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Mapping threats to wilderness character in the National Wilderness Preservation System

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ABSTRACT

The National Wilderness Preservation System in the United States provides the greatest level of protection for the ecological and social values of lands held in trust for future generations. Although designated wilderness is the cornerstone of the US conservation portfolio, designation alone doesn't assure the protection of these areas, which are degraded by threats both inside and external to the area. This paper describes new methods for quantifying the location and cumulative magnitude of threats to wilderness, allowing agency managers and the public to evaluate whether the legal mandate from the 1964 Wilderness Act to "preserve wilderness character" is being upheld. These new methods have also been used in developing wilderness stewardship plans and analyzing the potential effects of proposed projects that would degrade wilderness character. The methods described here were developed and tested in seven wildernesses in a variety of ecological, geographic, and administrative settings, and are directly applicable to evaluating threats and improving the management of all 110 million acres of designated wilderness in the United States, as well as all areas that are increasingly recognized internationally as wilderness.

1. Introduction

The US National Wilderness Preservation System (NWPS) is the world's largest highly-protected conservation network (IUCN and UNEP, 2015). Established with the passage of the Wilderness Act in 1964, the NWPS is currently composed of 765 individual wilderness areas, totaling approximately 110 million acres (Wilderness Institute, 2016). These areas protect a wide variety of habitats, including deserts, wetlands, grasslands, mountains, tundra, and coastal areas, and range in size from the Pelican Island Wilderness in northern Florida at 5.5 acres to the Wrangell-Saint Elias Wilderness in southeast Alaska at 9 million acres.

Each wilderness is managed by one or more federal agencies: Bureau of Land Management, National Park Service, U.S. Fish and Wildlife Service, and U.S. Forest Service (hereafter BLM, NPS, FWS, and FS respectively). These agencies are mandated by the Wilderness Act to administer wilderness "for the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness, and so as to provide for the protection of these areas, the preservation of their wilderness character."

Although wilderness is typically considered the utmost expression of conservation in the U.S., to date there has been no means for showing when, where, and how the ecological and social values of wilderness, expressed through the phrase "wilderness character," are improving or degrading. In this paper, we demonstrate spatial methods (that have now been tested in seven wildernesses) to map threats to wilderness character. We describe the lessons learned and the limitations in developing these maps, and we demonstrate how these maps can be used to evaluate the effects of proposed projects on wilderness character. Ultimately, the purpose of this paper is to present new methods that integrate the ecological and social values of wilderness into a holistic understanding that has important applications to preserving wilderness as a cornerstone of the U.S. conservation portfolio.

1.1. Defining wilderness character

Legal scholars (e.g., McCloskey, 1999; Rohlf and Honnold, 1988) have confirmed that preserving wilderness character is the primary legal mandate of the Wilderness Act, as has the United States Congress (1983), stating, "The overriding principle guiding management of all wilderness areas, regardless of which agency administers them, is the Wilderness Act (Section 4(b)) mandate to preserve their wilderness character." Despite this clear legislative mandate, the Wilderness Act does not define wilderness character nor is there legislative history on its meaning (Scott, 2002). Legal scholars point to the statutory section that defines wilderness (Section 2(c) of the Wilderness Act) for the

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expression of congressional intent, both ideal and practical, for the meaning of wilderness character (McCloskey, 1966, 1999; Ochs, 1999; Rohlf and Honnold, 1988). Based on this statutory definition of wilderness, the four federal agencies that administer wilderness identified the following five "qualities" of wilderness character to operationalize this definition into practical monitoring and management direction (Landres et al., 2015): 1. untrammeled, 2. natural, 3. undeveloped, 4. solitude or primitive and unconfined recreation, and 5. other features of value. These qualities link on-the-ground conditions in wilderness and the outcomes of wilderness stewardship to the statutory definition of wilderness.

The qualities of wilderness character were originally developed to monitor how they change throughout an entire wilderness. This approach ignores two important considerations. First, it ignores the spatial variation in the status and trend of these qualities. Second, it ignores how these qualities interact to show the overall or cumulative status and trend of wilderness character. Additionally, monitoring alone is not sufficient for delivering conservation outcomes (Magness et al., 2010) and spatial products are required to support wilderness planning efforts and evaluate proposed actions inside or adjacent to wilderness.

1.2. Overview of mapping threats to wilderness character

We developed methods to map threats to the qualities of wilderness character and combine them to show the spatially-explicit cumulative impacts to wilderness character. The resultant maps depict the current degree of departure or degradation from an "optimal condition" of wilderness character. This optimal condition reflects an ideal manifestation of wilderness character as expressed in the Wilderness Act—in other words, a state in which there are no threats to wilderness character. These maps show tangible, on-the-ground degradation from this optimal condition, and can be used in the following ways:

- Set a baseline of current conditions from which future change in wilderness character can be monitored.
- Evaluate the potential impacts to wilderness character from projects and activities that are being proposed within or adjacent to a wilderness area.
- Help evaluate the cumulative potential impacts to wilderness character from alternative plans during development of a wilderness management plan.

To date, the scientific community has focused on inventorying attributes of landscapes such as remoteness and naturalness that make them more or less suitable for potential wilderness designation (McCloskey and Spalding, 1989; Aplet et al., 2000; Sanderson et al., 2002; Fisher et al., 2010; Carver et al., 2012; Watson et al., 2016). By combining these spatial attributes in a Geographical Information System (GIS), Lesslie and Taylor (1985), Carver and Fritz (1999) and Lesslie (2016) developed what they call a "wilderness quality continuum" for a landscape. This approach is useful for policy and planning decisions, such as identifying potential lands to protect as wilderness (Lesslie and Taylor, 1985; Muller et al., 2015). However, once a wilderness area is protected, how do managers assess current and potential threats that are both internal and external to the area?

