructure (5%). The high weight for the "departure from fire regime" measure reflects the extent and impact that this measure has on the biophysical resources indicator throughout the entire wilderness. The relative low weight for the "effects of human infrastructure" measure implies that this measure's impacts are localized and less severe than the other measures in the indicator. Furthermore, park staff can review the initial map outputs and modify the weighting scheme in order to reflect park experience about the condition of wilderness character, and then rerun and review subsequent maps until results are satisfactory. This interactive process runs the risk of allowing staff to "game the system" and produce a desired outcome, so caution and oversight is needed. Staff experience, however, has been shown to be highly accurate in judging resource conditions (Cook et al. 2009), which reinforces the necessity for SEKI staff to review the maps and adjust the weights to produce the most accurate maps possible.

Weights were also provided for "missing" measures should they become available in the future. These weights and their impact on the weights of existing measures are indicated in brackets. All maps are displayed using the "minimum – maximum" stretch method[9] unless otherwise stated. The color ramp depicts areas of intact, high quality wilderness character as blue and degraded areas of wilderness character as red.

[9] The stretch method defines the type of histogram stretching that was 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 were used as endpoints for the histogram (ESRI 2013).

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. 2008a).

Indicators and Measures

Measures were selected for each of the three indicators recommended in *Keeping It Wild* (Landres et al. 2008a). The indicators, their measures, and their relevance to the natural quality are listed below:

Indicator: Plant and animal species and communities

Sierra Nevada bighorn sheep were listed as federally-endangered in 2000. The NPS is working with other agencies to re-introduce them to some of their former range. Photo: California Dept. of Fish and Wildlife.

- Presence of non-native fish in naturally fishless water bodies – The presence of non-native predatory fish in SEKI water bodies relates directly to the health of aquatic ecosystems. The fish feed on native amphibians; the resulting amphibian displacement also affects other organisms such as invertebrate communities, snakes, and birds.

- Magnitude of invadedness by non-native plants – Alien plant species affect the natural quality by displacing native vegetation and altering desired ecosystem regimes resulting in a change to the natural environment.

- Areal extent of old marijuana grow sites – Marijuana grow sites affect natural characteristics because growers remove native vegetation, clear the ground, disrupt natural water systems, introduce chemicals, and poach/displace animals. Grow sites are generally in foothill or lower-montane areas where there are fewer degrading effects to the natural quality.

- Sierra Nevada bighorn sheep unoccupied former habitat – Sierra Nevada bighorn sheep (*Ovis canadensis sierra)* is an iconic, federally-endangered subspecies of bighorn sheep that has declined due to disease spread by domestic sheep and other factors. Parks are working with cooperating agencies to re-introduce sheep to some of their former range but until that time the sheep as a native herbivore are absent and thus ecological processes may be altered.

- Absence of frogs in former habitat – This is a direct measure of the degradation of the natural quality because loss of native mountain yellow-legged frogs (*Rana sierrae* and *R. muscosa*) indicates changes in the natural system. These frogs are also eligible for Endangered Species Act listing.

- Presence of blister rust in white pines, caused by a non-native pathogen, *Cronartium ribicola* – A key measure of the degradation of iconic white pines which play an important role in montane and sub-alpine ecosystems. The occurrence of blister rust increases rates of tree mortality, altering forest structure and species composition. Five-needle white pines are foundational species in treeline forests of the Sierra Nevada and other Pacific West Region parks, creating locally stable conditions required by many other species, and stabilizing fundamental ecosystem processes (Ellison et al. 2005). If a foundation tree species is lost from these systems, it will likely lead to a cascade of secondary losses, shifts in biological diversity, and ultimately affect the functioning and stability of the community (Ebenman and Jonsson 2005).

Indicator: Physical resources

- Ozone concentration – This is a direct measure of the degradation of the natural quality as ozone is one of the most damaging pollutants in the parks. If current ozone concentrations remain relatively constant, or increase, they may lead to shifts in forest structure and composition, affect the genetic composition of pine and sequoia seedling populations, and contribute to increased susceptibility to fatal insect attacks, death rates, and decreased recruitment (Ferrell 1996, Miller 1996).

- Nitrogen deposition rate – This is a direct measure of the degradation of the natural quality because deposited nitrogen alters aquatic systems. Increased nitrogen and phosphorous inputs are contributing to long-term eutrophication, changes in nutrient cycles, and shifts in phytoplankton communities in Sierra Nevada lakes (Goldman et al. 1993, Sickman et al. 2003). Episodic acidification threatens Sierra Nevada lake ecosystems at elevations above 3500 meters.

- Night sky darkness (light pollution) – Ambient light from cities and other developments close to wilderness may alter night functions of ecosystems. Animals can experience increased orientation or disorientation from additional illumination and are attracted to or repulsed by glare, which affects foraging, reproduction, communication, and other critical behaviors. Artificial light disrupts interspecific interactions evolved in natural patterns of light and dark (Longcore and Rich 2004).

Indicator: Biophysical processes

Many areas of the parks have a long tradition of recreational stock use extending more than 120 years. Photo: NPS.

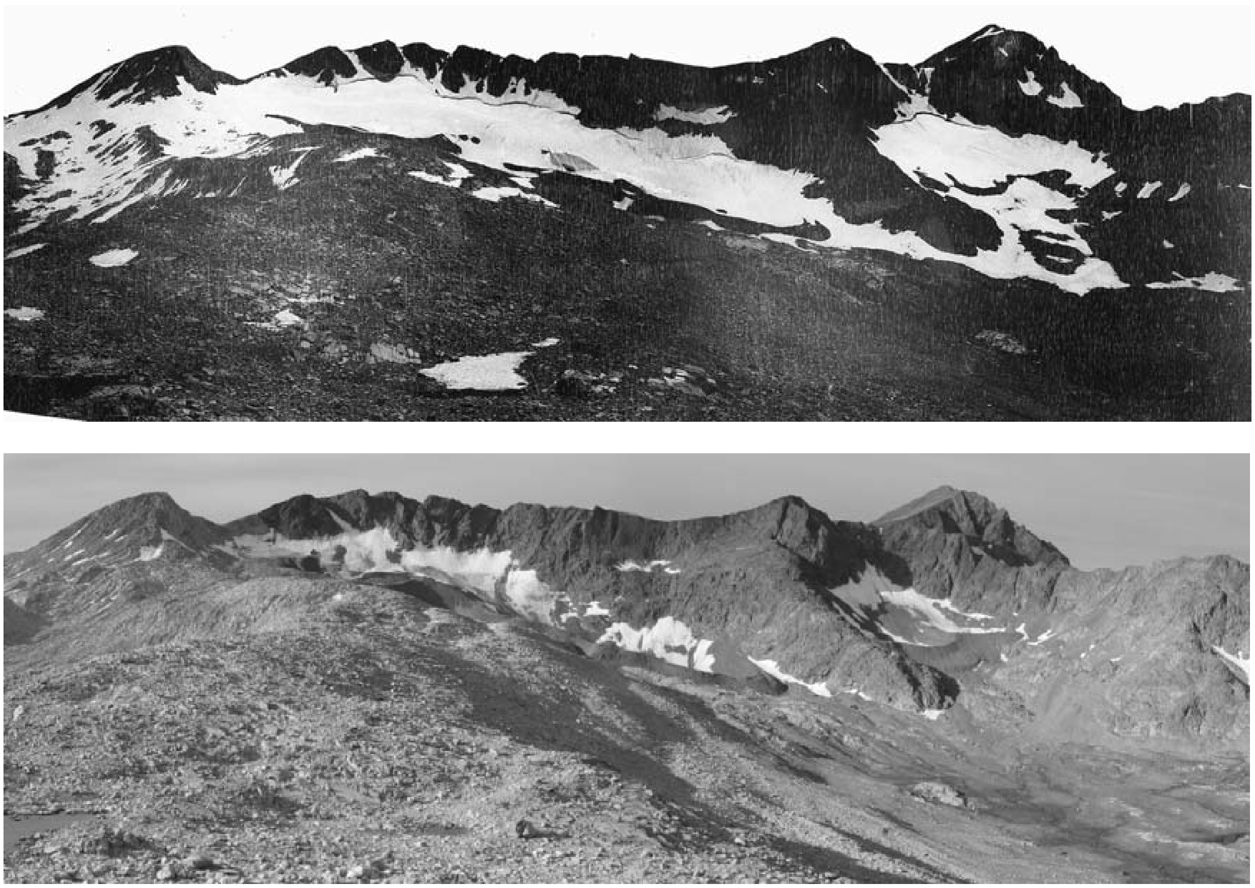
- Number of stock nights in meadows with stock grazing – A *stock night* represents an overnight stay by any pack animal, whether or not the animal grazed or was fed supplemental feed, and without reference to the more conventional animal unit night. An *animal unit* is equal to approximately 1,000 pounds of grazing animal; an *animal unit night* refers to an overnight stay by that animal. In range management almost everything is compared to cows, which at approximately 1,000 pounds are rated at 1.00 animal unit night. According to this system, an overnight stay by a horse or mule is defined as 1.25 animal unit nights, as these animals eat 25% more than cows. We use stock nights for this report as this metric facilitates combining data from multiple years to calculate average stock nights and grazing intensity. These measures serve as a proxy for overall effects on biophysical processes in meadows, which are viewed as keystone units in the ecosystem, with relation to vegetation, wildlife, and aquatic/hydrological systems.

- Departure from historic fire regimes – Fire is a process that helps link terrestrial, atmospheric, and aquatic systems through its role in moving nutrients across these systems. Fire regimes–in combination with climate and topography–shape vegetation structure and pattern on the landscape, affect water quality and quantity, and indirectly affect wildlife habitat. Euroamerican settlement resulted in fire exclusion from fire-dependent systems in the Sierra Nevada, with large changes to vegetation structure and composition and associated ecological processes.

- Effects of human infrastructure on natural systems – The built environment has effects on natural systems from direct displacement or through introducing unnatural barriers/pathways.

Climate Change-related Measures

The project team and advisers discussed potential measures related to climate change effects on the natural quality of wilderness. However, a lack of adequate spatial data to capture climate and streamflow trends across the extensive landscape of SEKI meant that these impacts could not be included in the analyses. Spatial data are available for glacier retreat, but only for a time range of 1903- 2004. Because this dataset did not include data through 2012, it was not possible to evaluate glacial extent change for the recent years of interest for this project. These measures can be re-evaluated for inclusion in future wilderness character mapping efforts as new data become available. Following is a summary of trends in Sierra Nevada climate, glaciers, and streamflow that are related to a warming climate.



Goddard Glacier, Kings Canyon National Park. Top photo taken on August 13, 1908 by G.K. Gilbert (USGS Photographic Library). Bottom photo taken by Hassan Basagic on August 14, 2004 (Basagic 2008).

Weather/Climate: In the Sierra Nevada region, there have been some notable trends of increasing temperatures in the past several decades. The average air temperature has risen since the mid-1970s, and the average minimum (nighttime) temperature has risen even more dramatically. The annual averages over the last 10 years approach or exceed that of any other decade on record throughout the southern Sierra (Edwards and Kelly 2011). Warming temperatures cause the snow to melt earlier in the year, and precipitation to fall as rain at higher elevations. These effects decrease the total winter snow accumulation, reducing water availability for park ecosystems and local communities during the dry summer season.

Glaciers: Basagic and Fountain (2011) used historic photographs, geologic evidence, and field mapping to determine the magnitude of area change over the past century at 14 glaciers in Sequoia & Kings Canyon and Yosemite national parks. Glacier extents were derived from vertical aerial and ground-based photographs, and measured with global positioning system (GPS). Eight of the glaciers studied were in SEKI. The glacial areal extent change between 1903 and 2004 ranged from -31% to -78%, averaging -55%. Rapid retreat occurred over the first half of the 20th century beginning in the 1920s and continued through the 1960s after which recession ceased by the early 1980s and some glaciers advanced. Since the late 1980s glaciers resumed retreat with a rapid acceleration starting in the early 2000s. Area changes correlate significantly with changes in summer and winter air temperatures. Warmer winter temperatures lengthen the summer melt season by increasing the temperature of the snowpack so that less energy is required in the spring to warm the snowpack to melting temperatures. Spring air temperatures and precipitation may be important to glacier ablation due to increased warming that accelerates melt and late spring snowfall which increases albedo and decreases melt. If the glaciers continue to shrink at current (1972–2004) rates, most will disappear in 50–250 years (Basagic and Fountain 2011).

Streamflow: Climate-related changes in snowpack and snowmelt patterns will have major effects on river flow patterns. Changes in hydrologic patterns are already occurring or are anticipated to occur with expected temperature increases. Examples of these include: flooding caused by rain-on-snow events, earlier snowmelt, earlier and more prolonged summer low flows, and periodic drying of perennial streams. A recent assessment of Sierra Nevada region stream gauges and snow courses indicated that snowmelt is occurring earlier, and less of the total stream discharge is occurring between April and July when most of snowmelt runoff has historically occurred (Andrews 2011).

Some changes in these important physical processes of the natural quality can be linked to anthropogenic climate change. Such trends suggest these processes and systems cannot be called “free from the effects of modern civilization”.

Data sources, processing and cautions

A wide variety of data were used to create the natural quality map, including data on plants, animals, and the environments in which they exist. These data sources were both vector and raster data and exhibited high variation in scale, mostly high levels of accuracy, and differing levels of completeness (Table 2). Additional measures were considered but not included in the spatial map due to inadequate data, because they were considered too site-specific, or there were issues with seasonality. These measures included: lake chemistry deviation from normal, water-borne pathogens, streamflow quantity and timing, air-borne contaminant deposition, glacial areal extent, bird species richness, and bear-human interactions. For each dataset, the local data steward's position title is provided in parentheses.

Table 2. Natural quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is for its respective measure across the parks' landscapes) were evaluated in a qualitative sense by park staff familiar with these data.

Measures	Source	Type	Scale/ Resolution	Accuracy	Completeness
Non-native fish	NAT_Species_NonNative_Fish_py_20130325, RiversStreams_StrahlerOrder_seki	Polygon & Polyline	1:24,000	High	High
Non-native plants	NAT_Species_NonNativePlants_py_20130429, NAT_Species_NonNativePlants_pt_20130620	Point & Polygon	1:100,000	High	Low
Marijuana grow sites	NAT_Species_MarijuanaGardens_py_20130322	Polygon	1:24,000	Medium	Low
Bighorn habitat	NAT_Species_BighornHabitat_py_20130326	Polygon	1:100,000	High	High
Frog absence	NAT_Species_FrogAbsence_py_20130405	Polygon	1:24,000	High	High
Blister rust	NAT_Species_BlisterRust_pt_20130605	Polygon	1:100,000	High	High
Ozone concentrations	NAT_PhysRes_Ozone_ra_20130405	Raster	3500m	High	High
Nitrogen deposition	NAT_PhysRes_NitrogenDep_py_20130418	Polygon	4000m	High	High
Night sky darkness	SEKI_2km_clip	Raster	900m	Low	Low
Stock grazing	NAT_BioProcess_AUN_py_20130322	Polygon	1:24,000	High	High
Departure from fire regime	NAT_BioProcesses_FireRegime_py_20130325	Polygon	30m	High	High
Effects of human infrastructure	NAT_BioProcess_HumanInfrastructure_ln_20130502, NAT_BioProcess_HumanInfrastructure_pt_20130502, NAT_BioProcess_HumanInfrastructure_py_20130508	Point, polyline & polygon	1:24,000	High	Medium

Presence of non-native fish in naturally fishless water bodies

- *Sources:* Point dataset that represents lakes in SEKI that are known to contain non-native fish populations as of 2012 (SEKI Aquatic Ecologist, Knapp 2003). Nearly all lakes in the parks have been surveyed since the late 1990s. Polyline dataset that represents rivers below 1828m (6000ft) and streams above 3048m (10,000ft) that are estimated to have non-native fish. Due to uncertainty about the presence of non-native fish in rivers between 1828 - 3048m, this elevation band was removed from the dataset. While this means we may underestimate the presence of non-native fish across the landscape, there are insufficient data to evaluate the probability of fish presence in this mid-elevation zone. All restored lakes and streams were removed from the datasets as they are currently documented as fishless.

- *Processing:* (1) Non-native fish point feature class is joined with SEKI lakes polygon feature class. Lake polygons are classified and extracted based on presence of non-native fish. (2) The lake data and stream data are added together and all locations of non-native fish are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- Cautions: Every lake in the dataset has not been surveyed, and there is no estimate available for the quantity that might not be surveyed. The streams containing non-native fish are an approximation based on subject matter expertise; they are not based on field measurements.

Magnitude of invasiveness by non-native plants

- *Sources:* Point dataset capturing the presence of non-native plants in wilderness in Sequoia and Kings Canyon (2002 - 2012) (SEKI Restoration Ecologist). These data result from an integration of the following sources: (1) SEKI Vegetation Mapping, Accuracy Assessment, and Rapid Assessment Plots, 2000 - 2004; (2) USGS Kern Canyon Alien Plant Survey, 2004 - 2005 (McGinnis 2005); (3) NASA Invasive Plant Habitat Modeling. Polygon dataset: derived from the Park Wide Weeds geodatabase. These data show non-native plant observations within the park and what actions (if any) have been taken to control the species.

- *Processing:* Point datasets are merged. Polygon data are extracted from the Park Wide Weeds geodatabase to capture the most recent observation (up to 2012) of the presence of non-native plants inside wilderness. Overlapping polygons or points are only counted once. Locations of all non-native plants are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* These data measure presence or absence of non-native plants for a given pixel and do not provide a metric for intensity within that pixel or surrounding pixels. The data only include areas in the park that have been surveyed and do not necessarily represent a survey for invasive plants across the entire park. The foothills area has a higher abundance of invasive species due to the severity of past disturbances.

Areal extent of old marijuana grow sites

- *Sources:* Polygon dataset (SEKI GIS Specialist)

- *Processing:* Locations of old marijuana grow sites are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- Cautions: This dataset only contains information from 2001 through 2011 and only represents where growing operations were found. The most recent data are considered sensitive information and excluded from the present study.

Bighorn sheep unoccupied former habitat

- *Sources*: Polygon dataset showing occupation status for bighorn sheep (SEKI Wildlife Biologist). "Vacant" indicates areas where bighorn sheep were formerly known to exist but are no longer present.
- *Processing*: Locations of former bighorn sheep habitat are given a value of 1. Layer was converted to raster and values were normalized to 0-255.
- *Cautions*: None.

Absence of frogs in former habitat

- *Sources:* Point dataset representing all water bodies in which mountain yellow-legged frogs (either *Rana sierrae* or *R. muscosa*; MYLF) of any life stage (i.e., egg masses, tadpoles, juveniles, or adults) were seen at least once within two time periods (1997 - 2006 and 2007 - 2012) during surveys conducted by Dr. Roland Knapp, Research Biologist, University of California Sierra Nevada Aquatic Research Laboratory, and his field crews (SEKI Aquatic Ecologist).
- *Processing:* Assign points to associated lake polygons. Merge the two datasets and reclassify the records with the following: 0 = No observation was taken ("no data"; 3147 lakes); 1 = Frogs were present in 1997/2006, but were not present in 2007/2012 or no observation was taken in 2007/2012 ("negative change"; 351 lakes); 2 = Frogs were not present in 1997/2006 or no observation was taken in 1997/2006, but frogs were present in 2007/2012 ("positive change"; 16 lakes); 3 = Frogs were present in both 1997/2006 and 2007/2012 ("no change"; 259). Field named, "MYLF_LOSS" indicates a "1" where frog loss has likely occurred between the two time frames 1997 - 2006 and 2007 - 2012. Locations of frog absence are given a value of 1. Layer was converted to raster and values were normalized to 0-255.
- *Cautions:* These datasets measure presence or absence of the species within a given lake; they do not capture the densities of frog populations. Some lakes visited for the time period 1997 - 2006 were not visited again during the time period 2007 - 2012. However, these data are considered a good representation of the widespread loss of frogs across the park, because the majority of sites were visited between the two time frames.

Presence of blister rust

Sources: Point dataset (Duriscoe and Duriscoe 2002) (SEKI Fire Ecologist and Sierra Nevada Network Ecologist). This dataset represents all plot-level data taken during a survey of SEKI from 1995 - 1998 for white pine blister rust. Each point represents a field plot in which data were collected for the survey. The field "Incidence" captures observations of blister rust: "0" values indicate no infestation. Polygon dataset in the SEKI Spatial Data Warehouse depicts vegetation data produced between 2000 and 2007 to describe vascular plant associations (SEKI Plant Ecologist).

- *Processing:* Produce a layer of vegetation types associated with blister rust, using the following queries in the SEKI vegetation map data: (1) *Pinus monticola* (western white pine), where PICODE = 3130, 3132, 3133, 4042, 4043, 4055, 4057, 4065, 4540; (2) *Pinus lambertiana* (sugar pine), where PICODE = 4021, 4073, 4080, 4081, 4094, 4095; and (3) subalpine white pines (foxtail, whitebark, and limber pines), where PICODE = 3140, 3142, 3144, 3148, 3150, 3200, 3202, 3203, 3204, 3205, 3520, 3530, 3540. Extract all blister rust plots in which blister rust occurs, where: Incidence > "0". Join blister rust occurrence with associated vegetation types layer. Final layer is weighted based on percentages of infestation per associated vegetation type. Scale from 1 – 10, where locations of infested western white pine are given a value of 1 and locations of infested sugar pine are given a value of 4. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* These data are a result of a sample survey and only partially represent the true distribution of blister rust across the parks.

Ozone concentrations

- *Sources:* TIFF image developed from passive ozone monitor data provided by Andrjez Bytnerowicz, USDA-FS, Pacific Southwest Research Station, Riverside, CA (SEKI Air Resource Specialist). Passive samplers were deployed for two-week periods in 2006, 2007 and 2008 during the highest ozone concentrations period of the year – June through October – to estimate average 24-hour ozone concentrations for each 2-week period. They were located over a broad area of the southern Sierra Nevada, including SEKI. A description of ozone passive samplers can be found in Bytnerowicz et al. (2003).

- *Processing:* Raster values were normalized to 0-255.

- *Cautions:* Very low-resolution (900m) dataset affects scalar consistency within the indicator.

Nitrogen deposition

- *Sources:* Polygon dataset derived from Fenn et al. (2010) (SEKI Air Resource Specialist). These data provide a relationship between modeled nitrogen deposition (for the calendar year 2002) and land cover within the State of California. They are the result of intersecting two polygon feature classes: the California Gap analysis vegetative land cover and total nitrogen deposition during the year 2002. The N deposition is at one spatial resolution, 4 km. The nitrogen deposition values included here are output from a Community Multi-scale Air Quality (CMAQ) model and were produced under the direction of Gail Tonnesen at the UC Riverside Bourns College of Engineering's Center for Environmental Research and Technology.

- *Processing:* Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Very low-resolution dataset affects scalar consistency within the Indicator. Nitrogen has variable influence on ecosystems, and this dataset cannot capture full spatial variability of impact.

Night sky darkness (light pollution)

- *Sources:* A TIFF image was provided by the NPS Natural Sounds and Night Skies Division (D. Duriscoe and J. White). The First World Atlas of Light Pollution (published in 2001) provided the first tool of its kind, allowing a prediction of visual sky quality over large geographic areas. Based upon Defense Meteorological Satellite Program (DMSP) data, the primary product of this work was predicted sky glow from anthropogenic light at the zenith above the observer. These data extend the sky quality prediction to an average luminance and integrated luminous emittance from anthropogenic sky glow over the entire hemisphere of the sky as observed from a given location. A simple algorithm based upon the inverse square law is applied to the zenith brightness predictions utilizing a 200km radius of influence for each location, and the results are correlated with actual field measurements over a wide range of sky luminance values. The analysis was conducted for areas in the conterminous United States only, with the intent of predicting sky quality in protected areas (specifically U.S. National Parks). The main unit measure was the Anthropogenic Light Ratio (ALR). This is a ratio of artificial light to natural sky brightness for the zenith (directly overhead) set at 252 μcd/m2 or 79 nanolamberts (abbreviated nL). A nanolambert is a linear unit of luminance. The Natural Sky measure of 79 nL is an average brightness for a moonless night sky.

- *Processing:* Raster values were normalized to 0-255.

- *Cautions:* The original DMSP data were collected in 1997. Since that time there have been increases in city populations around the United States, and California is no exception. The extent to which this increased population has led to a net increase in anthropogenic light is hard to determine. New images acquired by the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi-National Polar-orbiting Partnership (NPP) satellite in 2012 may be useful in answering this question. Calibration of these images and methods for extracting useful data are currently underway.

Number of stock nights in meadows with stock grazing

- *Sources:* Polygon dataset representing SEKI stock grazing intensity from 1985 to 2012 (SEKI Biological Science Technician). Units are reported in average stock use nights per hectare. A value of "0" units indicates that no use was reported. A separate source database was established that records the number of stock nights for each meadow number.

- *Processing:* Query SEKI stock use database for records of grazing ([Grazed] <> 'No') from 1985 to 2012 and total the number of stock nights for each meadow number. Adjust map meadow numbers and tabular meadow numbers where necessary, and calculate area (in hectares) for each meadow. Divide average stock nights by hectares to get a measure of summary grazing intensity and capture result in the field “AvgGrz_NitesPerHaYr.” Assign a value of 0 where no use is reported. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Some meadows have very small sizes which may or may not adequately represent the available grazing (grazing may be in nearby forested areas, for instance). These very small meadows may tend to overestimate grazing intensity (because 1 stock night on a 1-hectare meadow = 10 stock nights on a 10-hectare meadow).

Departure from historic fire regime

- *Sources:* Polygon dataset from NPS Integrated Resource Management Applications (IRMA) website (Folger 2013a) (SEKI GIS Specialist). The historic fire regime return interval values are based primarily on reconstructed fire history chronologies derived from tree-ring samples (obtained from fire-scarred trees in the vicinity of SEKI), or from the literature if the information for a vegetation type did not exist from within or near the park. SEKI uses the maximum average return interval for each vegetation class. The time since last fire is derived from historic fire records or based on the last widespread fire date recorded by the fire history reconstructions. A derived index is calculated to quantify the departure of the vegetation type from its pre-Euroamerican settlement fire return interval.

- *Processing:* Using the “GRIDCODE” field, high departure locations (2 - 5 intervals missed) are given a value of 1 and extreme departure locations (>5 intervals missed) are given a value of 2. Raster values were normalized to 0-255.

- *Cautions:* The information contained in these data is dynamic and will change over time.

Effects of human infrastructure on natural quality

- *Sources:* Point dataset in SEKI Spatial Data Warehouse providing locations of buildings inside the wilderness (SEKI Trails Supervisors). Hitch rails – point dataset depicting locations of hitch rails in wilderness (Biological Science Technician). Trails – polyline dataset depicting trail class locations inside wilderness (Trails Supervisors). Wilderness food storage boxes – point dataset depicting all food storage boxes inside wilderness (Wildlife

Biologist, Sub-District Ranger, and Biological Science Technician). Dams – polygon dataset depicting all dams and associated reservoirs in wilderness, extracted from Wilderness Boundary dataset in the SEKI Spatial Data Warehouse.

- *Processing:* Features are weighted based on an estimated area of impact within a 30 x 30m pixel. The area is given in square meters, and the sum of the area of each piece of infrastructure represents "nature lost." The proportion of "nature lost" to "nature present" (or total infrastructure area divided by the total pixel area) becomes the "weight" of that pixel. Values for area of impact were applied to the attribute tables of Trail Class, Food Storage, and Hitch Rails under a field called, "Impct_sqm.". Details on estimated impact areas:

  i. *Buildings:* Entire buffered area of buildings; 15m buffered area accounts for trampled areas between buildings.
  ii. *Hitch Rails:* 150m²; Hitch rail impacts are typically 5-6m x 10-15m
  iii. *Trails:* With different possible paths through a given pixel, the average trail length would be 30m. Therefore: (1) *Trail Class 1*: 30m²; Class 1 trail impacts average 1m or less in width. (2) *Trail Class 2:* 60m²; Class 2 trail impacts average 2m or less in width. (3) *Trail Class 3:* 90m²; Class 3 trail impacts average 3m or less in width.
  iv. *Food Storage:* 100m²; typical trampling area around food storage boxes is about 5-6m radius.
  v. *Dam:* Entire buffered area of dam and associated lake, because the lake and dam displace the riparian ecosystem under water and under masonry.

  Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Values are an approximation; areas might overestimate or underestimate impact on the ground.

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 measure (Table 3). The "weighted" measures under each indicator total 100. In the future, should the data improve or become available, existing and new measures can be added to a subsequent iteration of the wilderness character map.

Maps

The weighted measures for each indicator were 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 were created, the raster calculator was used to add the three indicator maps together to create the natural quality map (Figure 5).

Table 3. Indicators and measures for the natural quality with weights and rationale.

Indicator	Measure	Weight	Rationale
Plant and animal species and communities	Non-native fish	25	The presence of non-native predatory fish in naturally fishless water bodies in SEKI is important because of wide ranging effects on aquatic ecosystems.
	Non-native plants	30	The magnitude of areas invaded by non-native plant species is important because of potential displacement of natives and alteration of plant environment.
	Marijuana grow sites	5	Areal extent of old marijuana grow sites is important but limited in geographic reach (foothills).
	Bighorn habitat	10	Bighorn sheep unoccupied former habitat is important as loss of an iconic species but limited in geographic reach.
	Frog absence	15	Absence of mountain yellow legged frogs in former habitat is indicative of wide ranging but limited habitat reduction and introduction of non-native pathogens.
	Blister rust	15	Presence of blister rust is a key measure of the degradation of white pines which are foundation species in many areas where they occur, acting as critical food sources for important animal species in montane to sub-alpine areas.
Physical resources	Ozone concentrations	45	These are important factors that impact both plant and animal species and affect terrestrial and aquatic systems.
	Nitrogen deposition	45	
	Night sky darkness	10	Ambient light from large population centers to west and east of parks affects predator prey relationships of native animals.
Biophysical processes	Stock grazing	25	Number of Stock Nights in meadows with stock grazing is an important proxy for effects on biophysical systems (meadows, hydrology, etc.).
	Departure from fire regime	70	Departure from historic fire regime is an important indicator of overall health of interrelated biophysical systems in foothill and montane areas. Wide ranging.
	Effects of human infrastructure	5	There is limited importance of human infrastructure impact on biophysical environment due to small spatial extent.
		300	

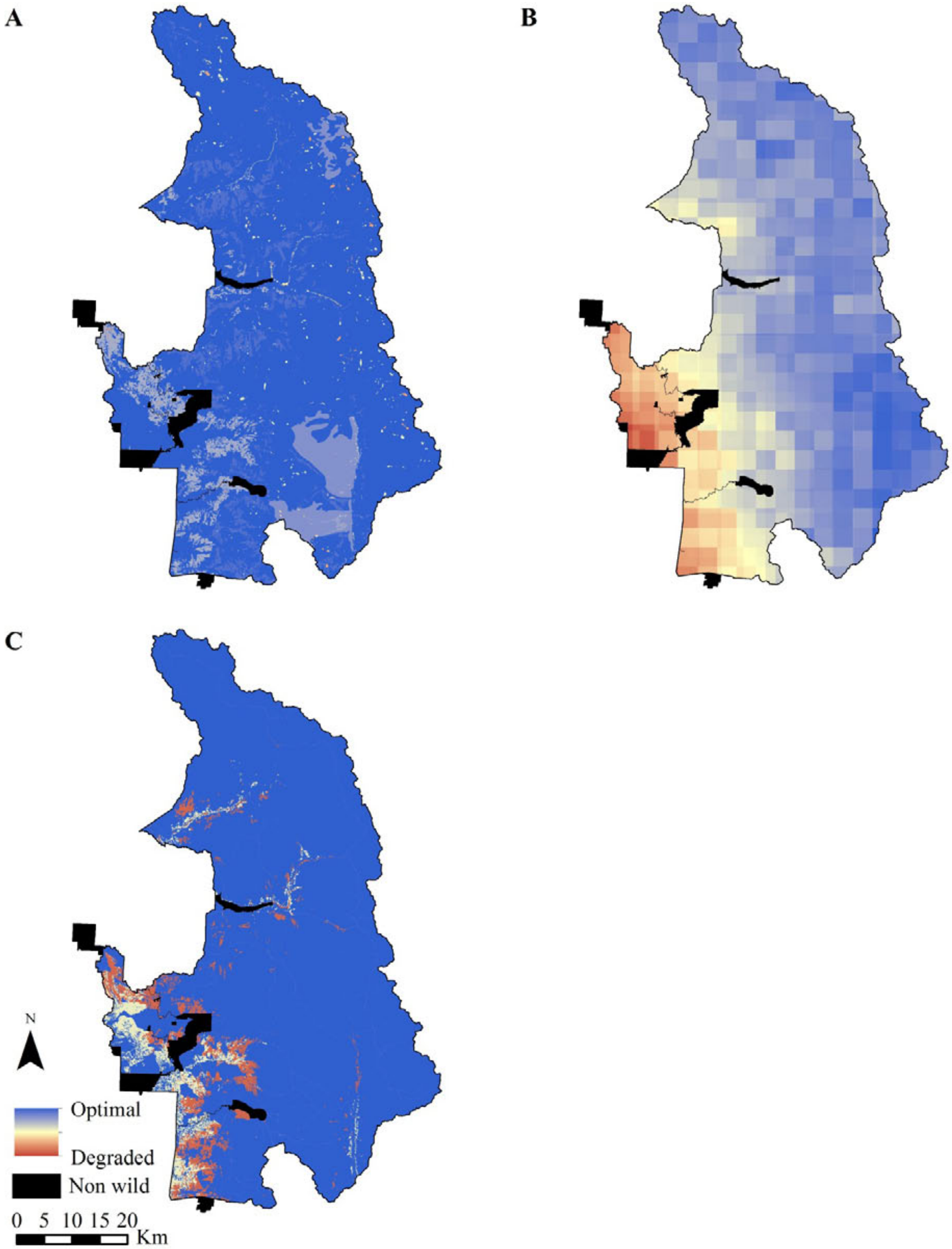


Figure 4. Indicator maps for (A) plant and animal species and communities, (B) physical resources, and (C) biophysical processes. Blue depicts optimal quality and red depicts degraded quality.

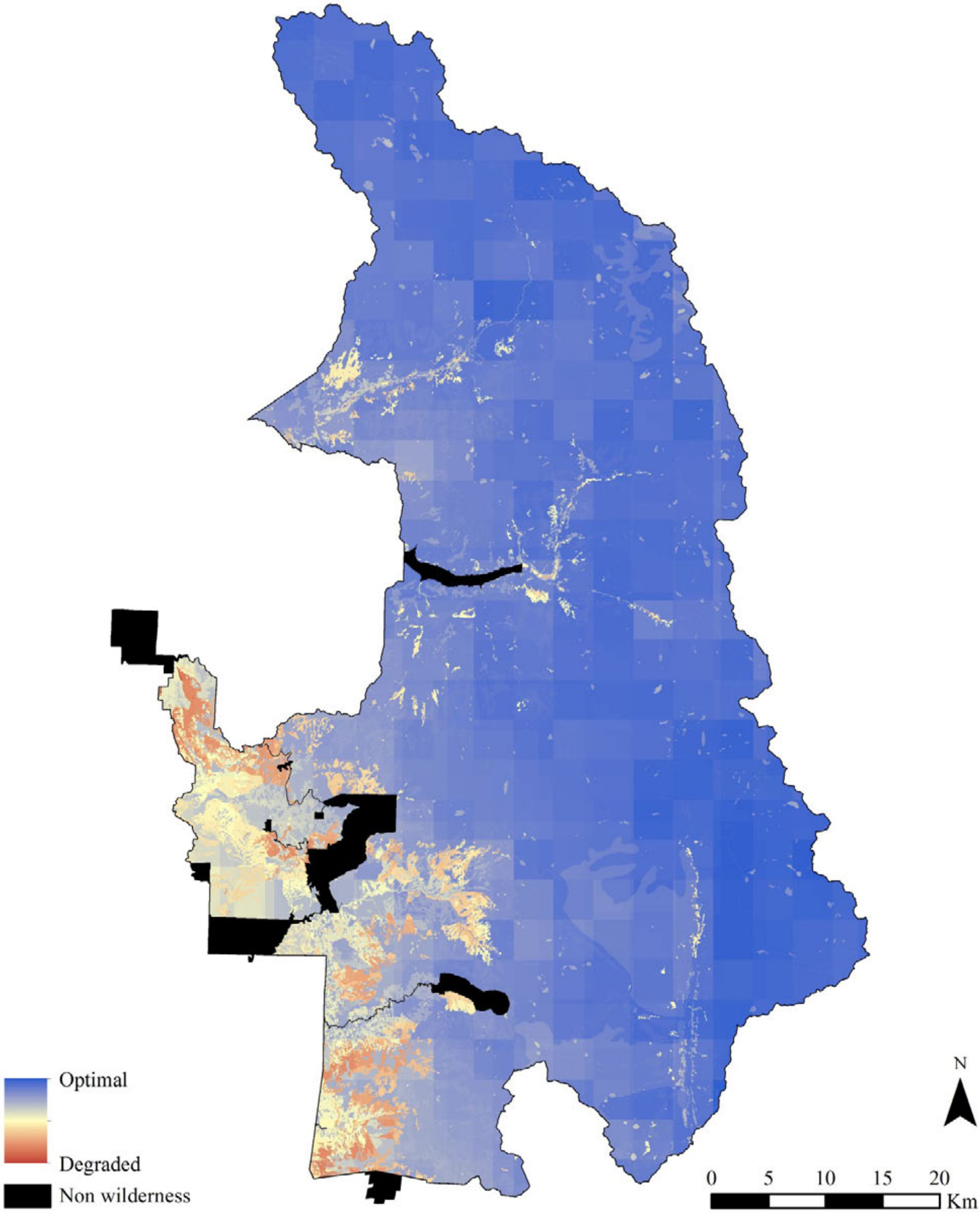


Figure 5. Natural quality of wilderness character. Blue depicts optimal quality and red depicts degraded quality. To view a higher resolution version of this map, please see the separately published Appendix 2 (Tricker et al. 2014).