To address this question, Tulloch et al. (2015) used spatial data to understand the distribution of threats in and adjacent to protected areas and the costs of managing them. Threats and impacts to wilderness character are defined as a combination of historical activities that continue to degrade wilderness character (e.g., historical logging activity, departure from natural fire regimes), current actions or influences that degrade wilderness character (e.g., non-native invasive species, administrative motorized/mechanized use), and impending issues that are likely to degrade wilderness character into the future (e.g., change in winter temperature, night sky obfuscation) (Tricker et al., 2017). Approaches to mapping threats range from depicting the spatial distribution of a single threat (e.g., Schmidt et al., 2002) to additive scoring approaches for multiple threats (Halpern et al., 2008). The approach outlined in this paper draws on this body of work by using spatial data and GIS techniques to map individual threats to the qualities of wilderness character.

The hierarchical framework for monitoring trends in wilderness character (Landres et al., 2015) is used to develop spatially-explicit maps of threats to wilderness character. This framework divides wilderness character into the following successively finer components:

Qualities – the primary elements of wilderness character that link directly to the statutory language of the Wilderness Act.

Indicators – distinct and essential components under each of the qualities.

Measures – specific elements for which data are collected to assess trend in an indicator.

The qualities and indicators are nationally consistent across all four wilderness managing agencies and across all wildernesses regardless of geographic location, ecosystem, and size. The measures are specific to each wilderness based on local threats, management concerns, and data availability. The mapping approach presented in this paper utilizes this framework to create a GIS-based model that iteratively builds a series of maps for each of these hierarchical levels (Fig. 1). Individual measures are mapped using spatial datasets and weighted to reflect their respective influence on wilderness character. These map layers are then added accumulatively using these weights to create maps for the indicators and qualities, and an overall map of threats to wilderness character.

2. Study areas

Seven wilderness areas were selected to test the robustness and compatibility of the mapping approach (Fig. 2, Table 1). These wilderness areas vary in size from 70,905 to 7,167,192 acres, range in distance from urban populations (urban-proximate versus remote), offer unique types of access (e.g., watercraft in the Boundary Waters Canoe Area Wilderness [BWCAW], shuttle buses in the Denali Wilderness, bush planes in the Gates of the Arctic Wilderness), have different levels of visitation (from 10,000 to over a million visitors per year), and fall within a variety of ecoregions (Table 1). The rationale for selecting these diverse types of study areas is not to present results from different wildernesses and compare them but instead to demonstrate that this mapping approach can be applied to any wilderness area within the NWPS.

3. Approach

Developing a map of threats to wilderness character involves several steps, encompassing a combination of administrative and technical tasks. The first step is assembling a multi-disciplinary team, including a project coordinator and a GIS specialist who have in-depth knowledge of the wilderness. This team is responsible for the following tasks that dictate the overall approach to each project: answer a set of strategic questions that will define the project parameters; select the measures to include in the wilderness character map; identify spatial data to depict the degradation to each measure; and choose weights that reflect the impact each measure has on the wilderness area.

There are several strategic decisions that underpin the entire process of developing these maps. These decisions must be discussed and agreed on by the project team at the beginning of the mapping process, which then provides the foundation for all subsequent tasks and allows the project to move forward in a deliberate and efficient manner. These decisions cover a wide scope of issues, such as determining project goals, how to interpret the wilderness character framework, how far back in time to track actions in wilderness and at what spatial resolution to perform the GIS analysis. These decisions are influenced by existing staff knowledge of wilderness character, data availability for

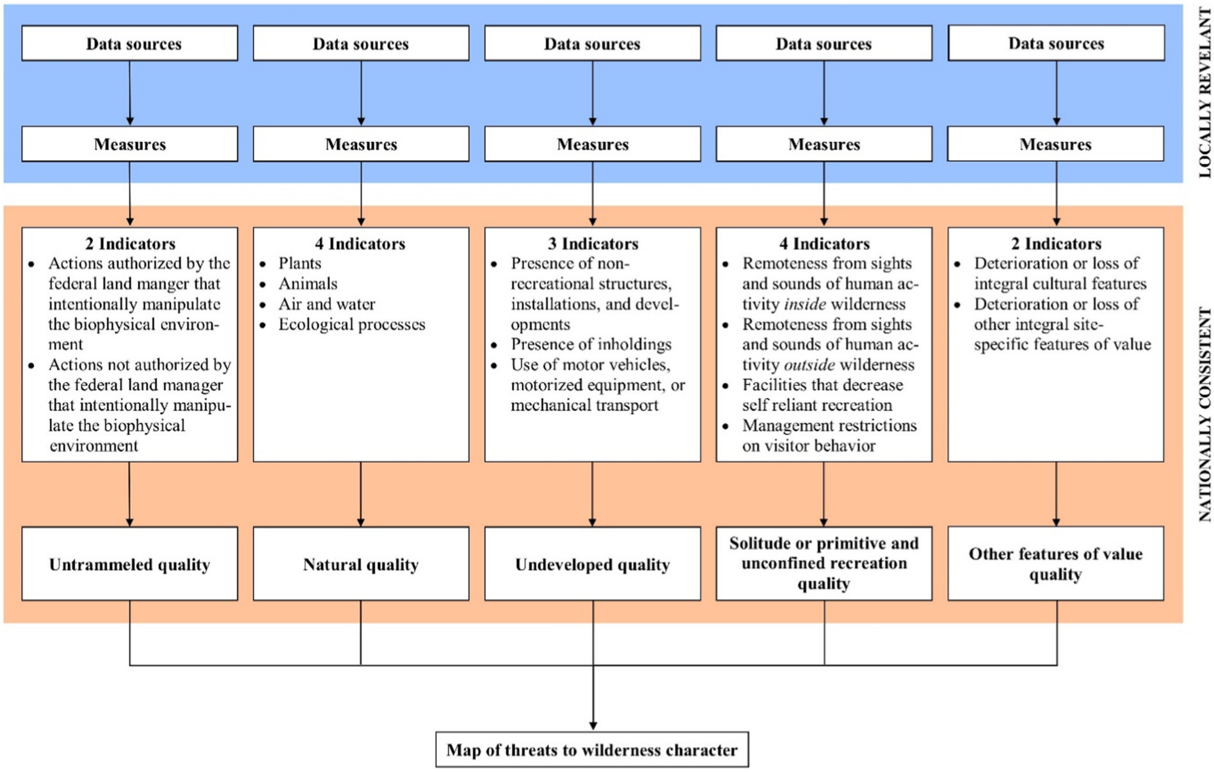

Fig. 1. Flow chart of the framework used for mapping threats to wilderness character.