Untrammeled Quality

The untrammeled quality is the degree to which wilderness is 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. 2008a).

There are important temporal questions to consider when developing a map of the untrammeled quality. *Keeping It Wild* tracks actions the year they occurred, and the long term effects of these actions should be tracked in the natural quality. However, for the purposes of this SEKI baseline map we provided a cumulative summary for all trammeling that has occurred from 2002 - 2012, as per staff decision. When this was not possible, the most recent complete datasets were used. (Other parks/units may choose to follow this protocol or devise a different method for counting management actions.)

Indicators and measures

Measures were selected for each of the two indicators recommended in *Keeping It Wild.* The indicators, their measures, and their relevance to the untrammeled quality are listed below:

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

Management-ignited prescribed burn in the Redwood Canyon area of Kings Canyon National Park. Photo: Tony Caprio.

- Naturally ignited fires that received a suppression response – This is a direct measure of the degradation of the untrammeled quality because suppressing naturally ignited fires is a deliberate manipulation of the park's biophysical processes.
- Prescribed fires (management ignited) – Intentional ignitions, even though the desired outcome is to return natural fire regimes, is a deliberate manipulation of the landscape which degrades the untrammeled quality.

- Non-native plant removal/control – The intentional removal of plants and animals, even though it is to restore habitat for native species, is a deliberate manipulation of the natural process which degrades the untrammeled quality.

- Non-native fish control – The act of capturing and killing resident animals impacts the untrammeled quality, even though it is done to restore natural systems.

- Restoration of disturbed lands – The methods and act of restoring lands is a manipulation and as such degrades the untrammeled quality.

Electrofishing is a method used to kill and remove non-native fish from streams near lakes where mountain yellow-legged frogs are being restored. Photo: NPS.

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

- Marijuana grow sites – Intentional manipulation of park resources for illegal marijuana cultivation degrades the untrammeled quality through impacts to vegetative, wildlife and physical resources. [Note: only one measure for this indicator was included and therefore it is assigned the full weight of 100. Other activities were considered such as poaching, graffiti, and trespass cattle, but frequencies and exact spatial locations for these unauthorized activities have not been consistently recorded.]

Data sources, processing and cautions

The untrammeled quality map is composed of six measures (Table 4). Additional measures were identified but not included due to a lack of relevant data or other limitations: wildfire manipulation (outside of prescription sets and suppressions); native plant and animal manipulation; specimen collection; tree hazard removal; trespass animals; and illegal activities (poaching, unpermitted collecting, etc.).

Table 4. Untrammeled quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is for its respective measure across the parks' landscapes) were evaluated in a qualitative sense by park staff familiar with these data.

Measures	Source	Type	Scale	Accuracy	Completeness
Suppressed fires	UNT_Authorized_SuppressedFires_pt_20130627, UNT_Authorized_SuppressedFires_ln_20130627	Point & Polyline	1:100,000	Medium	High
Prescribed fires	UNT_Authorized_PrescribedFires_py_20130322	Polygon	1:24:000	High	High
Non-native plant removal/control	UNT_Authorized_NonNativePlantRemoval_py_20130429	Polygon	1:24,000	High	High
Non-native fish control	UNT_Authorized_NonNativeFishControl_ln_20130321, UNT_Authorized_NonNativeFishControl_py_20130321	Polyline & Polygon	1:24,000	High	High
Restoration	UNT_Authorized_Restoration_pt_20130501, UNT_Authorized_Restoration_ln_20130501, UNT_Authorized_Restoration_py_20130501	Point, polyline & polygon	1:24,000	Medium	Medium
Marijuana grow sites	UNT_Unauthorized_GrowSites_py_20130322	Polygon	1:24,000	High	Medium

Naturally ignited fires that received a suppression response

- *Sources:* Polygon dataset from NPS Integrated Resource Management Applications (IRMA) website (Folger 2013b) (SEKI GIS Specialist). This coverage represents the SEKI fire history from 1921 through 2012.

- *Processing:* Extract all naturally ignited fires: field "SpecificCa" select value "1", or Lightning between years 2002 and 2012. Eliminate fires described as "Natural Outs" or "Managed for resource benefit" (FireType: 21; 23; 49) and include all "Suppressed Fires" (FireType: 14; 11) between years 2002 and 2008. All fires after 2008 were manually classified by a SEKI fire expert. Fire suppression documentation was altered as a result of policy change in 2008. Between 2008 and 2012, the official record does not differentiate among the actions taken toward a natural fire; contained/confined fires, monitored fires, and suppressed fires are often captured under the same category (FireType: 11) within the record. Features were revised to best represent "action taken on the ground." Smallest fires are represented by the perimeter of the fire coverage. Small fires probably receive the most extensive action relative to their area, so it's reasonable to use the entire polygon. Large to mid-sized fires are represented by locations of fire lines, ground disturbances, and helicopter landings. Larger fires are permitted to burn more freely across a larger extent, so it is important to be more spatially explicit about actions taken on the ground. These features are determined on a case-by-case basis with assistance by subject matter experts (Fire Ecologist, GIS Specialist, and Prescribed Fire Specialist); they are developed through existing GIS data and heads-up digitizing. Locations where suppression responses occurred are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Fire occurrence depends on local weather and fuel conditions. The decision to allow a fire to burn in wilderness depends on air quality-related restrictions as well as regional and national fire danger ratings. Thus this dataset can have high variance from year to year. Not all suppression efforts were spatially documented at the time of the incident and much of the information was created from institutional memory.

Prescribed fires (management ignited)

- *Sources:* Polygon dataset downloaded from NPS IRMA website (Folger 2013b) (SEKI GIS Specialist). This coverage represents the SEKI fire history from 1921 through 2012.

- *Processing:* Extract all "Prescribed fire, management ignited" records (FireType: 48) between years 2002 and 2012. Locations where prescribed fires have occurred are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Management ignition of prescribed fires in wilderness depends on variable weather and fuel conditions, air quality-related restrictions on burning, and the approval of a burn as an appropriate action in wilderness. Thus, this dataset can have high variability from year to year. The burned area within a fire perimeter may have varying coverage and intensity.

Non-native plant removal/control

- *Sources:* Polygon dataset from Park Wide Weeds geodatabase (SEKI Restoration Ecologist). These data show non-native plant observations within the parks and what actions (if any) have been taken to control the species.

- *Processing:* The "Most Recent Visit" query ([MostRecentVisit] = Yes) provides the most accurate and informative snapshot of the magnitude of invasive plants within Wilderness as of 2012. These data are further refined by extracting locations where treatment has occurred. Locations where non-native plant removal/control occurred are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Invasive plant treatment includes hand-pulling and chemical application, and the optimal method is determined based on the characteristics and species found at a specific location. The priority for any treatment activity is to minimize impact on the ground as effectively as possible. Hand-pulling disturbs the ground, increasing the risk of distributing seeds and damaging nearby plants. Hand-pull treatments are likely to be repeated several times in order to achieve successful eradication. Chemical application is more localized and does not often require repeated treatments; however, it still has significant long-term ecological impact due to the introduction of chemicals into the natural environment. This study does not distinguish between the two treatments, because there is no way to quantify the relative impacts of either treatment.

Non-native fish control

- *Sources:* Polygon dataset represents restored lake (lentic) habitats in Sequoia and Kings Canyon National Parks (2001 to 2012) (SEKI Aquatic Ecologist and Aquatic Ecosystem Specialist). These water bodies represent areas in which restoration crews have either completely removed non-native trout or areas in which ongoing restoration is occurring. Polyline dataset represents restored stream (lotic) habitats in Sequoia and Kings Canyon NPs (2001 to 2012). These stream segments represent locations in which restoration crews have either completely removed non-native trout or locations in which ongoing restoration is occurring.

- *Processing:* Locations where non-native fish control occurred are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* None.

Restoration of disturbed lands

- *Sources:* (1) Point and polygon datasets depict marijuana grow sites where restoration has occurred (SEKI GIS Specialist, SEKI Restoration Ecologist, and Sub-District Ranger); (2) polygon dataset delineates area of impact for the Upper and Lower Halstead Meadow Restoration Project, developed by Evan Wolf from University of California Davis (SEKI Restoration Ecologist; and (3) polyline dataset digitized from hand-drawn paper map depicting corridors in which significant meadow and landscape restoration has occurred as part of trail management between 2006 and 2012 (SEKI Trails Supervisors).

- *Processing:* Locations where restoration of disturbed lands occurred are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- Cautions: Marijuana restoration areas dataset only contains information from 2001 through 2011, because most recent data are considered sensitive information. Meadow and landscape restoration data were created from institutional memory.

Marijuana grow sites

- *Sources:* Polygon dataset depicting marijuana grow site areas (SEKI GIS Specialist).

- *Processing:* Locations of marijuana grow sites are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Dataset only contains information through 2011and only represents where growing operations were found, because most recent data are considered sensitive information.

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 measure (Table 5).

Table 5. Indicators and measures for the untrammeled quality with weights and rationale.

Indicators	Measures	Weight	Rationale
Authorized actions	Suppressed fires	20	Important to know how often suppression of naturally set fires occurs and its impacts.
	Prescribed fires	25	Important to know how often fire is introduced.
	Non-native plant removal/control	20	Important to understand how often and over what area this is occurring.
	Non-native fish control	20	Important to know scope and effects of removal.
	Restoration	15	Few and infrequent sites, but important to understand the impacts associated with these actions.
Unauthorized actions	Marijuana grow sites	100	Small scale spatially, but somewhat frequent occurrence with potential for long lasting impacts.
		200	

Maps

The weighted measures for each indicator are added together using a raster calculator to create maps for authorized and unauthorized actions (Figure 6). After these indicator maps are created, the raster calculator is used to add the two indicator maps together to create the untrammeled quality map (Figure 7). Please note that although the maps appear completely blue, very small areas of trammeling do exist but are difficult to see at this small scale.

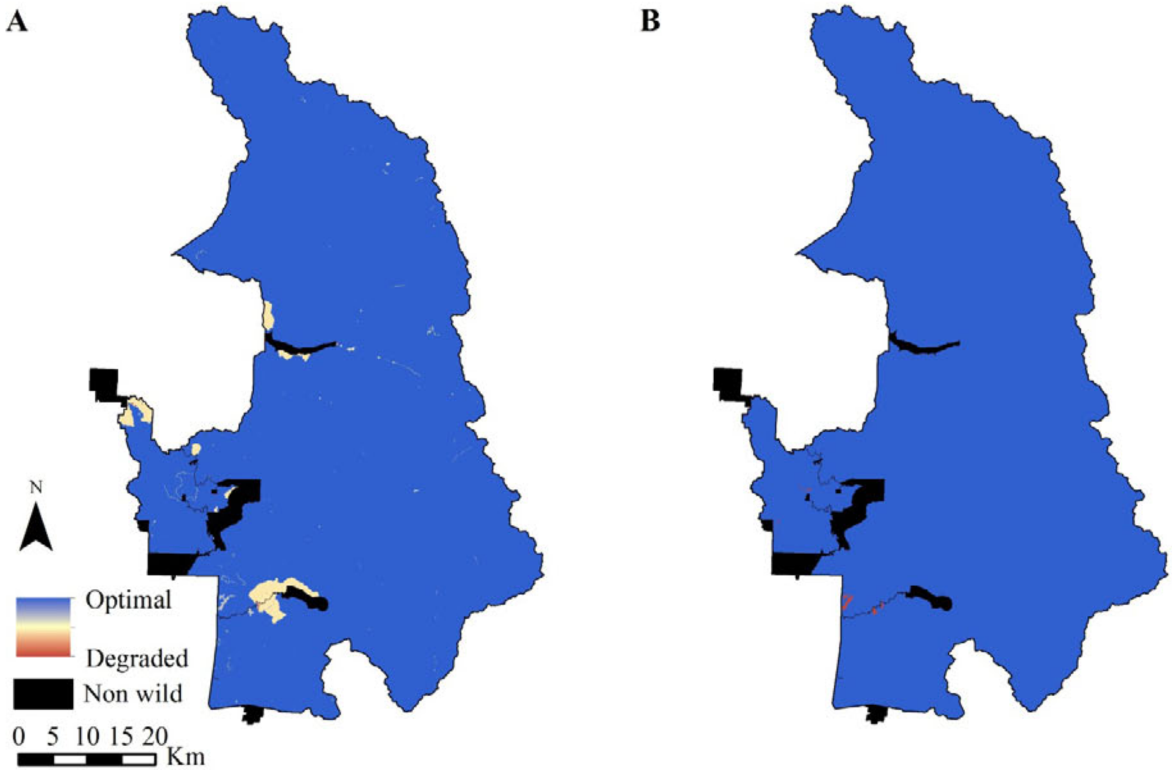


Figure 6. Indicator maps for (A) authorized actions and (B) unauthorized actions. Blue depicts optimal quality and red depicts degraded quality.

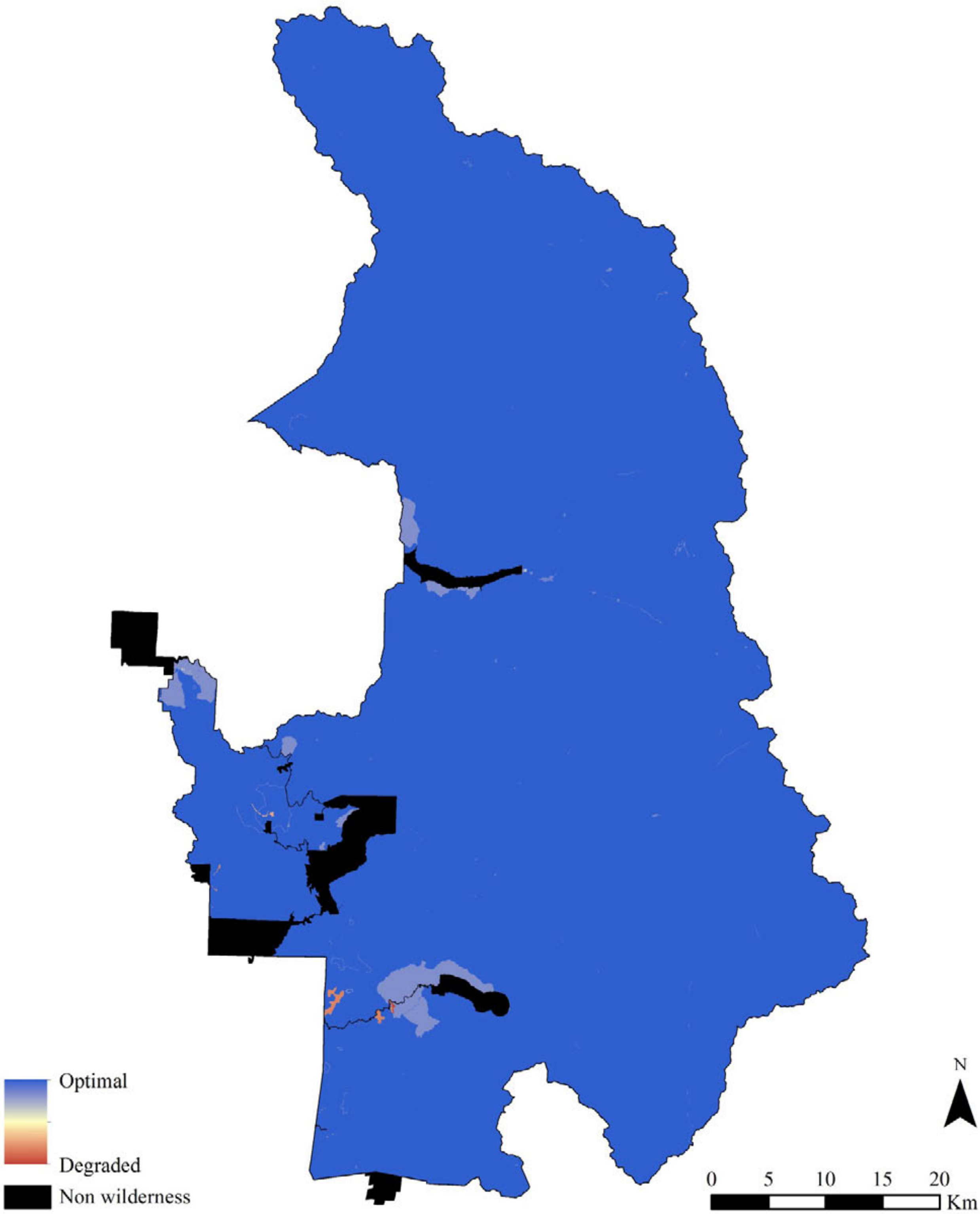


Figure 7. Untrammeled quality of wilderness character. Blue depicts optimal quality and red depicts degraded quality. To view a higher resolution version of this map, please see the separately published Appendix 2 (Tricker et al. 2014).

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 measures

Measures were selected for each of the three indicators recommended in *Keeping It Wild*. The following indicators, with their measures and relevance to the undeveloped quality, were used:

Indicator: Non-recreational structures, installations, and developments

Rae Lakes Ranger Station, re-built in 2011, Kings Canyon National Park. Photo: NPS.

- Wilderness buildings – Ranger stations and affiliated structures are a sign of human presence and degrade the undeveloped quality.
- Long-term monitoring/science equipment – Installations and structures, e.g. snow pillows and stream gauges, are a sign of modern human presence which degrades the undeveloped quality.
- Administrative support equipment – Authorized landing of aircraft, specifically helicopters, degrade the undeveloped quality. These are actions analyzed and permitted by the park – the park makes decisions about allowing or not allowing these types of uses.
- Authorized non-NPS infrastructure – Infrastructure such as power lines, dams, and other structures degrade the undeveloped quality.
- Benchmarks – Benchmarks for marking the boundary or peak summits are largely accepted as the minimum necessary for the administration of an area, while markers for installations

and proposed roads are considered unnecessary within wilderness. All types should be mapped, because they degrade the undeveloped quality.

Indicator: Inholdings, lands not owned or that contain mineral rights not wholly owned by the NPS

- Inholdings – These privately-owned lands currently degrade the undeveloped quality of wilderness, and this degradation continues for as long as these inholdings exist. The degradation has the potential to increase in the future if non-NPS interests increase the development status of their properties. These include the Empire Mine in Mineral King (authorized by the General Mining Act of 1872) and the Oriole Lake inholdings established as a small resort community in the early 20th century.

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

Helicopters are periodically used in wilderness to conduct searches, transport injured people from remote areas, and conduct fire suppression activities. Photo: NPS.

- Administrative helicopter use (Section 4(c) – Minimum Requirements Analysis or MRA) – Authorized landing of aircraft, specifically helicopters, degrade the undeveloped quality. These are actions analyzed and permitted by the park. The park makes decisions about allowing or not allowing these types of uses.

- Emergency helicopter use – Administrative use of helicopters for emergency situations, e.g. medical or search actions, degrades the undeveloped quality. These are actions permitted by the park. The park makes decisions about allowing or not allowing these types of uses.

- Administrative use (Section 4(c) MRA) – Administrative use of motorized vehicles, motorized equipment, and mechanical transport degrades the undeveloped quality. Examples include chainsaws, rock drills, wheelbarrows, and 4-wheel all-terrain vehicles. These types of equipment get occasional use for trail maintenance or repair to administrative or recreational support structures in wilderness. These are actions analyzed and permitted by the park. The park makes decisions about allowing or not allowing these types of uses.

Data sources, processing and cautions

The undeveloped quality datasets are all vector data, of fine scale, and generally of moderate to high accuracy and completeness (Table 6). Additional measures were identified but not included due to a lack of relevant data or other shortcomings: wilderness debris; unauthorized 4(c) actions; and emergency 4(c) (non-helicopter) actions.

Table 6. Undeveloped quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is for its respective measure across the parks' landscapes) were evaluated in a qualitative sense by park staff familiar with these data.

Measures	Source	Type	Scale	Accuracy	Completeness
Wilderness buildings	UND_NonRec_BackcountryBuildings_pt_20130621, UND_NonRec_RangerStations_pt_20130318	Point	1:24,000	High	High
Long term monitoring/science	UND_NonRec_Science_pt_20130515	Point	1:24,000	High	High
Admin support equipment	UND_NonRec_Admin_pt_20130628	Point	1:24,000	High	High
Authorized non-NPS infrastructure	UND_NonRec_AuthorizedNonNPS_pt_20130329, UND_NonRec_AuthorizedNonNPS_ln_20130605	Point & Polyline	1:24,000	High	High
Benchmarks	UND_NonRec_Benchmarks_pt_20130503	Point	1:24,000	High	High
Inholdings	UND_Inholdings_py_20130319	Polygon	1:24,000	High	High
Administrative helicopter use	UND_Motorized_AdminHeli_pt_20130329	Point	1:100,000	Medium+	High
Emergency helicopter use	UND_Motorized_EmergencyHeli_pt_20130329	Point	1:100,000	Low+	Medium
Administrative 4C MRA use	UND_Motorized_Admin4CMRA_RockDrill_pt_20130624, UND_Motorized_Admin4CMRA_Chainsaw_ln_20130624	Point	1:100,000	Low	Low

Wilderness buildings

- *Sources:* Point datasets extracted from the SEKI Spatial Data Warehouse: (1) ranger stations and; (2) park buildings (SEKI Assistant Wilderness Coordinator, Trails Supervisor, Wilderness Coordinator, and Biological Science Technician).

- *Processing:* Locations of historic buildings are given a value of 1, and non-historic buildings a value of 2. For this document, "historic" is defined as being listed on, or having been determined eligible for listing on, the National Register of Historic Places (NRHP). Both listing and a determination of eligibility for listing on the NRHP require concurrence of the California State Historic Preservation Office. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Not all ranger stations have the same frequency of use and magnitude of impact on the surrounding environment.

Long term monitoring/science equipment

- *Sources:* The following point datasets were used: (1) Remote Area Weather (RAW) Stations; (2) Weather Stations; (3) Snow Pillows; (4) Snow Survey Stations (Datasets 1-4, SEKI Air Resources Specialist, extracted from the SEKI Spatial Data Warehouse); (5) Research Permit Installations (SEKI Science Coordinator and Data Technician, queried from Research Permit Database). These data include all "long-term" (more than three years) installations in 2011. (6) Study Site Installations (SEKI Science Coordinator and Data Technician, queried from Research Permit Database). These data include all study sites in use as of 2013. (7) Fire-related Study Site Installations (SEKI Fire Ecologist).

- Processing: RAW stations, weather stations, and snow pillows are sometimes spatially coincidental, e.g. a weather station transmits the data from a snow pillow at the same location. Duplicates are removed to avoid double-counting. Decommissioned weather stations are identified and removed from the dataset. All point data are merged, and the following weighting system (scaled from 1 – 5) is applied to the different locations:

    i. 1 = Lowest impact site: a very small installation, such as a plot marker, tree tag, or small sensor.

    ii. 3 = Moderately impacted site: installation type varies, and is determined on a case-by-case basis.

    iii. 5 = Highest impact site: a larger installation or combination of installations, including weather stations, stream gauges, and snow pillows.

  Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Snow courses are excluded from present study. Animal collars are also excluded to avoid overestimation of impact. Collars are considered too mobile or too short-term to track accurately.

Administrative support equipment

- *Sources:* Point datasets depicting locations of: (1) communication stations; (2) drift fences; (3) water sources (all three extracted from SEKI Spatial Data Warehouse); and (4) helispots. Helispots are heads-up digitized through consultation with the Supervisory Forestry Technician to depict locations of areas that have been manipulated to provide safe landing areas for a helicopter between 2000 and 2012.

- *Processing:* Merge all point datasets. Locations of administrative support equipment are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* The development of helispots is infrequent: helicopters usually land in meadows or above timberline, where development is unnecessary. Helispots are generally not used more than once.

Authorized non-NPS infrastructure

- *Sources:* (1) Point dataset depicting Dorst area microwave relay tower; (2) Polyline dataset depicting road segments servicing the Oriole Lake inholdings; and (3) Polygon dataset depicting dams (including Crystal Lake Designated Potential Wilderness Addition with helicopter landing site), Bearpaw Meadow High Sierra Camp, Moro Rock power line, and Summit Meadow to Cedar Grove power line. All datasets extracted from SEKI Spatial Data Warehouse. These datasets all represent Designated Potential Wilderness Additions to the Sequoia-Kings Canyon Wilderness. These are areas that could become designated wilderness if the non-conforming uses discontinue.

- *Processing:* Locations of authorized non-NPS infrastructure are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* None.

Benchmarks

- *Sources:* Several point datasets extracted from the SEKI Spatial Data Warehouse: (1) Benchmarks; (2) Ground control points; (3) Survey Points; (4) Survey Control Points (SEKI GIS & Data Coordinator).

- *Processing:* Merge all point data. Locations of all benchmarks are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Benchmarks are given a very low weight due to their small size and minimal impact.

Inholdings

- *Sources:* Polygon dataset showing all land parcels for Tulare County, California (SEKI GIS & Data Coordinator, and Tulare County Assessor's Office).

- *Processing:* Extract all privately-owned parcels of land within the parks. Locations of inholdings are given a value of 1. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* None

Administrative helicopter use

- *Sources:* Excel spreadsheet containing latitude/longitude location, number of landings, and mission type for all helicopter activity between 2010 and 2012 (SEKI Wilderness Coordinator and Wilderness Office Assistant).

- *Processing:* Reformat spreadsheet, import data into GIS format, and extract all points classified as "Administrative" helicopter use. There are often multiple landings per point location. The locations of these landings are summarized using a pivot table, classified into three categories, and assigned the following values: 1 (1 - 3 landings), 2 (4 - 9 landings), and 3 (9 or more landings). Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Not all helicopter landings may have been recorded in the spreadsheet.

Emergency helicopter use

- *Sources:* Excel spreadsheet containing latitude/longitude location, number of landings, and mission type for all helicopter activity between 2010 and 2012 (SEKI Wilderness Coordinator and Wilderness Office Assistant).

- *Processing:* Reformat spreadsheet, import data into GIS format, and extract all points classified as "Emergency" helicopter use. There are often multiple landings per point location. The locations of these landings are summarized using a pivot table, classified into three categories, and assigned the following values: 1 (0 - 2 landings), 2 (3 - 5 landings), and 3 (6 or more landings). Note: Emergency helicopter data include "0" values for a number of landings, representing bucket drops made during fire events. We include fewer landings within each category compared to the administrative helicopter use. This is because Minimum Requirement Analyses are done ahead of time for administrative helicopter use, which consider how to minimize impacts on wilderness character to the extent possible. For emergency helicopter use, patient welfare usually takes precedence, and thus these landings are estimated to have a higher impact on the undeveloped quality of wilderness. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Not all helicopter landings may have been recorded in the spreadsheet.

Administrative 4(c) MRA use

- *Sources:* Point dataset depicts rock drill use and polyline dataset depicts chainsaw use. Both datasets was heads-up digitized to capture motorized equipment used on maintained trails between 2009 and 2012 (SEKI Assistant Wilderness Coordinator and Trails Supervisors).
- *Processing:* Locations of administrative 4(c) MRA use are given a value of 1. Layer was converted to raster and values were normalized to 0-255.
- *Cautions:* Management is not necessarily standard across the two parks; consistency issues arise in representing actions taken on the ground by different trail management crews. These data were not captured at the time of the action and were produced from institutional memory.

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 measure (Table 7). The "weighted" measures under each indicator total 100.

Table 7. Indicators and measures for the undeveloped quality with weights and rationale.

Indicator	Measures	Weight	Rationale
Non-recreational structures, installations, and developments	Wilderness buildings	31	Stations and affiliated infrastructure are notable and have effects.
	Long term monitoring/science equipment	21	Numerous individual footprints of varying sizes spread throughout the parks.
	Admin support equipment	21	Numerous individual footprints of varying sizes spread throughout the parks.
	Authorized non-NPS infrastructure	26	Limited scope but significant effects.
	Benchmarks	1	Numerous very small sites with little effect wilderness-wide.
Inholdings	Inholdings	100	Some potential for development with notable impacts on surrounding lands.
Use of motor vehicles, motorized equipment, or mechanical transport	Administrative helicopter use	45	Frequent occurrence in wide area through summer.
	Emergency helicopter use	35	Important recurring actions with short-term high impacts on the wilderness.
	Admin 4(c) MRA use	20	Frequent approved actions with cumulative effects.
		300	

Maps

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

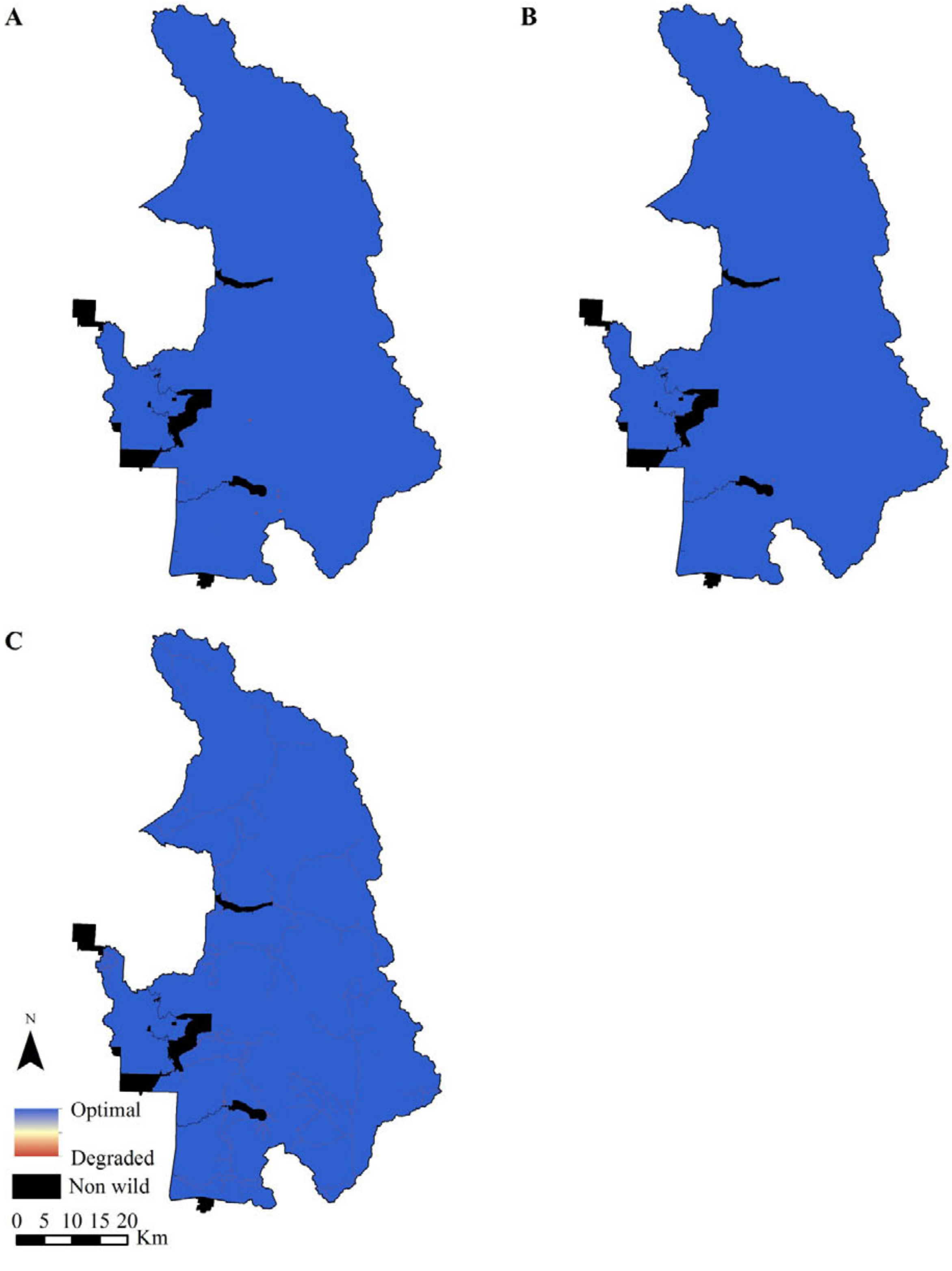


Figure 8. Indicator maps for (A) non-recreational structures, installations, and developments; (B) inholdings; and (C) use of motor vehicles, motorized equipment, or mechanical transport. Blue depicts optimal quality and red depicts degraded quality. Due to the small scale of the degradations relative to the large scale of these maps, the impacts on the undeveloped quality are difficult to see. These impacts are somewhat more visible in the combined map (Figure 9).

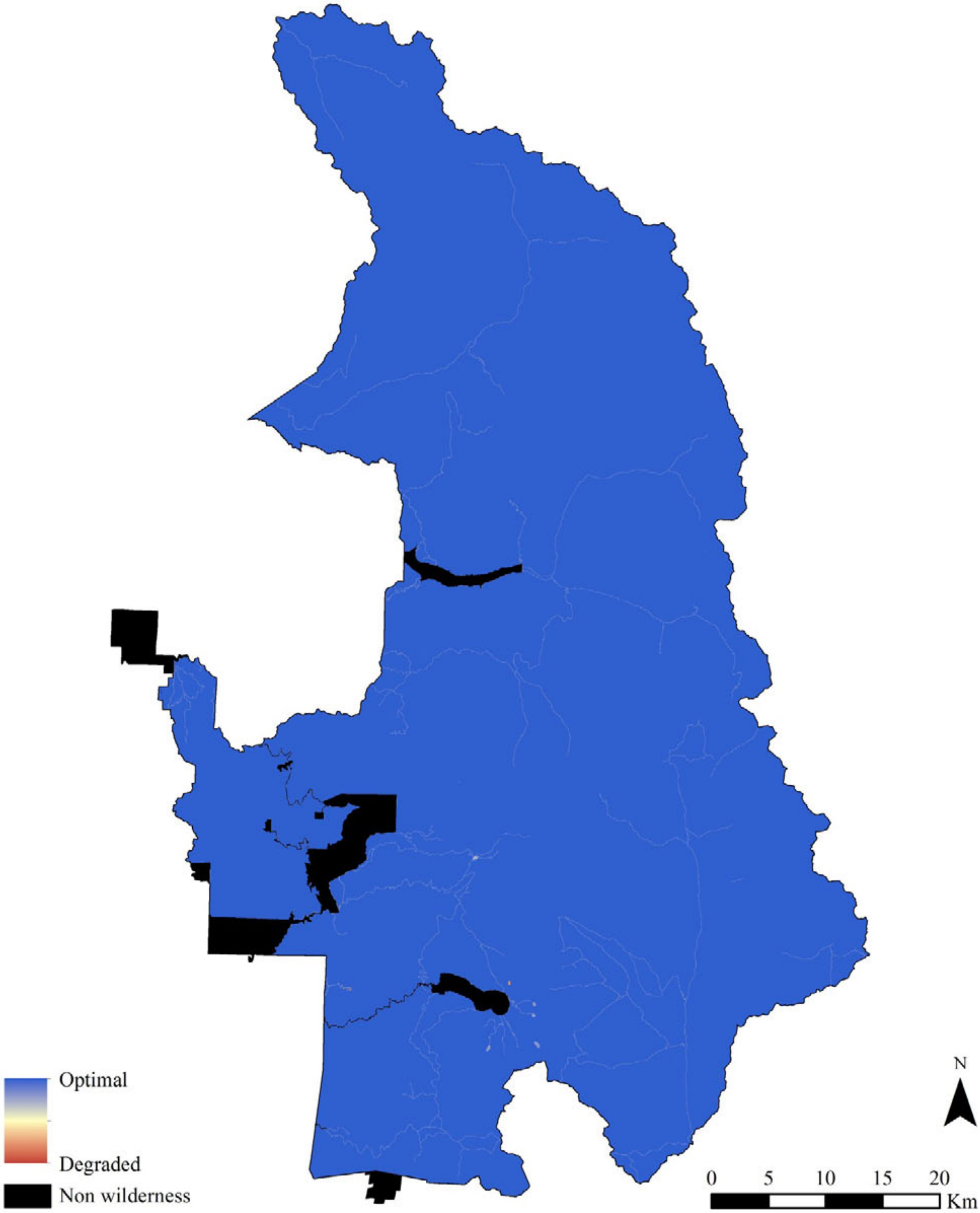


Figure 9. Undeveloped quality of wilderness character. Blue depicts optimal quality and red depicts degraded quality. To view a higher resolution version of this map, please see the separately published Appendix 2 (Tricker et al. 2014).