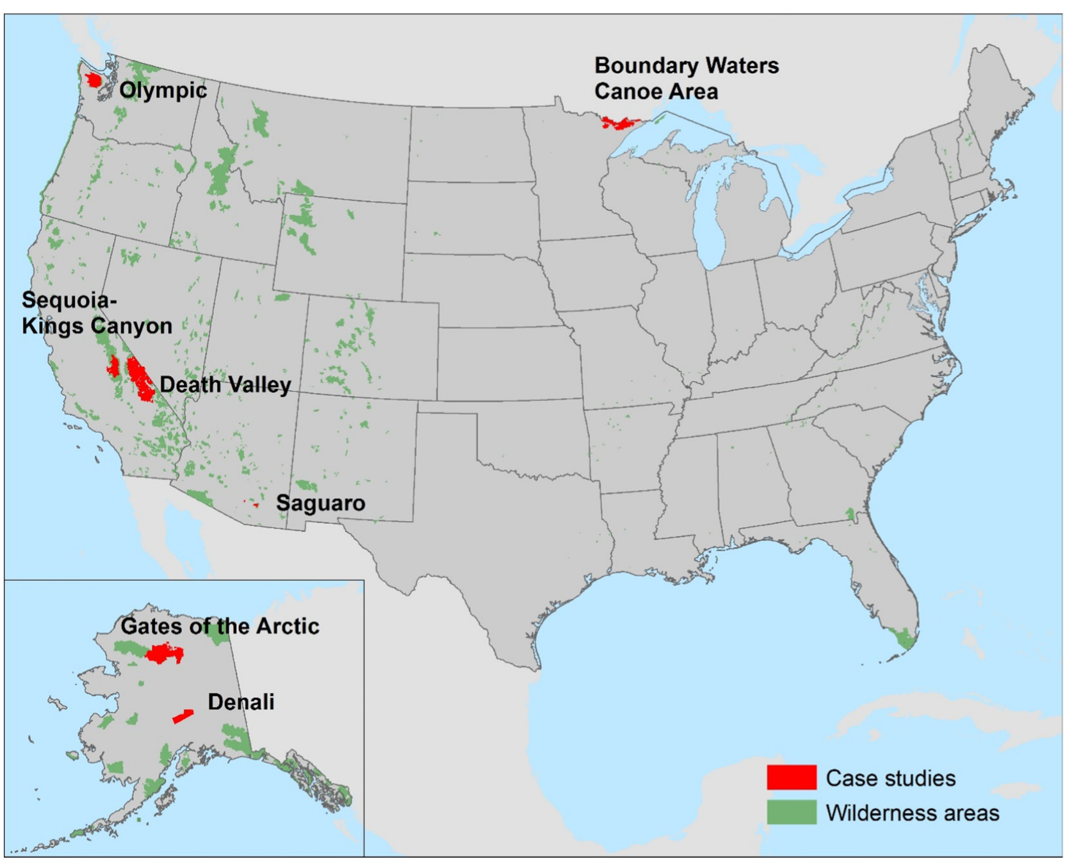

Fig. 2. Case study sites for mapping threats to wilderness character.

Table 1
List of wilderness areas that have mapped threats to wilderness character.

Wilderness	State	Designated	Acreage	Level II ecoregion
Death Valley	CA	1994	3,102,497	Warm deserts
Olympic	WA	1988	876,669	Western cordillera/ Marine west coast forest
Denali	AK	1980	2,124,783	Boreal cordillera
Saguro	AZ	1976	70,905	Western Sierra Madre piedmont/Warm deserts
Sequioa-Kings Canyon	CA	1984	768,112	Western cordillera
Boundary Waters Canoe Area Wilderness	MN	1964	1,090,000	Mixed wood shield
Gates of the Arctic	AK	1980	7,167,192	Brooks Range tundra

measures, and the uniqueness of each wilderness area.

Each wilderness is unique in its combination of geographic setting, biophysical properties, enabling legislation, and administrative direction (Landres et al., 2015). As a consequence, measures that represent features, conditions, and actions that threaten wilderness character vary from one wilderness to the next. Selecting measures for each study area was an iterative and collaborative decision-making process. Possible measures were first identified by the multi-disciplinary team, and then evaluated for both their relevance to the indicator and the availability and quality of the required data. Wilderness staff assessed data quality for each dataset using two metrics: accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is across the wilderness). In general, only measures that were relevant and that had readily available data of sufficient quality were included. In some cases, potential measures had insufficient or nonexistent data but were still acknowledged for their significance to their respective indicators. As data improve or become available, these “data gap measures” will be reevaluated for inclusion in future iterations of a map of threats to wilderness character.

Both raster and vector datasets were used to generate measures that depict the distribution of threats across a wilderness area. Raster-based data are composed of cells on a grid, where each cell contains a value representing information, and vector-based data describe features using a point, line or polygon. Raster data were either obtained from national datasets such as departure from historic fire regime (LANDFIRE, 2012), air quality (Clean Air Status and Trends Network, 2016) and soundscape (Mennitt et al., 2013); or from more localized, project-specific datasets such as night sky (Duriscoe et al., 2007), overflight noise pollution (Betchkal, 2013), or customized vegetation maps (Wolter et al., 1995). The majority of vector data were agency-produced or commissioned, including datasets depicting infrastructure (buildings, roads, trails, campsites, and toilets), wildfire perimeters, non-native invasive species, science installations, and administrative motorized use. Certain datasets were developed specifically for the mapping projects, such as joining tabular records with relevant spatial data to depict trail encounters, travel zone occupancy and poaching incidents, or newly digitized spatial data based on institutional knowledge (such as rangers drawing specific features onto paper maps). Last, some vector data were obtained from national, regional, or state sources, such as for rivers (e.g., National Hydrography Dataset), invasive species (e.g., Mojave Desert Inventory and Monitoring Network) or fish and wildlife (e.g., Minnesota Department of Natural Resources).