Solitude or Primitive and Unconfined Recreation Quality

The solitude or primitive and unconfined recreation 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 measures

Measures were selected for each of the four indicators recommended in *Keeping It Wild.* The following indicators, with their measures and relevance to the solitude or primitive and unconfined recreation quality, were used:

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

Views of scenic vistas like these sky pilot flowers and alpine lakes are a highlight of wilderness experiences. Photo: NPS.

- Travel time model – Calculates the time it takes a person of average fitness to travel across the landscape from various access points (trailheads), taking into account cost surfaces[10] (elevation and land cover) and barrier features (steep ground and water).
- Viewshed inside model – Calculates the line-of-sight viewshed impacts (using distance decay) of modern human features inside the wilderness.
- Campsite inventories (weighted density) – Indicates use levels and patterns compared against the baseline. Considers campsite density, volume and level of impacts.

[10] Cost surfaces are used in surface modeling to establish the impedance for crossing each individual cell in a grid.

- Outfitter use nights – A measure of human presence generated by commercial services which can degrade the opportunity for solitude or primitive and unconfined recreation.

- Visitor use nights/quota information/party size – A measure of the levels and locations of human presence degrading the opportunity for solitude or primitive and unconfined recreation.

Indicator: Remoteness from occupied and modified areas outside the wilderness

- Overflights – Based on military overflights only and estimated from a known flight path over the wilderness area. The ambient noise from this flight path degrades the opportunities for remoteness and solitude.

- Viewshed outside model – Calculates the line-of-sight viewshed impacts (using distance decay) of modern human features that are outside the wilderness (as viewed from inside the wilderness).

- Soundscapes – Measure of human presence outside the wilderness degrading the opportunity for solitude inside the wilderness.

Indicator: Facilities that decrease self-reliant recreation

Food storage boxes protect food from bears in the Sequoia-Kings Canyon Wilderness but also decrease self-reliant recreation. Photo: Sandy Graban.

- Trail class – Developed and maintained trails with bridges, causeways, signs, etc. concentrate and direct visitor use and degrade the opportunity for solitude and being free from the "imprint of man's work."

- Toilets for visitors – Structures concentrate use and are a sign of human presence, affecting solitude and remoteness.

- Designated campsites – Areas designated for camping constrain recreation and concentrate use affecting solitude, remoteness, and freedom of movement.

- Food storage boxes – These installations concentrate use and provide ease of use reducing self-reliance, solitude, and remoteness.

- Bearpaw Meadow High Sierra Camp (summer only) and Pear Lake Ski Hut (winter only) – Structures where the services and facilities that are provided reduce self-reliance, remoteness, solitude, and unconfined recreation.

Indicator: Management restrictions on visitor behavior

- Access/Use restrictions – Agency restrictions that inhibit free choice for all types of primitive wilderness recreation degrade the opportunity for solitude, remoteness and unconfined recreation for users. Agency restrictions that modify visitor behavior degrade the opportunity for unconfined recreation.

- Recreational stock restrictions (use and access) – Agency restrictions that dictate what type of pack animals are allowed (for an accepted primitive type of recreation) and where they can go degrade the opportunity for primitive and unconfined recreation.

Travel time and viewshed modeling

Two models were employed to depict remoteness from the sights and sounds of people inside and outside the wilderness. The travel time model was used to delineate areas of SEKI that may be considered more remote than others due to the considerable time and distance required to reach these places. The viewshed model was used to delineate the line of sight impacts of modern human features existing inside and outside wilderness. These analyses were extended into a buffer zone 15km outside the wilderness boundary for the travel time model and 30km for the viewshed model to allow for edge effects occurring outside the park. These buffer zones were necessary to account for edge effects[11] from visible human features and points of access immediately outside the park. These models analyzed a variety of inputs, including road networks, land cover, and all modern human developments occurring in and around the parks.

<u>Travel time</u>

Travel time is modeled in SEKI based on a GIS implementation of Naismith's Rule[12], with Langmuir's correction[13]. Terrain and land cover information are used to delineate the relative time

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[11] A problem created during spatial analysis, when patterns of interaction or interdependency across borders of the bounded region are ignored or distorted (ESRI 2013).

[12] 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).

[13] 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.

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 5km/hr over flat terrain and adds a time penalty of 30 minutes for every 300m of ascent and 10 minutes for every 300m 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 300m of descent. Slopes between 0 and 5 degrees are assumed to be flat. The angle at which terrain is crossed (i.e., the horizontal and vertical relative moving angles[14]) 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 8. Ancillary data layers are used to modify walking speeds according to ground cover (e.g., Naismith's 5km per hour on the map can be reduced to 1km per hour or less when walking through dense vegetation). They also include barrier features that force a detour as "null" values[15].

Table 8. Naismith's Rule expressed in the vertical relative moving angle (VRMA) field.

VRMA (Degrees)	Vertical Factor
-40	2.40
-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	2.90
30	4.19
40	5.75

- *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 10m Digital Elevation Model (DEM), resampled to 30m, provides terrain elevation data, the CALVEG dataset provides the land cover data

[14] 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.

[15] 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.

(USFS 1992, USFS 2013), and the USGS National Hydrologic Dataset (NHD) provides the streams data. All other datasets, including trails and roads, are provided by SEKI.

- *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 the network of trailheads used to access the SEKI wilderness. It should be noted that the SEKI wilderness areas are part of a larger system of connected wilderness areas (see Figure 2) and it can take a day or more of hiking to access much of the SEKI wilderness.

  2. *Cost surface:* We primarily used a pre-existing cost surface model (CSM) for inside the parks' boundaries. This model was based on the "Travel Time Cost Surface Model" developed by Frakes et al. (2007). It was created primarily for the Sierra Nevada Network Inventory & Monitoring Program (SIEN) for incorporation into monitoring project sample designs. Former SEKI GIS Coordinator Pat Lineback initiated the cost surface development for SEKI, and SIEN Biological Science Technician Sandy Graban continued and completed its development with support from Wilderness Ranger George Durkee and other park staff. Original land cover impedance values were calculated only within the SEKI boundary, as the parks' vegetation map was used, which is the most robust dataset available but does not extend beyond park boundaries. Impedance values are assigned to the various land cover classes that inhibit walking speeds when traveling off trail in SEKI. This input is supplemented with an additional cost surface grid for land cover that extends to 15km beyond the park boundary. For a full list of land cover impedance 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 SEKI terrain. Trails are overlaid onto the cost surface at 4km per hour for formal trails and 2.5km per hour for informal trails. Roads are overlaid onto the cost surface at 4km/hr. Finally, rivers can be time-consuming to cross in SEKI. Existing travel cost values created by Sandy Graban for the SEKI Strahler stream order dataset were adapted to represent crossing times for the various stream sizes in SEKI.

  3. *Barriers to movement:* These are areas in SEKI that are considered impassable on foot and include all lakes and any areas where slope angles exceed 40 degrees. The barrier features are coded as NoData (null values) in the cost surface, which forces the model to seek a solution that involves walking around the obstacle.

  Raster values were normalized to 0-255. The normalized values were then inverted to reflect high degradation of solitude values near access points, and lower degradation further away from these features (Figure 10).

- *Cautions*: Naismith'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, or navigational skills.

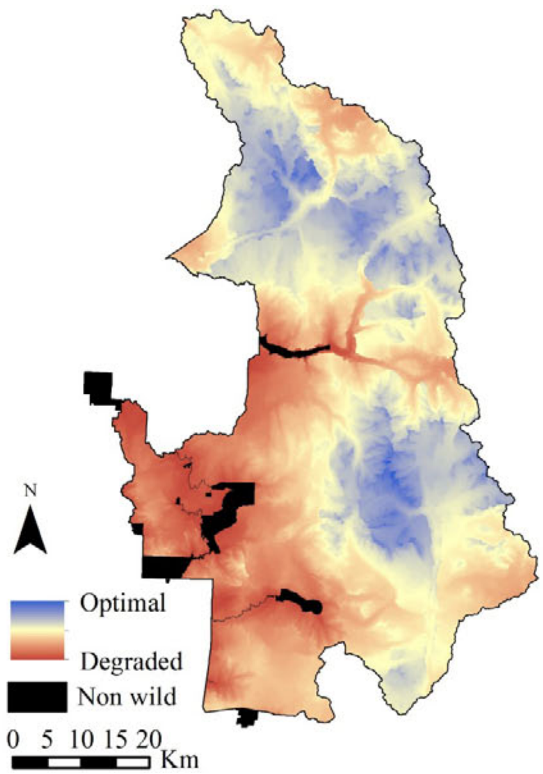

Figure 10. Travel time model. This map depicts the fastest route it would take a person to walk to every pixel in SEKI from the source grid (trailheads). Red indicates the pixels that are within quicker reach and therefore we assume that these pixels represent a lower opportunity for solitude, and blue represents pixels that will take longer to reach and therefore represent greater opportunity for solitude.

Viewshed

The visual impacts of modern anthropogenic features in the SEKI wilderness are modeled using a custom-built software tool. The presence of these artificial features, which may be located within or adjacent to the wilderness, is 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 focused 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, 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[16].

- *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 large spatial extent of SEKI and relative lack of anthropogenic features allows feature information to be collated and formatted manually (Table 9). A resolution of 30m for feature inputs was considered adequate for this analysis. Viewshed distance and height information were determined for each feature by the working group. The resampled USGS 10m Digital Elevation Model (DEM) was used to provide terrain elevation data. The DEM was augmented with the heights from land cover classes from the CALVEG dataset.

- *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[17] 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, it is possible to estimate the visibility between every pair of cells in a high-resolution landscape model utilizing only moderate computing resources.

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[16] 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.

[17] A voxel is a volumetric pixel.

Table 9. Human features impacting viewshed. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is for its respective measure across the parks' landscapes) were evaluated in a qualitative sense by park staff familiar with these data.

Features INSIDE	Data source	Viewshed distance	Height	Accuracy	Completeness
Buildings	SLD_RemoteIn_Viewshed_BuildingHeight_pt_20130429	5-15km	5-12m	High	High
Mines	Heads-up digitized	5km	5m	Low	Low
Roads	SEKIgis.DBO.TRANS_Roads_ln	5km	3m	Medium	High
Science installations	SLD_Viewshed_ScienceInstallations_pt_20130617	5km	Individual	High	High
Bridges	SLD_Viewshed_Bridges_pt_20130617	5km	3-7m		
Trails (only Class 2&3)	SLD_Facilities_TrailsClass_ln_20130424	1km	1m	High	High
Communication towers/stations	SLD_Viewshed_CommunicationStations_pt_20130619	5-15km	Individual	High	High
Dams & diversions	SEKIgis.DBO.BND_Wilderness_py extracted from potential wilderness polygons	15km	5m	High	High
Power lines/utility poles	SEKIgis.DBO.FACILITY_UtilPowerLines_ln	15km	20m	High	High
Features OUTSIDE	**Data source**	**Viewshed distance**	**Height**	**Accuracy**	**Completeness**
Cities/towns	Heads-up digitized	30km	25m	Medium	Medium
Roads	SEKIgis.DBO.TRANS_RoadsRegional_ln	15km	5m	High	High
Highways	SEKIgis.DBO.TRANS_HighwaysNHPN_ln	30km	5m	High	High
Reservoirs	Heads-up digitized	30km	50m	Medium	Medium
Hydropower stations	Heads-up digitized	15km	15m	Medium	Medium
Large transformers/utility lines	PLATTS 2005	30km	15m	Medium	Medium
Park buildings/structures	SLD_RemoteIn_Viewshed_BuildingHeight_pt_20130429	5-15km	Individual	High	High
Water facilities	SLD_Viewshed_WaterFacilities_StorageTanksSewerTreatment_pt_20130619	15km	7m	High	High
Flume	SEKIgis.DBO.FACILITY_UtilFlumes_ln	15km	3m	High	High
Big Pine dish array	Heads-up digitized	30km	50m	Medium	Medium
Communication towers, repeaters	SLD_Viewshed_CommunicationStations_pt_20130619	15km	Individual	High	Medium

Table 9. Human features impacting viewshed. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is for its respective measure across the parks' landscapes) were evaluated in a qualitative sense by park staff familiar with these data (continued).

Features OUTSIDE	Data source	Viewshed distance	Height	Accuracy	Completeness
Fire lookouts	SLD_Viewshed_FireLookouts_py_20130619 Heads-up digitized	30km	5m	High	High
Helispot	SEKI_Viewshed_HeliLandingsAreas_pt_20130619 Heads-up digitized	15km	3m	High	High

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 estimations 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 9, which can then be combined together to create viewshed maps for features both inside and adjacent to the wilderness.

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 the proportion of the features that 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.

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

1. The cell resolution was limited to 30m for all features;
2. A "pessimistic" re-sampling was done to generate the 30m feature inputs guaranteeing that features smaller than this area were included[18] and that the

[18] 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 10m building in a 30 x 30m 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.

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 1km, 5km , 15km and 30km maximum viewshed distances, and for features both inside and adjacent to the wilderness

The model outputs for the different viewshed distances are combined together using the MINIMUM function in ArcGIS to produce grids of viewshed impacts for features both inside and adjacent to the SEKI wilderness. Raster values were normalized to 0-255. The normalized viewshed measure were then inverted to reflect high degradation of solitude values near human features and lower degradation further away from these features (Figure 11).

- *Cautions*: Categorizing the anthropogenic features in SEKI into specific viewshed distances requires careful consideration as to how well each type of feature may blend in with the local background. For example, the majority of science installations are largely unnoticeable from distance because of their shape and profile, and thus are assigned a maximum viewshed distance of 5km. Larger and more prominent features, such as the Big Pine dish array, are assigned a maximum viewshed distance of 30km.

  Depending on the angle of view, trails and roads can be largely unnoticeable once past a short distance. In a majority of the wilderness area, trails are not visible from a great distance. In a minority of the cases, trails can be seen from afar, for example when they traverse a barren hillside. A group decision was made to limit the height to 1m and the viewing distance to 1km favoring the majority of the visitors' experience. However, roads are set at a height of 5m in anticipation of traffic, especially to capture the impact of traffic lights at night. Thus, a number of these features are calibrated negatively to anticipate a worst case scenario.

  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 5m 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.

  Lastly, the current version of the viewshed tool places the 'person' (in the viewshed) on top of all the viewshed features such as vegetation or buildings (as opposed to placing this 'person' in amongst the vegetation). Therefore, areas where the vegetation exceeds 3m need to be removed manually from the output. This limitation is being addressed and future versions of software will eliminate this issue.

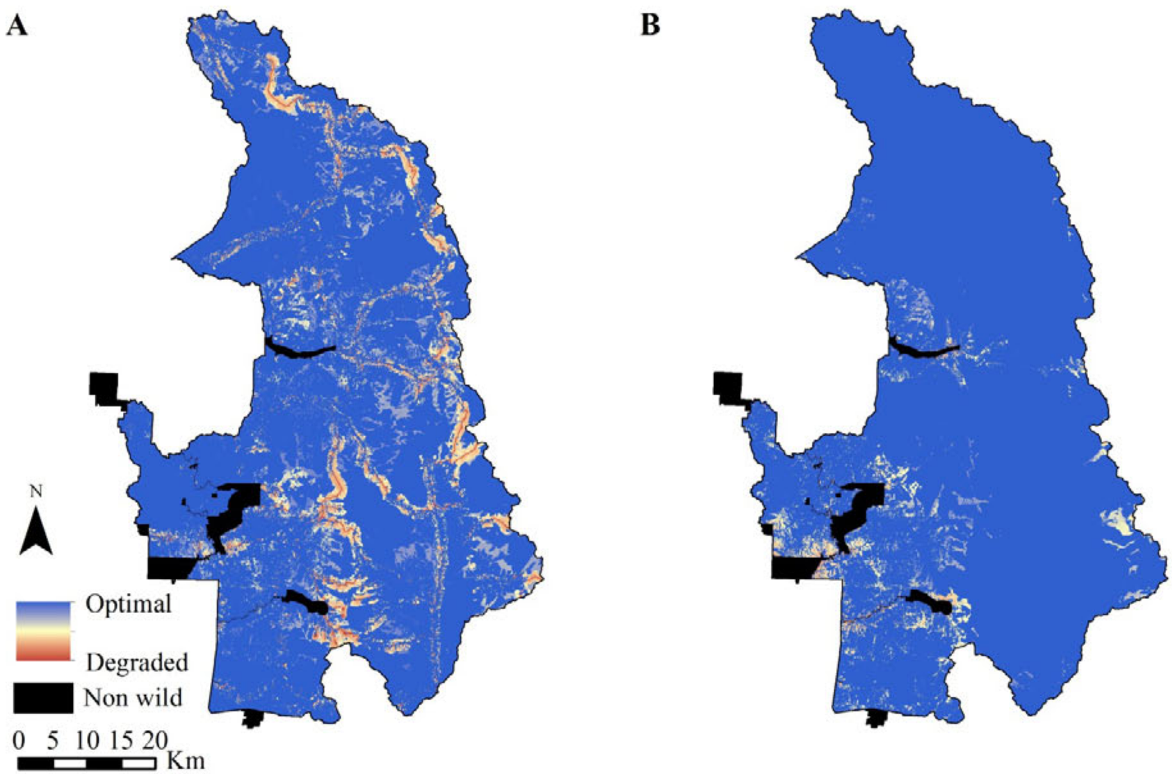

Figure 11. Viewshed impacts for (A) features inside the wilderness and (B) features outside the wilderness. Blue depicts optimal quality and red depicts degraded quality.

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 10), which encompass a range of different scales, variability in accuracy and completeness, and both vector and raster data. Additional measures were identified but not included due to a lack of relevant data or other shortcomings: dark skies and visibility.

Table 10. Solitude and primitive and unconfined quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is for its respective measure across the parks' landscapes) were evaluated in a qualitative sense by park staff familiar with these data.

Measures	Source	Type	Scale/ Resolution	Accuracy	Complete-ness
Travel time	(1) USGS DEM 10m, (2) SEKI Vegetation inside the parks, (3) USFS CALVEG outside the parks (4) USGS NHD, (5) SEKI roads, (6) SLD_Facilities_TrailsClass_ln_20130424	Polyline & Raster	(1) 10m, (2) 1:24,000, (3) 30m, (4) 1:24,000, (5) 1:24,000 (6) 1:24,000	High	High
Viewshed	See Table 8				
Campsite inventories	SLD_RemoteIn_CampsiteInventories_ra_20130624	Raster	30m	High	Medium+
Outfitter use nights	SLD_RemoteIn_OutfitterUse_py_20130502	Polygon	1:100,000	Medium	Medium
Visitor use nights/quota information/party size	SLD_RemoteIn_VisitorUseNights_py_20130625	Polygon	1:100,000	Medium+	Medium+
Overflights	SLD_RemoteOut_OverflightsMilitary_py_20130523	Polygon	1:250,000	Medium	Medium-
Dark skies*	N/A				
Visibility*	N/A				
Viewshed outside	See Table 8				
Soundscapes	SEKIMask_Impact_L50dBA	Raster	270m	Medium	Medium
Trail class	SLD_Facilities_TrailsClass_ln_20130424	Polyline	1:24,000	High	High
Toilets for visitors	SLD_Facilities_Toilets_pt_20130619	Point	1:24,000	High	High
Designated campsites	SLD_Facilities_DesigCampsites_pt_20130319	Point	1:24,000	High	High
Food storage boxes	SLD_Facilities_FoodStorage_pt_20130619	Point	1:24,000	High	High
Bearpaw HSC & Pear Lake	SLD_Facilities_Structures_py_20130325	Polygon	1:24,000	High	High
Access/use restrictions	SLD_ManageRestrict_AccessUseRestrictCamping_py_20130620, SLD_ManageRestrict_AccessUseRestrictFire_py_20130402, SLD_ManageRestrict_AccessUseRestrictFoodStorage_py_20130620, SLD_ManageRestrict_AccessUseRestrictPartySize_py_20130620	Polyline & Polygon	1:100,000	High	High
Recreational stock restrictions	SLD_ManageRestrict_StockRestrict_py_20130625	Polygon	1:100,000	High	High

* No data

Campsite inventories (weighted density)

- *Sources:* Point dataset depicting wilderness campsite locations, based on inventories conducted in Sequoia and Kings Canyon in 2006, 2007, and 2012 (SEKI Wilderness Coordinator and Biological Science Technician; David Cole and David Parsons, USFS Aldo Leopold Wilderness Research Institute). Cole and Parsons (2013) report on changes in campsite impacts in the parks over a 30-year period. Magnitude of impact was based on campsite density, vegetation composition, total area of the campsite, barren core area, campsite development, litter and duff, social trails, and tree mutilations.

- *Processing:* Each point has a Condition Class value (1 – 5) and a Condition Class weight. Class 1 = 1; Class 2 = 6; Class 3 = 30; Class 4 = 75; and Class 5 = 150. Kernel density[19] analysis was performed using Condition Class weight as the population field with an output cell size of 30m. Several iterations were required to determine the best method for kernel search radius (500m). Areas with "0" values were eliminated from the final raster/TIFF image product. Raster values were normalized to 0-255.

- *Cautions:* At the time of the inventory, approximately 14% of the campsites within the current data were identified for "obliteration," indicating that management action should be taken to completely remove the campsite. Management action was taken on these locations, and it is highly likely that conditions on the ground have improved in recent years. Historic data from 1978 to 1981 are available in point and tabular form. However, these data were considered incomplete at the time of this study because Condition Class values were not spatially referenced. Several methods were tested in an attempt to integrate historic information, but the results were discarded as they were considered inaccurate or potentially misleading.

Outfitter use nights

- *Sources:* (1) Commercial Stock Outfitter Use (SEKI Biological Science Technician). Text format, tab-delimited dataset is queried from existing stock use database. Commercial trips are obtained by multiplying the total number of nights or days by the total number of packers and clients, for each Wilderness Travel Zone (WTZ)[20] in 2012. (2) Commercial Non-Stock

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[19] Calculates a magnitude per unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline (ESRI 2013).

[20] In the mid-1970s, SEKI's research scientists divided the parks' backcountry (now wilderness) into travel zones. Each zone was loosely based on geographic features (watersheds). These zones were used in user capacity planning and assigned an individual overnight use capacity. The park then implemented a trailhead quota system to assist in maintaining appropriate levels of use within each travel zone. SEKI continues to use wilderness travel zones (WTZ) as a way of monitoring and analyzing visitor use patterns.

Outfitter use –Excel spreadsheet dataset summarizes day and night use by WTZ in 2012 (Assistant Wilderness Coordinator). Length of commercially supported trip is determined by the number of days that a commercial outfitter is present in the wilderness. (3) Wilderness Travel Zones polygon dataset located in SEKI Spatial Data Warehouse. Polygons depict areal units used in the Wilderness Permit System.

- *Processing:* Both tabular data sources are joined to the WTZ polygon dataset using unique Zone numbers. Outfitter Use Nights are totaled, normalized, and scaled: (1) Total Outfitter Use Per Zone is obtained through a weighted sum [(Commercial Stock Outfitter use Nights + Commercial Non-Stock Outfitter Use Nights) *2) + (Commercial Stock Outfitter Use Days + Commercial Non-Stock Outfitter Use)]; (2) Normalized Outfitter Use is obtained by dividing Total Outfitter Use Per Zone by the square kilometer area of each WTZ; and (3) Scaled Outfitter Use is obtained by scaling the Normalized Outfitter Use from 1 to 100. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Only zones with reported stock outfitter use appear in the dataset (zones with no reported stock outfitter use were omitted). Non-stock outfitter use data are not well reported by outfitters. The non-stock outfitter data that were used were assembled from multiple sources (NPS and USFS wilderness permit databases, commercial use reporting forms, and trip itineraries) and may have a high margin of error.

Visitor use nights/quota information/party size

- *Sources:* (1) Permit database maintained by the Wilderness Office (Wilderness Coordinator and Wilderness Assistant). The Wilderness Permit database captures wilderness use information from 2007 to 2012. (2) Wilderness Travel Zones polygon dataset located in SEKI Spatial Data Warehouse. Polygons depict areal units used in the Wilderness Permit System.

- *Processing:* Total Visitor Use Nights per WTZ was obtained from the Wilderness Permit Database using a query that: (1) multiplies the number of people by the number of nights per permit for the years 2009 through 2012 (stock use and cancelled permits were excluded); and (2) summarizes the total visitor use nights by WTZ. The tabular results of the query are joined to the WTZ polygon feature class using unique zone numbers, and visitor use nights are normalized and scaled: (1) Normalized Visitor Use Nights for 2009 – 2012 is obtained by dividing Average Total Visitor Use Night by the square kilometer area of each WTZ; and (2) Scaled Visitor Use Nights for 2009-2012 is obtained by scaling the Normalized Visitor Use Nights from 1 to 100. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* The Wilderness Permit Database may contain inconsistencies in data entry or interpretation over the past several years. Although USFS permit data are represented in these numbers, the margin of error for these data may be higher than for permits issued in SEKI.

Overflights

- *Sources:* Polyline dataset depicting general flight paths for entry and exit (ingress and egress) points for military airspace over SEKI (Wilderness Coordinator and U.S. Department of Defense, Air Force).

- *Processing:* Extend entry/exit polyline across the park and apply buffers to estimate area of sound impact: 1 kilometer buffer (higher sound impact) and 4 kilometer buffer (lower sound impact). Apply values: 1 kilometer buffer = 9 and 4 kilometer buffer = 6. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Commercial flight corridors, administrative overflights, and reported Military Low-Flyer Incidents were excluded due to lack of available data or data quality issues. Linear buffers of the military flight path offer a rough estimation of sound impact and do not account for variability introduced by terrain.

Dark skies

- *Sources:* Data not sourced.
- *Processing:* N/A
- *Cautions:* N/A

Visibility

- *Sources:* Data not sourced.
- *Processing:* N/A
- *Cautions:* N/A

Soundscapes

- *Sources:* Raster dataset provided by the NPS Natural Sounds Program (Mennitt et al. 2013). The existing sound pressure level is the acoustic condition as measured; it includes all acoustic energy. A natural level was synthesized by systematically removing all anthropogenic noise leaving only biological and geophysical sources. The following map (Figure 12) shows the A-weighted L50 impact sound pressure level, defined as the difference between the existing and natural sound pressure levels, during a typical summer day. The L50 is the sound level exceeded half of the time whereas A-weighting is an adjustment that reflects how the human ear perceives sound.

- *Processing:* Re-project raster to NAD 1983 UTM Zone 11N coordinate system and normalize values to 0-255.

- *Cautions:* Park staff had the following to say about this externally sourced dataset: It appears that the Mineral King Road (~300 cars/day during the summer) and Redwood Mountain road

(~30 cars/day during the summer) were not included in this analysis. The reviewing team did not agree with the moderately degraded soundscape in the alpine areas. They do not believe that visitors are impacted by human sounds coming from outside influences, except from overflights.

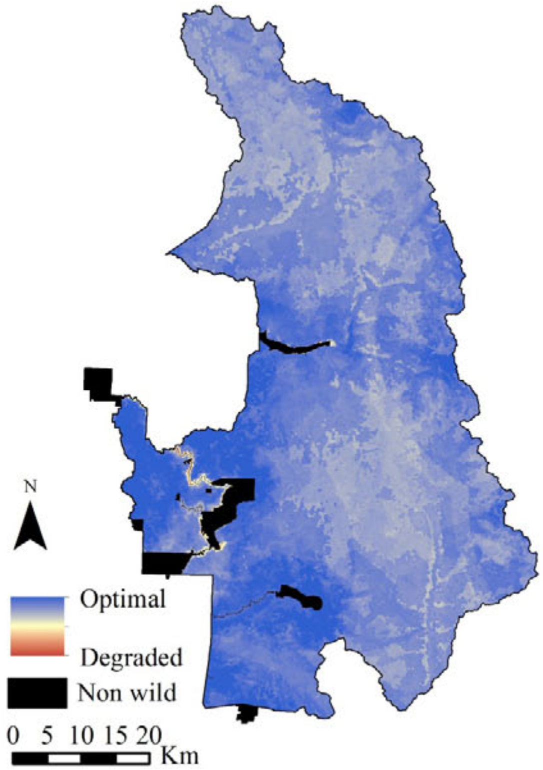

Figure 12. Soundscape map for Sequoia and Kings Canyon National Parks.

Trail class

- *Sources:* Polyline datasets for maintained and unmaintained trails located in SEKI Spatial Data Warehouse. A paper map showing all trails was created by Sequoia and Kings Canyon trail supervisors, highlighted by hand to show trail classes.

- *Processing:* Merge maintained trails and unmaintained (abandoned) trails polyline datasets and enter new trail classifications based on paper map. New descriptions are established for formal trails (designated and regularly maintained) using a range of class values established by the Forest Service Handbook 2309.18: Trails Management Handbook, pages 6 - 10: 1 = minimally developed, 2 = moderately developed, 3 = developed, 4 = highly developed, and 5 = fully developed (USFS 2008). Eliminated non-formal (i.e. abandoned and unmaintained) trails from the dataset. Note: Trail classes 4 and 5 are not wilderness appropriate and as such do not exist in SEKI wilderness. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* Trail Class serves as a proxy for other infrastructure (such as bridges, boardwalks, walls, and signs) because higher class trails are often associated with this type of infrastructure. Trail segments are collected through a variety of methods, including GPS and digitizing.

Toilets for visitors

- *Sources:* Point dataset depicting all toilets in wilderness, located in the SEKI Spatial Data Warehouse (Kings Canyon Sub-District Ranger).
- *Processing:* Revise point data based on feedback from subject matter experts: adjust locations and remove/add points where needed. Locations of toilets are given a value of 1. Layer was converted to raster and values were normalized to 0-255.
- *Cautions:* None.

Designated campsites

- *Sources:* Point dataset depicting designated campsites in wilderness, located in the SEKI Spatial Data Warehouse (Assistant Wilderness Coordinator).
- *Processing:* Locations of designated campsites are given a value of 1. Layer was converted to raster and values were normalized to 0-255.
- *Cautions:* None.

Food storage boxes

- *Sources:* Excel spreadsheet containing latitude/longitude coordinate information for food storage boxes inside wilderness (Wildlife Biologist, Trails Supervisor, and Sub-District Ranger).
- *Processing:* Import tabular latitude/longitude information into GIS format. Revise point data based on feedback from subject matter experts: adjust locations and remove/add points where needed. Locations of food storage boxes are given a value of 1. Layer was converted to raster and values were normalized to 0-255.
- *Cautions:* Dataset might have legacy issues with spatial accuracy, due to inconsistent datum, digitizing precision, undocumented changes, and collection methods.

Bearpaw Meadow High Sierra Camp (HSC) and Pear Lake

- *Sources:* Point and polygon datasets for buildings, located in the SEKI Spatial Data Warehouse (Wilderness Coordinator and Assistant Wilderness Coordinator).

- *Processing:* Assign the following values to the locations of the two structures: Pear Lake = 1 and Bearpaw Meadow HSC = 2. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* None.

Access/Use Restrictions

- *Sources:* Wilderness Coordinator, GIS & Data Coordinator and Assistant Wilderness Coordinator. Polygon datasets for fire restrictions, camping restrictions, and food storage restrictions, all extracted from SEKI Spatial Data Warehouse. Party size restrictions: hand drawn map provided by the wilderness office and a flyer that describes group size limits for 2012.

- *Processing:* The following actions were taken for each dataset:

  i. Fire restrictions and food storage: all park areas have some level of restriction. Extracted areas where no campfires are allowed. Apply the following weighting scheme to both datasets: restricted (no campfires allowed) areas = 2 and the remainder of the park = 1.

  ii. Camping restrictions: modified based on (1) polygon feature class that shows camping restrictions in specific areas, and (2) park policy mandating that camps must be located at least one mile from any road/development or should be located beyond a specified distance from individual trailheads. Apply a one-mile buffer to existing roadways; apply a half-mile buffer to specific maintained trail segments; and merge the resulting buffered areas with existing data. Locations of camping restrictions were given a value of 1.

  iii. Party size restrictions: the 2012 group size limits flyer indicates that in specific areas, groups that travel one-half mile off maintained trails are limited to no more than eight individuals. Redwood Canyon area has day use group size limit of 10, and the remainder of the park has a group size limit of 15. A half-mile trail buffer, watershed boundaries, wilderness travel zones, and park boundaries are used to delineate these areas. The following weights are applied: 8 members = 20, 10 members = 15, and 15 members (remainder of the park) = 10.

  iv. The four restrictions are then converted to rasters and values were normalized to 0-255, before being adding together in the raster calculator and re-stretched to 0-255 to create the overall measure.

- *Cautions:* Hand-digitizing techniques may introduce uncertainty in the data. Not all possible use restrictions were used in this compilation.

Recreational stock restrictions (use and access)

- *Sources:* Polygon dataset based on the 1986 Stock Use and Meadow Management Plan, existing trails spatial data, and 2012 temporary public closure documents (Biological Science Technician). Four restriction types were captured through digitizing or geoprocessing techniques: (1) stock travel - specific areas closed to stock, (2) stock camping - areas in which only day use and pass-through stock travel was permitted in 2012, (3) stock grazing - areas that received grazing restrictions based on overall stock-type, night limits, head limits, overall stock prohibition, and user group limitations; and (4) travel within maintained trail corridors - areas within one-half mile of maintained trails and routes. Areas that do not have stock restrictions were omitted from this dataset.

- *Processing:* The following values were applied to the four restriction types: travel restrictions (within maintained trail corridors) and grazing restrictions = 25, camping restrictions = 50, and access prohibited = 100. Layer was converted to raster and values were normalized to 0-255.

- *Cautions:* These data are a simplified version of stock restrictions; their intended use is for the current exercise only.

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 measure (Table 11). The “weighted” measures under each indicator total 100. Although data for dark skies and visibility are unavailable, these “missing” measures are still assigned weights. In the future, should the data improve or become available, these measures can be added to subsequent iterations of the wilderness character map. The revised weights for indicators with missing data are recorded in brackets in Table 11.

Maps

The weighted measures for each indicator were 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 13). The first two indicators were added together to depict opportunities for solitude inside wilderness and the latter two indicators were added together to depict opportunities for primitive and unconfined recreation inside wilderness (Figure 14). Finally, the raster calculator was used to add the four indicator maps together to create the solitude or primitive and unconfined quality map (Figure 15).

Table 11. Indicators and measures for the solitude or primitive and unconfined recreation quality with weights and rationale. The first set of weights equals 100 for those measures with data currently available. A second set is provided in brackets for all measures, those with and without data.