Once measures are selected for a wilderness, each is evaluated independently to determine the magnitude of its effect (e.g. Allan et al., 2013) on wilderness character. To accurately portray the variable magnitudes of the measures' effects, each measure was assigned a “weight” (Carver, 1991)—a value from 1 (low impact) to 10 (high impact)—by the project team, along with an associated rationale explaining the decision (Table 2). This approach captures the “rich picture” associated with local conditions that would otherwise be lost if applying a fixed weighting strategy across all wilderness areas (Carver et al., 2013).

3.1. GIS mapping techniques

Wilderness character maps are the product of combining weighted measures, each represented by a grid of normalized values, into a set of indicator and quality maps that underpin the overall map. This raster-based approach enables mathematical operations on individual cells (Gorenflo, 2002), which is particularly useful in trying to analyze and combine threat rankings (Salafsky et al., 2003). However, no two wildernesses are the same, and each study area selected a unique set of measures that represent threats to wilderness character. Therefore, this section covers standardized GIS techniques for creating a wilderness character map, but certain measures will require customized methods for processing raw data. In these instances, it is important to work with subject-matter experts most familiar with these data to accurately depict their spatial impact and, as with the other measures, clearly document all processing methods.

Individual measures were mapped by applying GIS processing techniques to their respective datasets using ArcGIS (ESRI, Redlands, CA). Initial tasks involve obtaining and storing these data in a folder framework, projecting all data to the local coordinate system, and performing data preparation tasks such joining tabular records to spatial data or clipping data to the mapping extent. For vector-based data, features representing threats to wilderness character were assigned values to represent their spatial impact on the landscape. This task utilized either a simple binary approach for features such as non-native invasive species (i.e., presence = 1; absence = 0) or a range of values for datasets representing different types of features such as research installations (where the size of the feature dictated the assigned value). Certain vector data, such as point locations of collared animals (which are considered installations under the undeveloped quality), may require additional processing techniques, such as density analysis, to provide for more intuitive interpretation of the raw data. Finally, specific GIS models can be utilized to analyze the viewshed impacts in the study area from human features occurring both inside and adjacent to wilderness, or identify areas of a wilderness that are more remote than others due to the time “cost” of travelling across the landscape from access points. All vector data were then converted to gridded rasters at the specified resolution.

Once all datasets representing measures are in raster format, the values for each grid are normalized by linear rescaling (slicing) the input values onto a standardized scale of 0–255 on an equal interval basis (Eastman et al., 1995). This normalized range of values allows datasets, and therefore measures, to be evaluated together on a common relative scale (Carver et al., 2008) whereby the “polarity” of these individual map layers are maintained so lower values represent optimal conditions and higher values represent degraded conditions (Carver et al., 2012). For example, soundscape and nitrogen deposition measures use different units (decibels vs. parts per billion) and cannot be analyzed together if they are not normalized.

The normalized measures were added together after being multiplied by their respective weights (i.e., simple weighted linear summation, see Malczewski, 2006) to produce a series of maps for each indicator. The resulting maps for each respective quality were combined to produce the overall map of threats to wilderness character. Each project team then reviewed the map outputs and modified measures or the weighting scheme as necessary to reflect their knowledge of the condition of wilderness character on the ground. For example, data that represent suppressed fires (polygons of the fire extent) for the untrammeled quality are often amended to only depict where suppression activities occurred (e.g., instances of fire lines, backburning, and fuel reduction). While this interactive process runs the risk of allowing staff to “game the system” to produce a desired outcome, staff experience

Table 2
Measures, weights and rationales from the untrammeled quality for the BWCAW map.

Indicator	Measure	Weight	Rationale
Actions authorized by the federal land manager that manipulate the biophysical environment	Naturally ignited fires that received a suppression response	10	Highest weight because wildfire suppression in the Superior National Forest has been occurring for over a century and has had a significant effect on wilderness ecosystems.
	Fish stocking	8	High weight because fish have been stocked throughout the area that is now the wilderness for at least 80 years.
	Prescribed fires	8	High weight because prescribed burning is widespread in the wilderness.
	Fish surveys	5	Medium weight because surveying entails numerous manipulative actions.
	Non-native plant treatments	2	Low weight because the extent of non-native plants is mainly limited to disturbed areas and treatments are generally restricted to manual removal.
	Dam water level manipulation	1	Lowest weight because only a limited number of dams are still active and functioning.
	Animal manipulation	1	Lowest weight because agency animal captures occur relatively infrequently and only in a few locations for the purposes of habitat manipulation and research.
	Soil disturbance	1	Lowest weight because there are few locations where significant soil disturbance has taken place relative to the size of the wilderness.
	Fish spawn collection	1	Lowest weight because spawn are only collected from two lakes.
Actions not authorized by the federal land manager that manipulate the biophysical environment	Vandalism of natural resources	2	Low weight because there are few locations of unauthorized vandalism relative to the size of the wilderness.
	Poaching	1	Lowest weight because citations are likely infrequent relative to the number of actual violations.

has been shown to be highly accurate in judging resource conditions (Cook et al., 2009).