Indicator	Measure	Weight	Rationale
Remoteness from sights and sounds of people inside the wilderness	Travel time	20	Access and remoteness into the wilderness are important resources to assess for management
	Viewshed	10	Important to assess due to effects of impacted views on solitude
	Campsite inventories	30	Important aspect to assess; density and impacts affect the opportunity for solitude
	Outfitter use nights	20	Important to assess commercial service impacts to solitude
	Visitor use nights/ quota information/ party size	20	Important to assess overall use by volume and location
Remoteness from occupied and modified areas outside the wilderness	Overflights	25 (20)	Important indicator to feeling of remoteness and solitude
	Dark skies*	(10)	Important to feeling of remoteness and solitude
	Visibility*	(30)	Important resource issue with relation to feeling of remoteness
	Viewshed outside	50 (30)	Important resource issue detracts from feeling of remoteness
	Soundscapes	25 (10)	Important to feeling of remoteness and solitude
Facilities that decrease self-reliant recreation	Trail class	60	Very noticeable on the landscape – decreases self-reliance
	Toilets for visitors	10	Moderately noticeable but limited on the landscape – decreases self-reliance
	Designated campsites	10	Moderately noticeable but limited in scope – influential on self-reliance
	Food storage boxes	10	Moderately noticeable – decreases self-reliance
	Bearpaw Meadow & Pear Lake facilities and operations	10	Notable operations – decrease self-reliance, primitive recreation and solitude
Management restrictions on visitor behavior	Access/use restrictions	85	Impacts visitor use and behavior
	Recreational stock restrictions	15	Does not impact as many visitors – only impacts a specific type of visitor use
	* No data	400	

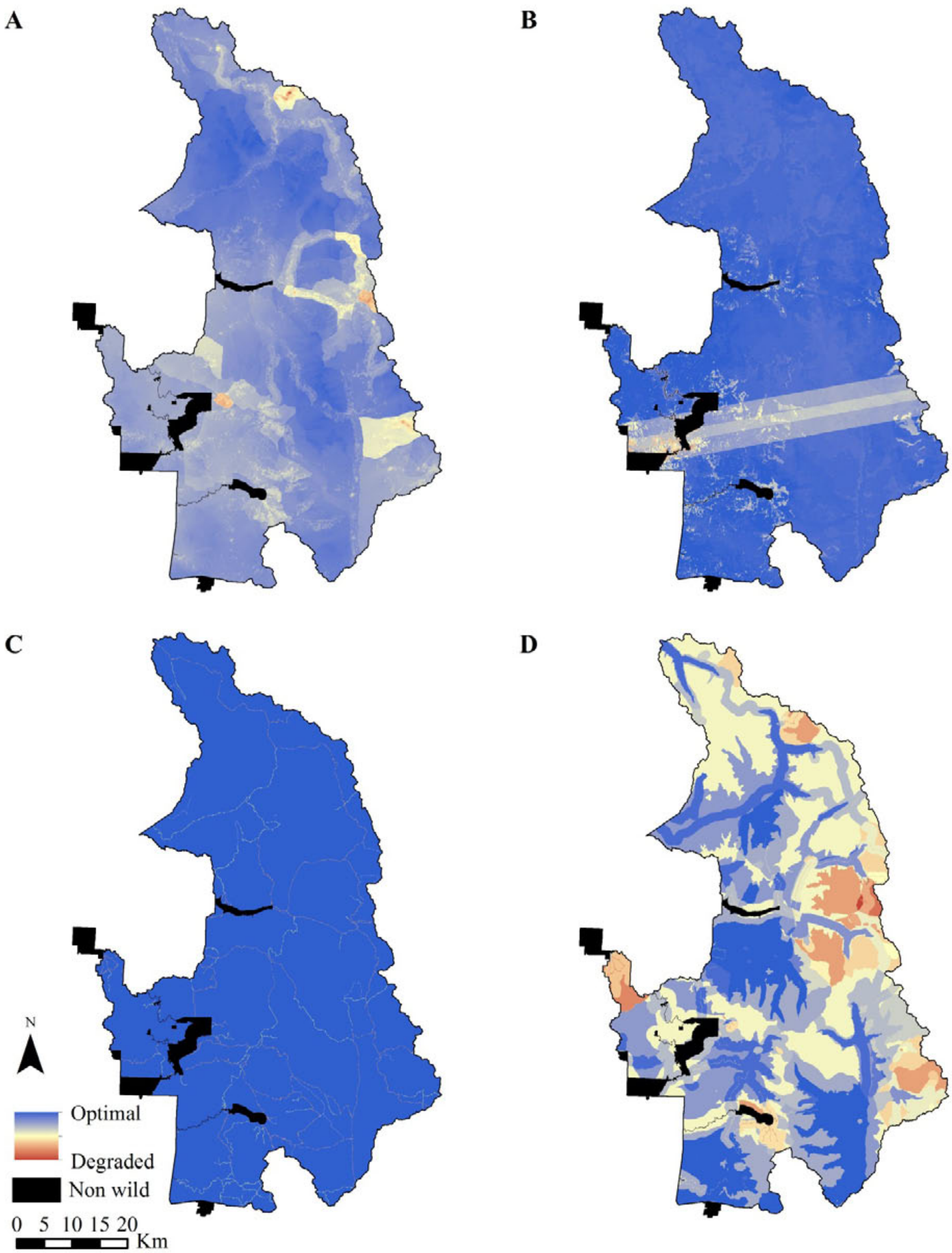

Figure 13. Indicator maps for (A) remoteness from sights and sounds of people inside the wilderness, (B) remoteness from occupied and modified areas outside the wilderness (the yellow corridor represents the military overflight path), (C) facilities that decrease self-reliant recreation, and (D) management restrictions on visitor behavior. Blue depicts optimal quality and red depicts degraded quality.

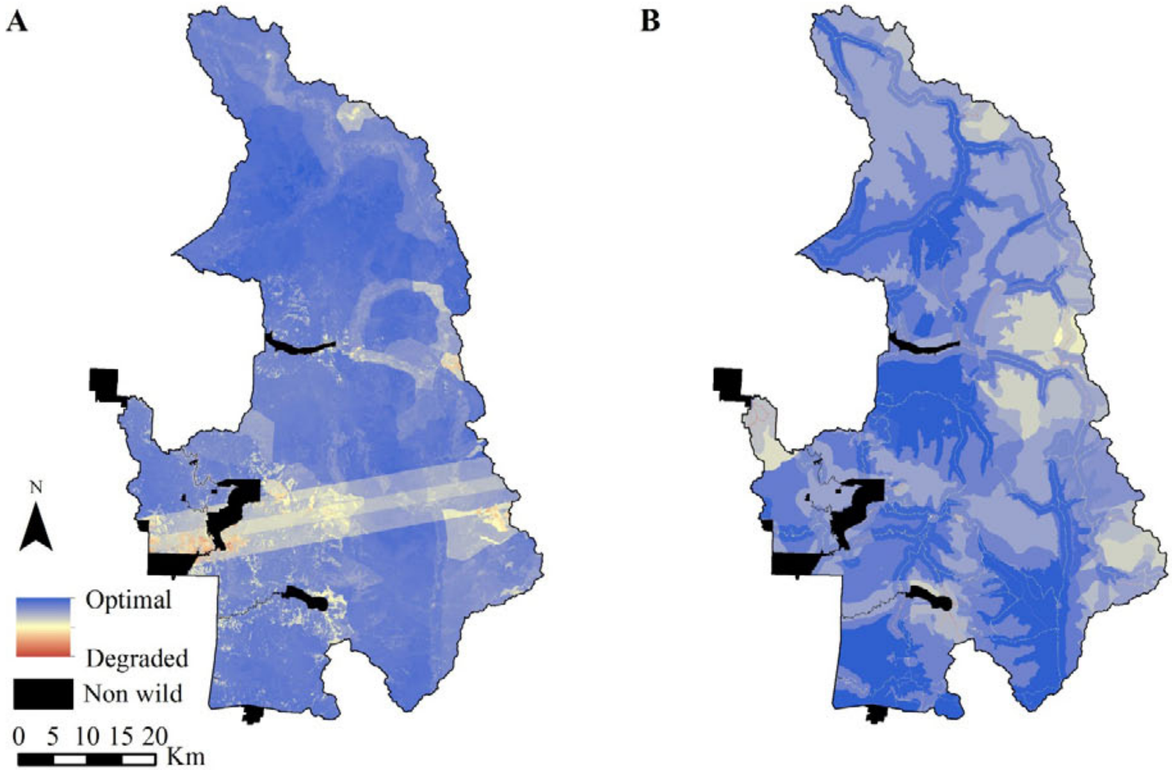

Figure 14. Combined indicator maps for (A) opportunities for solitude inside wilderness (west-east yellow corridor represents the military flight path), and (B) opportunities for primitive and unconfined recreation inside wilderness. Blue depicts optimal quality and red depicts degraded quality.

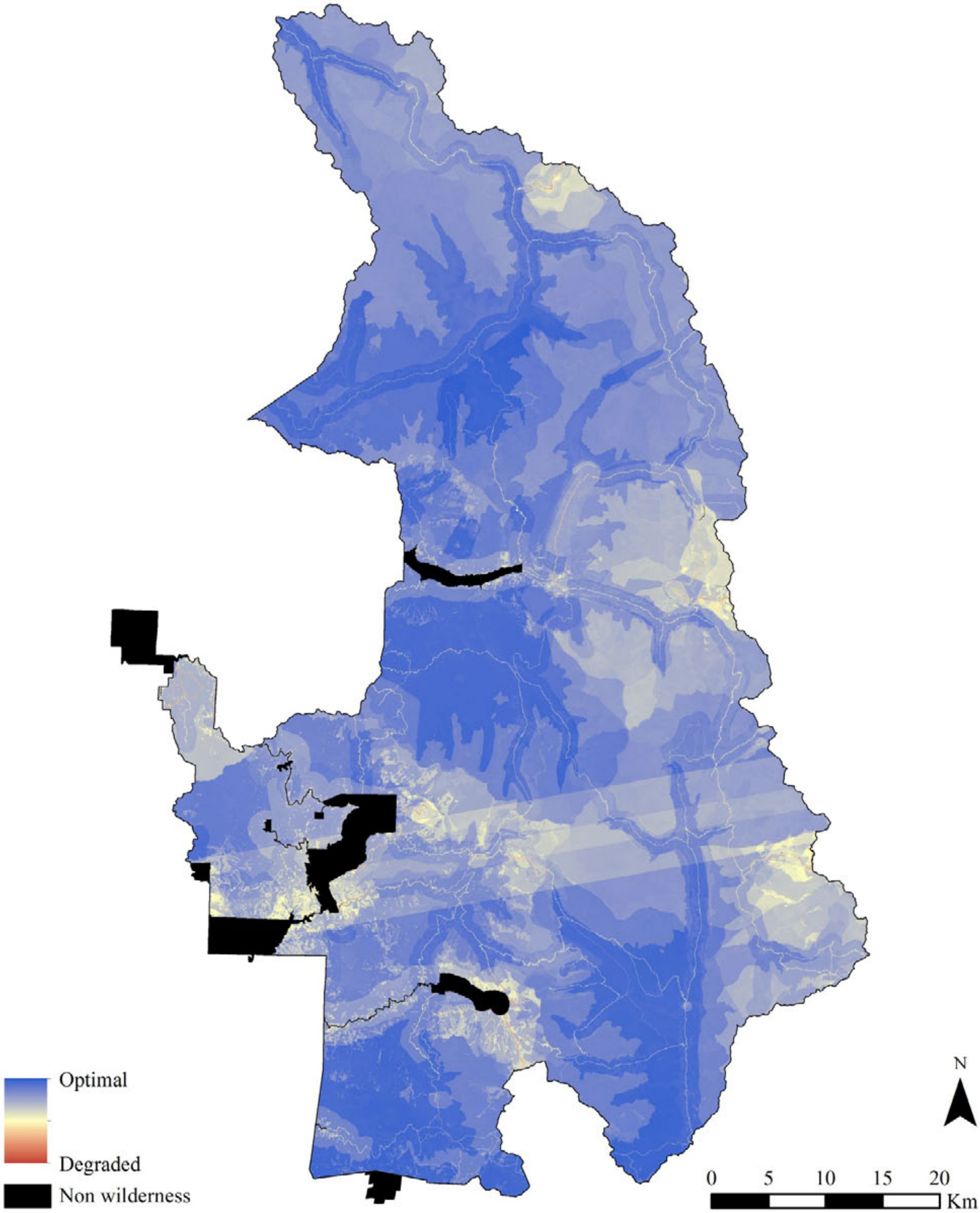

Figure 15. Solitude or primitive and unconfined recreation quality of wilderness character. West-east yellow corridor represents the military flight path. Blue depicts optimal quality and red depicts degraded quality. To view a higher resolution version of this map, please see the separately published Appendix 2 (Tricker et al. 2014).

The Wilderness Character Map

The methodology described above produced four maps, one for each of the qualities of wilderness character. These maps were then combined to produce a single map of overall wilderness character quality in SEKI. Because all four qualities are equally important and no quality is held in higher or lower regard than the other, the four qualities are added together without using weights (Figure 16).

Interpreting and discussing these maps requires a clear understanding of the methods that were used and their limitations. For example, it is noticeable that the natural and solitude maps are distinctly different in appearance to the untrammeled and undeveloped maps. This is because the latter 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, some data, such as visitor use, were spread across travel zones when in reality this use is concentrated to smaller areas within travel zones. The maps represent a grid of values (approximately 3.7 million pixels at 30m resolution). The maps use 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 were generated through the analysis of a multitude of measures: to understand why these areas are degraded one must “drill down” into the individual qualities, indicators, and measures.

An equal interval reclassification[21] of the wilderness character map was performed to assess the range of values of all the pixels onto a scale of 1-100. These values were then split into ten equal categories (i.e., 0-10, 11-20, 21-30, and so on). All pixels, now allocated in one of the ten categories, identify the current status of wilderness character at SEKI (Figure 17). Pockets of the highest quality category (91-100) are found (moving north to south) around Southern San Joaquin River drainage; Middle Fork Kings River drainage; upper reach of South Fork Kings River; Sugarloaf/Roaring River drainage; North Fork Kern River headwaters; and Western Kern plateau. The largest category (81-90) covers large swathes of the northern and central parts of the wilderness (and comprises over 50% of the total wilderness area). The six smallest categories occur mostly in the southwest part of the wilderness (which contains the main developed areas and provides ‘drive-up’ access) or along the trail network. Looking at the histogram of the distribution of pixel values (Figure 18), it is clear that the majority of the park has mostly high quality wilderness character with the dominant category being 81-90.

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[21] 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 2013).

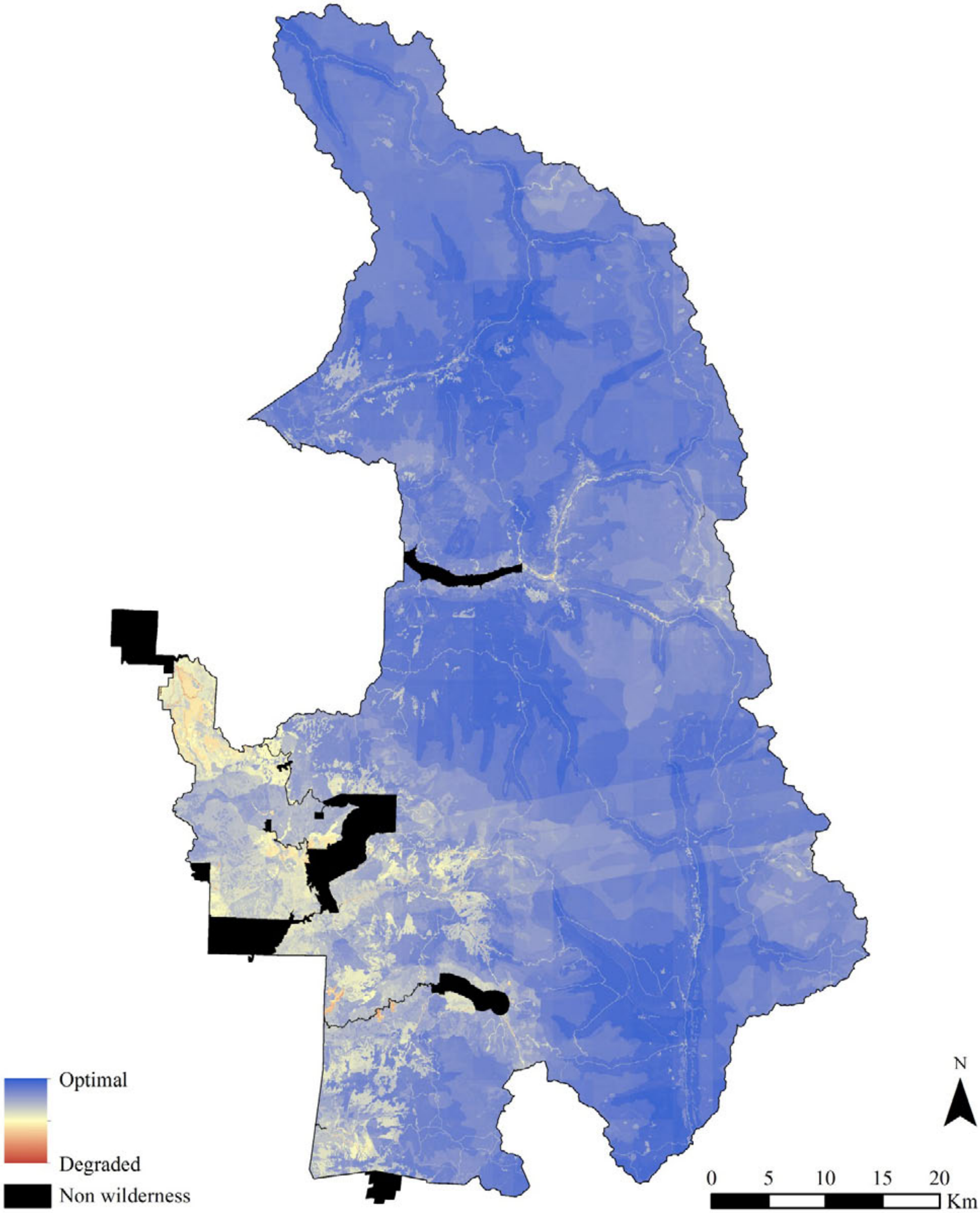

Figure 16. Map of wilderness character in Sequoia and Kings Canyon National Parks. Blue depicts optimal quality and red depicts degraded quality. To view a higher resolution version of this map, please see the separately published Appendix 2 (Tricker et al. 2014).