4. Results and discussion

Interpreting the wilderness character maps required a strong understanding of the measures selected, the datasets that represent them, the methods for developing the map, and a grounding in location-specific factors (such as topography, visitor trends, and management issues). For the seven study areas, maps depicting impacts to untrammeled, undeveloped, and the other features of value qualities were typically created using discrete datasets (e.g., locations of installations or trails). Therefore, these quality maps tended to appear largely in optimal condition owing to the presence of these impacts relative to the scale of the wilderness. Conversely, the natural and solitude qualities utilized both discrete and continuous datasets (e.g., departure from historic fire regimes). As a result, the maps for these latter two qualities are characterized by a wilderness-wide range of values that clearly depict areas of optimal and degraded wilderness character (see Fig. 3) and have a strong influence on the wilderness character maps. This outcome was consistent with experience and understanding of wilderness character that staff had acquired at their respective wilderness areas.

For the wilderness character maps, an equal interval reclassification of the map values into 10 categories improves interpretation of each map. Using the BWCAW map as an example, areas that exhibit both degraded and optimal wilderness character are clearly discernable (Fig. 4). It is essential to work with local wilderness staff to interpret these results and develop a supporting narrative for each map. In the BWCAW, the most degraded categories are highly correlated with lakes that allow motorized use and have visitor congestion issues. In contrast, the optimal categories are primarily found away from entry points and popular travel routes and within areas that are actively managed to reduce degradations to wilderness character.

Histograms depicting the distribution of the grid cells across the 10 reclassed categories provide a summary of the condition of wilderness

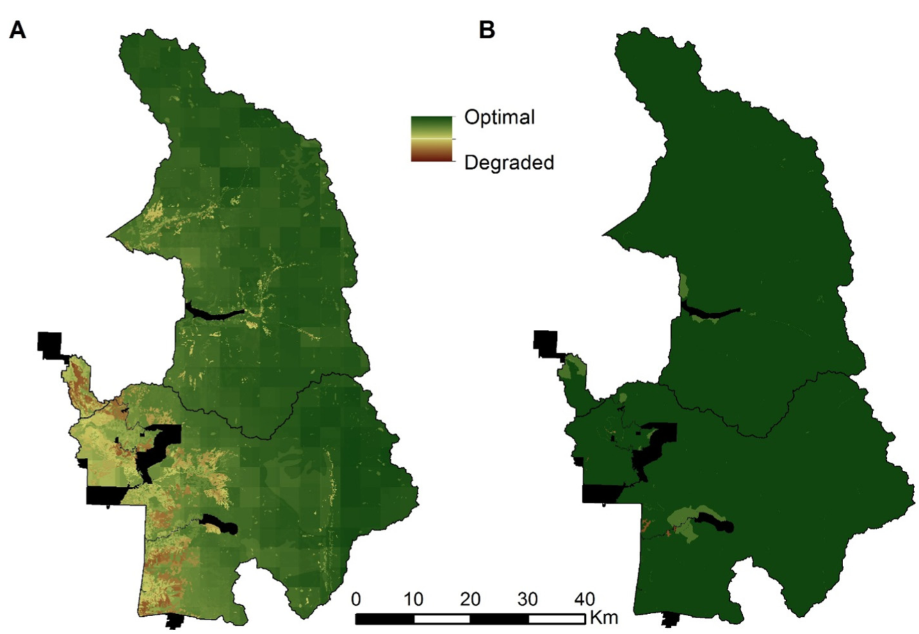

Fig. 3. Maps for Sequoia-Kings Canyon Wilderness depicting threats to A) Natural and B) Untrammeled qualities of wilderness character.

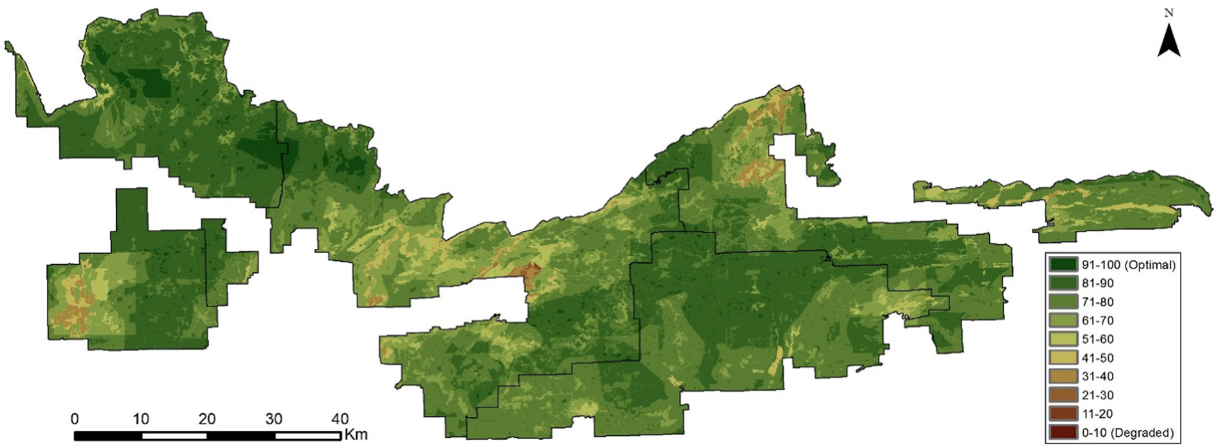

Fig. 4. Map of threats to wilderness character for the Boundary Waters Canoe Area Wilderness, reclassed into ten equal categories.

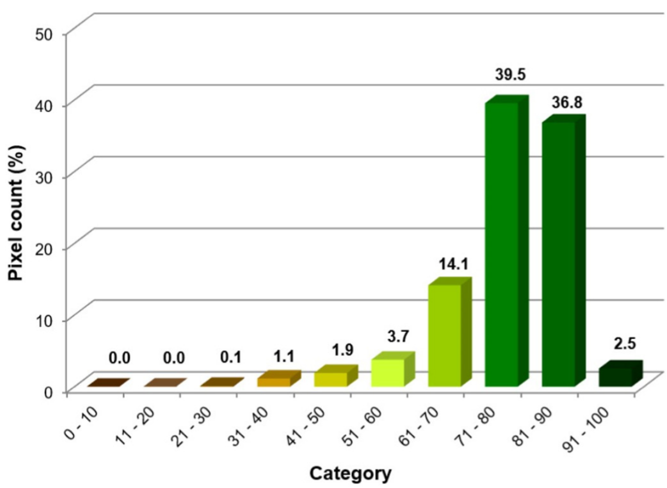

Fig. 5. Histogram of the reclassed map of threats to wilderness character for the BWCAW.

character for each study area. For example, the histogram of the reclassified BWCAW wilderness character map (Fig. 5) shows that the majority of grid cells fall within the 71–80 (39.6%) and 81–90 (36.8%) categories, which indicates that large portions of the wilderness exhibit few impacts to wilderness character. Examining the histograms for all the wilderness character maps reveal that the majority of these wildernesses are characterized by large areas approaching optimal conditions. The one noticeable exception is the Saguaro Wilderness within Saguaro National Park – a small and compartmentalized urban-proximate wilderness on the outskirts of Tucson, Arizona – which had an even spread of grid cells across the middle categories of the histogram, with the second highest category being 31–40 (22.5%). Factors such as the proximity of the wilderness to the city (viewshed, soundscape and night sky impacts), the ease of access via the many trailheads and trails (especially in the smaller Tucson Mountain District which is bisected by a road), and specific management issues, such as invasive species and climate change impacts, all contributed to large identifiable areas of degraded wilderness character. Because of the significant seasonal changes in Denali National Park and Preserve, wilderness character maps were produced for both summer and winter, with all changes between the two seasons occurring under the Solitude quality. In the summer map, the highest category is 81–90 (48.6%) whereas in the winter map the highest category shifts to 71–80 (41.64%). The main reason for the changes is the majority of the park becomes easier to access in the winter, either through the use of snowmobiles or dog sled teams.

The spatial model used to produce wilderness character maps is sensitive to uncertainty in the form of the weights assigned to the data inputs. This is a common source of uncertainty in spatial multi-criteria decision models of the type outlined in this paper (Carver, 1991; Malczewski, 2006; Feick and Hall, 2004). To test the robustness of the wilderness character mapping approach to weighting uncertainty, a Monte Carlo method (bootstrapping) is used to simulate the effects of errors associated with model inputs (in this case the model weights) by adding random "noise" to the initial inputs and repeating the model a large number of times (Carver et al., 2013). For the Death Valley wilderness, the weights for each input were randomized by 10%, and then rescaled before being used to generate the wilderness character map. This process was repeated 100 times, after which mean and standard deviation of all the iterations was derived to demonstrate the overall sensitivity of the spatial model to weight uncertainty and identify any areas of localized sensitivity (Fig. 8). Areas affected the most by weighting uncertainty, indicated by high standard deviation, are located predominantly along the western side of the wilderness and in smaller locations in the north and southeast. Closer examination of these areas reveal the presence of overlapping impacts from multiple inputs. Therefore, greater caution is required when interpreting results in these particular areas.

4.1. Benefits

There are several benefits that wilderness managers and the public derive from this standardized process to map threats to wilderness character, including developing a baseline for assessing management performance in the future, supporting new Wilderness Stewardship Plans, assessing emerging threats to wilderness character, and improving both internal and external communication.

Following Noss (1990), a mapping framework that identifies and depicts the major components of wilderness character at several levels of organization can be used to establish a baseline of current conditions in wilderness areas and allow managers to assess changes over time with future reruns of a wilderness character map. (It is important to stress that future reruns of a wilderness character map not only involve employing the original GIS techniques and weighting schemes used in the baseline map, but also utilizing updated data that has been collected using standardized methods.) Further, evaluating the effect of management activities on attributes of wilderness character is a primary duty of wilderness stewardship (Landres et al., 2015). By mapping threats to wilderness character, we improve the ability of managers to understand how different activities contribute to the overall condition of wilderness character. For example, staff at Denali National Park and Preserve reviewed the undeveloped quality map when considering a new research application for 16 proposed monitoring plots within the

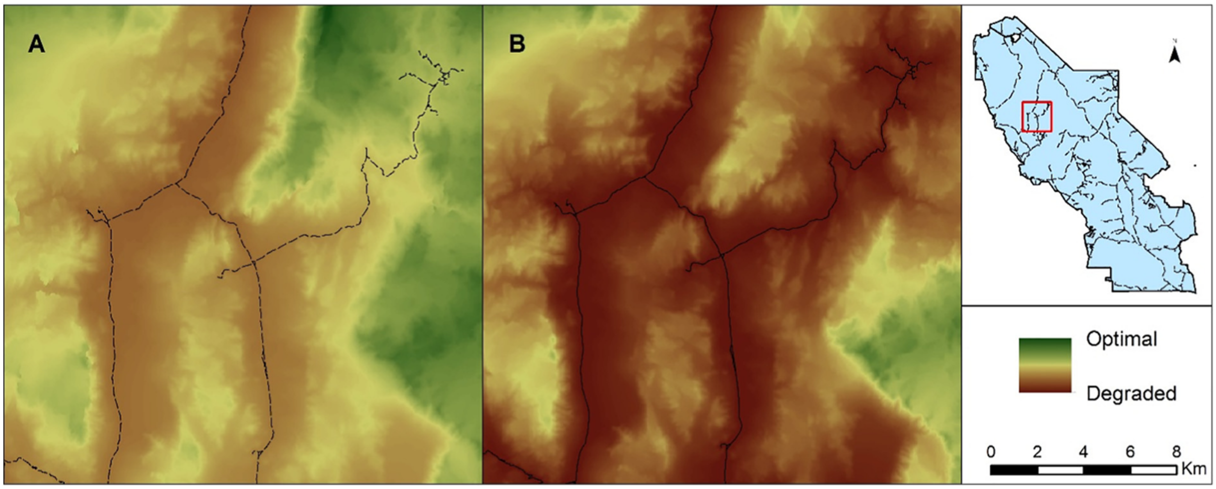

Fig. 6. “What if?” analysis of the impacts of a road upgrade on remoteness in Racetrack Playa area, in Death Valley National Park. (A) demonstrates accessibility to the adjacent wilderness using the existing (unpaved) road network and (B) demonstrates how access times would be reduced if the road to the Racetrack Playa were to be paved.

wilderness. The development of these monitoring plots, including the use of helicopters, would have increased the existing accumulative impacts under this quality. Finally, the ability to identify locally applicable measures and apply weights that reflect local conditions and priorities (Carver et al., 2013) ensures a robustness to this approach that allows it to be applied to any wilderness, irrespective of size, location or urban proximity.