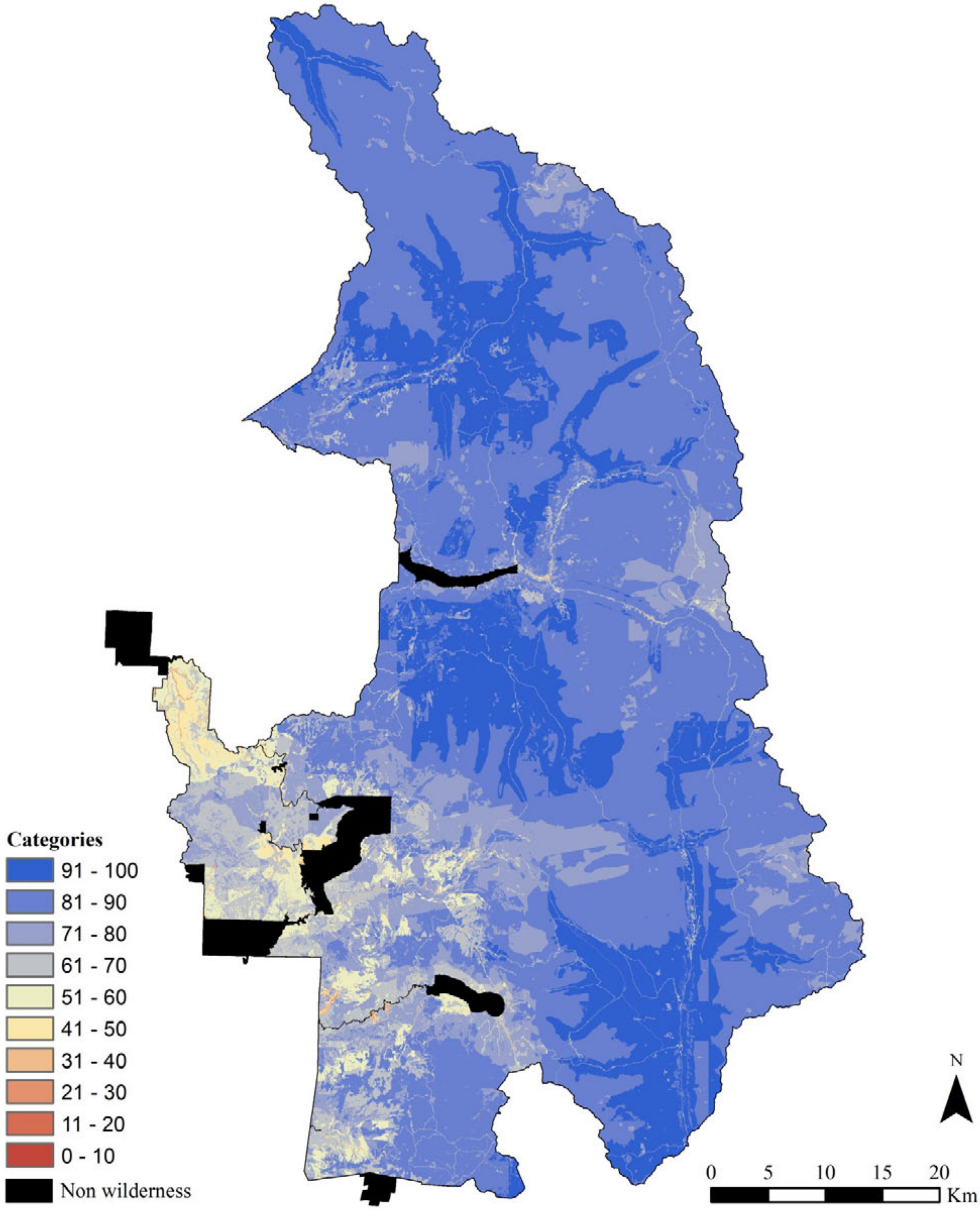

Figure 17. Map of wilderness character in Sequoia and Kings Canyon National Parks reclassed into ten equal categories. Blue depicts optimal quality and red depicts degraded quality.

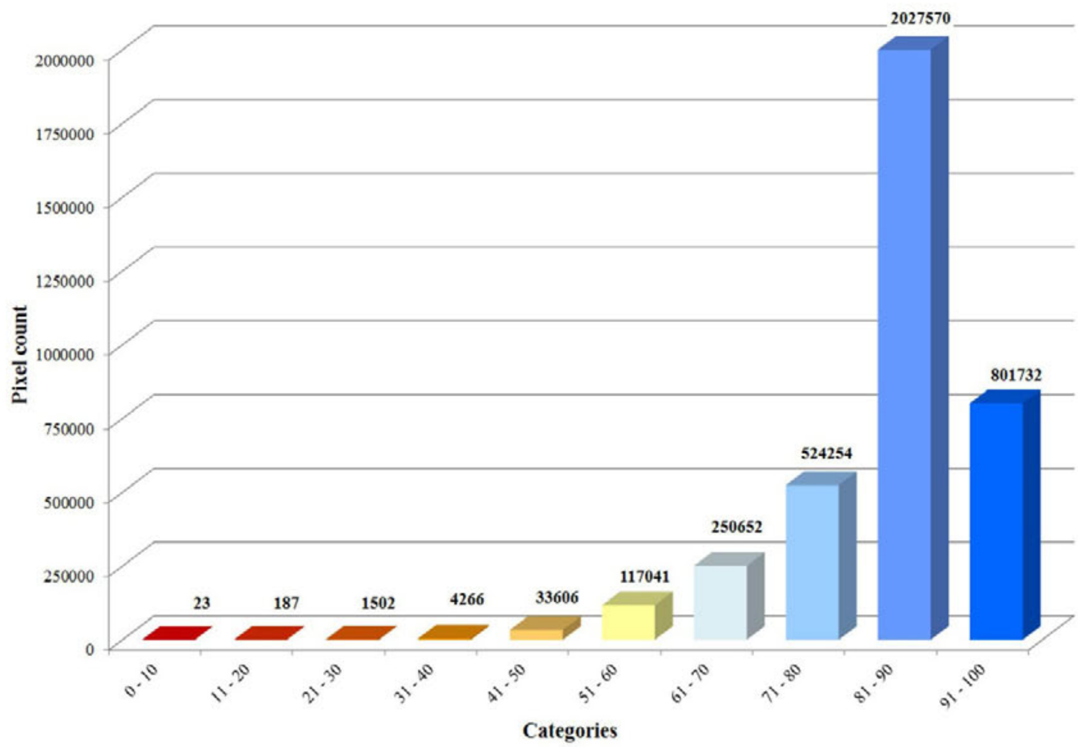

Figure 18. Histogram of the wilderness character map values.

Improvements

The map products presented in this document could be improved in a number ways. The maps are highly dependent on the wide range of spatial datasets that define wilderness character and the weightings assigned to each measure. As the data quality becomes more accurate and complete, and the missing data gaps are filled, the maps will improve. The availability of improved land cover maps and a higher resolution Digital Surface Model will increase the accuracy and effectiveness of the travel time and viewshed models.

The issue of data quality also highlights the need for the NPS as a whole to manage its spatial database more effectively. Clear communication with staff or scientists conducting work or research in wilderness can allow for the generation or improvement of spatial datasets that can be used to inform the map products. While generally successful in these areas, SEKI should continue to improve communication with external researchers and among park staff. Increased collaboration and involvement will allow staff to better realize how they can contribute to - and benefit from - spatial data and GIS applications.

Park databases 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 wilderness 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.

With optimal interaction between park staff and researchers, and between park staff of varying disciplines, the accuracy and extent of information in databases and available to park management can be improved. This would result in more effective and efficient stewardship of SEKI's wilderness character.

This mapping approach also highlighted the difficulties in accounting for "value added" features of the landscape. Whilst the concept of wilderness character is positive, most of the measures identified in *Keeping It Wild* are measures of loss or degradation from an ideal condition. 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 mountain yellow-legged frog (MYLF) (an important imperiled species in SEKI) exist would mean that all the other pixels would be devalued for that same measure, even though they might not even be suitable or historic habitat for MYLF. A similar paradox exists for recreational stock restrictions. Stock restrictions are in place to protect natural resources. In this case, the map depicts a loss of unconfined recreation and thus a degradation of the solitude and primitive or unconfined recreation quality of wilderness character without accounting for the value added to wilderness character by the preservation of a primitive and traditional type of recreation. 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, and common to almost all GIS analyses, is the tendency for end-users to ascribe false levels of reliability and precision to the maps because they look accurate. These map products are only an estimate of selected measures of wilderness character and their spatial 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). These maps do not portray the symbolic, intangible, spiritual, and experiential values of wilderness character that are unique to individual persons, locations, and moments. The maps should be viewed as a tool that wilderness stewards can use to further refine the effectiveness of their efforts to "preserve the wilderness character" and perpetuate "the enduring resource of wilderness" (Public Law 88-577).

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Appendix 1. Travel impedance for land cover classes

The impedance column provides walking speed times (in kilometers per hour) for each land cover type, according to their perceived impedance when "walking" through the landscape.

SEKI Land Cover Class	Impedance (kph)
Alpine Talus Slope	1.6
Alpine Scree Slope	2.4
Alpine Snow Patch Communities	4
Alpine Fell-field	4
Mesic Rock Outcrop	2.4
Boulder Field	1.6
Conifer Reproduction	1.6
Sparsely Vegetated Undifferentiated	4
Sparsely Vegetated Riverine Flat	4
Non-alpine Talus	1.6
Sparsely Vegetated to Non-vegetated Exposed Rock	4
Dome	4
Sparsely Vegetated Rocky Streambed	2.4
Alpine Permanent Snowfield/Glacier	4
Water	0
Urban/Developed	4
Canyon Live Oak Forest Alliance	2.4
Canyon Live Oak/Birchleaf Mountain Mahogany Forest Mapping Unit	2.4
Canyon Live Oak/Whiteleaf Manzanita Forest Association	2.4
Canyon Live Oak-(Ponderosa Pine-Incense-cedar) Forest Superassociation	2.4
Canyon Live Oak-California Laurel Forest Superassociation	2.4
Canyon live oak/Greenleaf Manzanita Forest Association	2.4
Interior Live Oak Woodland Alliance	2.4
Interior Live Oak-Canyon Live Oak Woodland Association	2.4
Interior Live Oak-California Buckeye/Birchleaf Mountain Mahogany-California Redbud Forest Association	1.6
Quaking Aspen Forest Alliance	2.4
Quaking Aspen/Willow spp. Forest Mapping Unit	1.6
Quaking Aspen/Willow spp. Talus Mapping Unit	1.6
Quaking Aspen/Big Sagebrush Forest Superassociation	2.4
Quaking Aspen/Meadow Mapping Unit	4
California Black Oak Forest Alliance	2.4
California Black Oak/(Bracken Fern) Forest Mapping Unit	4
Blue Oak Woodland Alliance	4
Blue Oak/Brome spp.-American Wild Carrot Woodland Association	4
Blue Oak-Interior Live Oak/Brome spp.-American Wild Carrot Woodland Association	4
Blue Oak-California Buckeye-(Interior Live Oak) Woodland Mapping Unit	4
Black Cottonwood Temporarily Flooded Forest Alliance	2.4
Black Cottonwood Forest Association	2.4
White Alder Temporarily Flooded Forest Alliance	2.4
White Alder-Red willow-California Sycamore Forest Association	2.4
Bigleaf Maple Forest Alliance	2.4

SEKI Land Cover Class	Impedance (kph)
California Sycamore Temporarily Flooded Woodland Alliance	2.4
California Sycamore-(Canyon Live Oak-Interior Live Oak) Forest Mapping Unit	2.4
California Buckeye Woodland Alliance	4
California Buckeye-Canyon Live Oak Woodland Association	1.6
Montane Broadleaf Deciduous Trees Mapping Unit	4
Sierra Lodgepole Pine-Quaking Aspen-(Jeffrey Pine) Forest Alliance	2.4
Sierra Lodgepole Pine-Quaking Aspen/(Kentucky Bluegrass) Forest Mapping Unit	2.4
Sierra Lodgepole Pine Forest Alliance	2.4
Sierra Lodgepole Pine/(Bog Blueberry) Forest Mapping Unit	4
Sierra Lodgepole Pine Rocky Woodlands Superassociation	4
Sierra Lodgepole Pine-(Whitebark Pine)/(Ross Sedge-Shorthair Sedge) Forest Superassociation	4
Sierra Lodgepole Pine/Big Sagebrush Forest Association	4
Sierra Lodgepole Pine Mesic Forest Superassociation	2.4
Sierra Lodgepole Pine Xeric Forest Superassociation	2.4
Ponderosa Pine Woodland Alliance	2.4
Ponderosa Pine-California Black Oak/Whiteleaf Manzanita Woodland Association	2.4
Ponderosa Pine-Incense-cedar Forest Alliance	2.4
Ponderosa Pine-Incense-cedar-Canyon Live Oak/Mountain Misery Forest Association	2.4
Ponderosa Pine-Incense-cedar/Mountain Misery Forest Association	2.4
Ponderosa Pine-Incense-cedar-California Black Oak Forest Association	2.4
Jeffrey Pine Woodland Alliance	4
Jeffrey Pine/Greenleaf Manzanita Woodland Association	2.4
Jeffrey Pine/Whitethorn Ceanothus Woodland Association	2.4
Jeffrey Pine-White Fir/Roundleaf Snowberry/Squirreltail Woodland Association	2.4
Jeffrey Pine-Canyon Live Oak/Whiteleaf Manzanita Woodland Association	2.4
Jeffrey Pine-California Red Fir Woodland Association	4
Single-leaf Pinyon Pine Woodland Alliance	4
Single-leaf Pinyon Pine-Canyon Live Oak/Whiteleaf Manzanita Woodland Association	2.4
Western White Pine Woodland Alliance	4
Western White Pine/(Greenleaf Manzanita-Bush Chinquapin-Oceanspray) Woodland Mapping Unit	4
Whitebark Pine Woodland Alliance	4
Whitebark Pine/DavidsonÆs Penstemon Woodland Association	4
Whitebark Pine/Shorthair Sedge Woodland Association	4
Whitebark Pine-Mountain Hemlock Woodland Association	4
Limber Pine Woodland Alliance	4
Foxtail Pine Woodland Alliance	4
Foxtail Pine/Bush Chinquapin Woodland Association	4
Foxtail Pine Woodland Superassociation	4
Foxtail Pine-Western White Pine Woodland Superassociation	4
Dead Foxtail Pine Mapping Unit	4
Foxtail Pine-Sierra Lodgepole Pine-Whitebark Pine) Krummholz Woodland Mapping Unit	4
Whitebark Pine-Foxtail Pine-Lodgepole Pine Woodland Superalliance	4
Foxtail Pine-Lodgepole Pine Woodland Superalliance	4
Giant Sequoia Forest Alliance	4
Giant Sequoia-Sugar Pine/Pacific Dogwood Forest Association	4

SEKI Land Cover Class	Impedance (kph)
Giant Sequoia-White Fir-California Red Fir Forest Association	4
Mountain Hemlock Forest Alliance	4
Mountain Hemlock-Western White Pine Forest Association	4
Mountain Hemlock-Sierra Lodgepole Pine Forest Association	4
Mountain Hemlock-Sierra Lodgepole Pine-Whitebark Pine Forest Mapping Unit	4
Mountain Hemlock-Sierra Lodgepole Pine-Western White Pine Forest Association	4
California Red Fir Forest Alliance	4
California Red Fir Forest Association	4
California Red Fir-Western White Pine Forest Association	4
California Red Fir-Sierra Lodgepole Pine/Whiteflower Hawkweed Forest Mapping Unit	4
California Red Fir-(Western White Pine)/(Pinemat Manzanita-Bush Chinquapin) Forest Mapping Unit	4
California Red Fir-White Fir Forest Alliance	2.4
White Fir -Sugar Pine Forest Alliance	2.4
White Fir Forest Mapping Unit	2.4
White Fir Mature Even-age Stands Mapping Unit	2.4
White Fir-(California Red Fir-Sugar Pine-Jeffrey Pine)/Whitethorn Ceanothus-(Greenleaf Manzanita) Forest Mapping Unit	2.4
White Fir-Sugar Pine-Incense-cedar Forest Superassociation	2.4
White Fir-Sugar Pine/Greenleaf Manzanita-Whitethorn Ceanothus Forest Mapping Unit	2.4
Sierra Juniper Woodland Alliance	4
Sierra Juniper/Curl-leaf Mountain Mahogany-Big Sagebrush Woodland Association	4
Sierra Juniper Woodland Association	4
Sierra Juniper/(Oceanspray-Big Sagebrush) Woodland Superassociation	4
Incense-cedar-White Alder Forest Association	2.4
Western White Pine-Sierra Lodgepole Pine-(California Red Fir) Woodland Superassociation	4
Birchleaf Mountain Mahogany Shrubland Alliance	1.6
Birchleaf Mountain Mahogany-California Redbud-California Flannelbush Shrubland Association	1.6
Birchleaf Mountain Mahogany-Whiteleaf Manzanita Shrubland Association	1.6
Chamise Shrubland Alliance	1.6
Chamise-Whiteleaf Manzanita Shrubland Association	1.6
Chamise-Chaparral Yucca Shrubland Association	1.6
Chamise-California Yerba Santa Shrubland Association	1.6
Chamise-Buckbrush Shrubland Association	1.6
Buckbrush Shrubland Alliance	1.6
Chaparral Whitethorn Shrubland Alliance	1.6
Whiteleaf Manzanita Shrubland Alliance	1.6
Greenleaf Manzanita Shrubland Alliance	1.6
Mountain Misery Dwarf-shrubland Alliance	4
Indian Manzanita Shrubland Alliance	1.6
Big Sagebrush Shrubland Alliance	2.4
Timberline Sagebrush Shrubland Alliance	4
Curl-leaf Mountain Mahogany Woodland Alliance	1.6
Chaparral Yucca Shrubland Alliance	2.4
Pinemat Manzanita Dwarf-shrubland Alliance	4
Water Birch Shrubland Alliance	1.6

SEKI Land Cover Class	Impedance (kph)
Mountain Big Sagebrush & Timberline Sagebrush & Oceanspray & Red Mountainheather Shrubland Superalliance	4
Bitter Cherry-Gooseberry spp.-(Mountain Maple) Shrubland Mapping Unit	1.6
Red Mountainheather Dwarf-shrubland Alliance	4
Greenleaf Manzanita-Bush Chinquapin-Whitethorn Ceanothus Shrubland Superalliance	1.6
Deerbrush Shrubland Alliance	1.6
Oregon White Oak Shrubland Alliance	1.6
Oregon White Oak-Birchleaf Mountain Mahogany Shrubland Association	1.6
California Grape Association	2.4
Sierra Willow/Swamp Onion Seasonally Flooded Shrubland Alliance	1.6
Oceanspray Shrubland Alliance	4
Bitter Cherry Shrubland Alliance	1.6
Willow spp./Meadow Shrubland Mapping Unit	4
Willow spp. Riparian Shrubland Mapping Unit	2.4
Willow spp. Talus Shrubland Mapping Unit	1.6
Upland Herbaceous	4
Shorthair Sedge Herbaceous Alliance	4
California Annual Grassland/Herbland Superalliance	4
Mesic Post Fire Herbaceous Mapping Unit	4
Post Fire Shrub/Herbaceous Mapping Unit	2.4
Intermittently to Seasonally Flooded Meadow	4
Semi-permanent to Permanently Flooded Meadow	4

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior

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