The four wilderness-managing agencies require individual wilderness areas to periodically review and/or revise their wilderness stewardship plans or equivalent planning document (typically done every 10 to 15 years, or sooner if conditions change significantly) to guide the preservation, management and use of wilderness resources, including wilderness character. Wilderness character maps can serve as an important tool for understanding the current condition of wilderness character and evaluating the cumulative impacts of different planning alternatives during the planning process (Magness et al., 2010). For example, Death Valley National Park was able to evaluate the potential impacts of upgrading unpaved roads under a planning alternative that seeks to improve backcountry access for visitors. Fig. 6 illustrates the impact this alternative would have on the remoteness measure if the 32-mile road to the iconic Racetrack Playa were paved (Carver et al., 2013). By making the impacts of different planning alternatives transparent, the Death Valley National Park Wilderness and Backcountry Stewardship Plan (2012) was successfully implemented and was praised by the National Parks Conservation Association (2013) for employing a process for assessing, monitoring and seeking to protect or improve wilderness character.

Similar to using wilderness character maps to depict the impacts of planning alternatives within wilderness, the maps can also evaluate the impacts of proposed actions that are outside the jurisdiction of local managers yet are adjacent to and affect the wilderness. The primary reason for developing a wilderness character map for Gates of the Arctic National Park and Preserve (GAAR) was to evaluate the impacts of two alternative proposed routes for an industrial access road (legislated under the Alaska National Interest Lands Conservation Act, 1980) running through the GAAR, although outside designated wilderness. After establishing a baseline map of wilderness character, GAAR staff identified new measures and adapted existing measures to capture the anticipated impacts of the two alternative proposed routes. Although it may seem obvious that a road closer to the wilderness boundary would have a larger impact on wilderness character than one farther away, the impact of a road is affected by its visibility and sound pattern, thus requiring further analysis. GIS models allow assessment of cumulative spatial impacts and are powerful and objective tools for informing environmental impact assessments. Fig. 7 quantitatively demonstrates the effects of the two proposed routes on the remoteness from sights and sounds of human activity outside wilderness indicator.

Developing a wilderness character map requires agency staff to communicate in a manner that draws on a collective understanding of wilderness. By depicting what is happening where in the wilderness, the different resource management programs within an agency can better recognize how their respective programs can contribute to preserving wilderness character; this understanding in turn fosters a stronger ethic of working together to carry out this mandate. Additionally, a spatially explicit understanding of threats to wilderness character serves to inform the public about the need for management action in wilderness, and facilitate public responses to proposed management actions.

4.2. Limitations and improvements

There are several limitations with this mapping approach and ways to improve it. Common to all types of GIS analyses is the tendency of end-users to ascribe false levels of accuracy to the resulting map products (Heywood et al., 2011). Wilderness character maps are only an estimate of selected measures of wilderness character and their spatial variability and pattern.

Some threats to wilderness character are highly temporal in nature. These may include overflights or adjacent motorized use that occur sporadically throughout the day, night sky impacts that are only relevant during darkness, or large shifts in visitation due to seasonality, particularly for Alaskan wildernesses. As a consequence, a worst-case scenario approach was used in which the impact (such as a motor vehicle on a road that is adjacent to or cherry-stemmed within the wilderness) is assumed to be “present” at all times even though very few vehicles may travel the road per day. Therefore, wilderness staff may choose to lower the weights for these temporal measures to reduce their overall influence on the wilderness character map.

While some actions, conditions, or features in wilderness may have a positive influence on wilderness character (e.g., the preservation of an endangered keystone species), such “value added” features are not incorporated in a wilderness character map. Similarly, when actions or features have a mix of both positive and negative effects (such as management regulations that confine visitors in order to protect natural resources), the selected measures only quantify the negative impacts. This “negative mapping” approach allows the full magnitude of threats to be depicted. In contrast, simultaneously displaying positive and

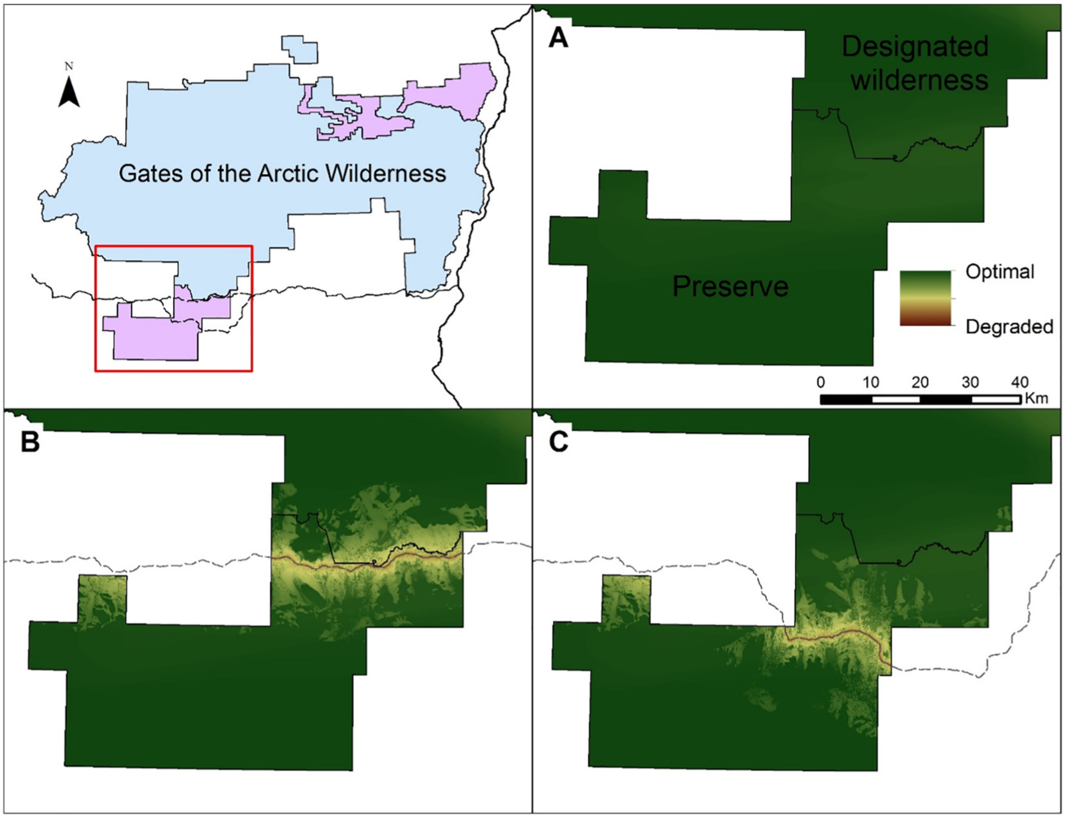

Fig. 7. Impacts to remoteness from sights and sounds of human activity outside wilderness in Gates of the Arctic National Park and Preserve. (A) Depicts current impacts to baseline map, (B) depicts impacts of the proposed northern route, and (C) depicts impacts of the proposed southern route.

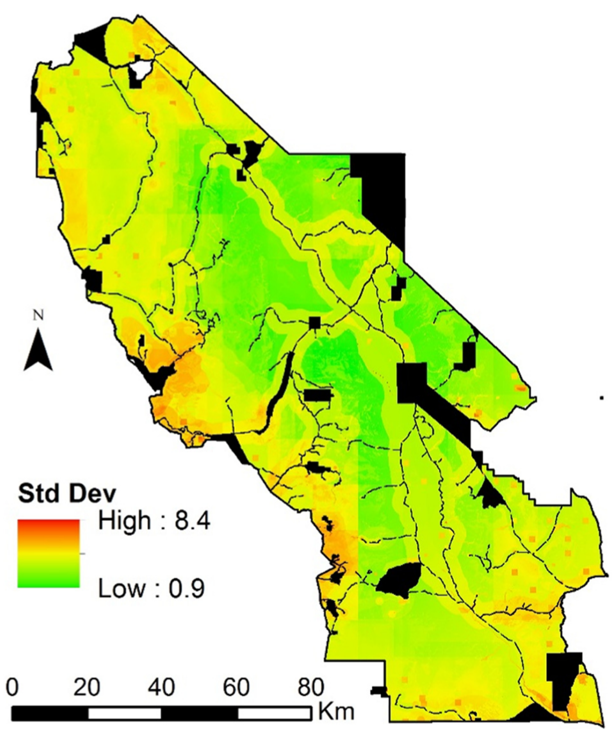

Fig. 8. Sensitivity to measure weight uncertainty for all measures used for depicting threats to wilderness character at Death Valley National Park.

negative impacts on a single map would result in these opposing influences being mutually offset or cancelled out, thereby obscuring the true extent of their individual effects on wilderness character. Therefore, the maps only depict threats to wilderness character and do not capture management activities that benefit or improve wilderness character.

A wilderness character map is sensitive to the quality of the spatial data used to depict each measure. Spatial data are rarely free of error (Heuvelink and Burrough, 2002), and when used as inputs to a GIS operation, the errors in the input will propagate to the output of the operation (Heuvelink, 1999). To ensure consistency and transparency, local staff are encouraged to evaluate each identified dataset for relevance (to the measure), accuracy, and completeness. If these data are deemed inaccurate or incomplete, the associated measure is excluded from the map and is instead recorded as a data gap measure. These measures can be included in future reruns of the map should these data improve or become available (Halpern et al., 2008).

Multi-disciplinary staff participation is essential to developing a wilderness character map. These staff are involved in every step of the project: selecting measures and weights, identifying data, reviewing draft maps and editing reports. Agency staff, however, typically have demanding workloads (including time in the field), are tasked with multiple job responsibilities or are seasonal employees, so their time may be fragmented making every step of creating useful maps more difficult. This concern is amplified for wildernesses that have fewer staff. Therefore, strong supervisor support is required to allow staff to fully participate. This participation has an unanticipated benefit: staff from different resource disciplines work together towards the common goal of understanding impacts to wilderness character, and for the first time, a person focused in a relatively narrow resource discipline can see how their expertise contributes to the larger goal of preserving wilderness character.

Finally, for many wilderness areas, interpretation of the Wilderness Act and agency wilderness policy by the unit leadership team can dictate the role of wilderness in day-to-day management activities, and turn in have an effect on the types of measures selected for a wilderness

character map. For example, wilderness staff may choose to ignore impacts from issues such as non-conforming activities because they are mandated by special provisions/legislation. However, even in situations where such uses are both legal and justifiable, nonconforming activities still degrade wilderness character (Landres et al., 2015).

5. Conclusion

Mapping threats to wilderness character is a new method designed to address the challenging monitoring, planning and management needs for wilderness stewardship. Building on existing techniques to map wilderness attributes, this approach provides a transparent framework for identifying and mapping measures that degrade wilderness character in designated wilderness areas. The composite maps of the combined measures portray the cumulative effects on wilderness character across an individual wilderness – this powerful, "big picture" approach can help inform wilderness stewards where to invest scarce resources and refine the effectiveness of their efforts to "preserve the wilderness character of the area" and perpetuate the "enduring resource of wilderness" (The Wilderness Act, 1964).

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