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Mapping Wilderness Character in Denali National Park and Preserve

Final Report

Natural Resource Report NPS/DENA/NRR—2016/1223

ON THE COVER
Photograph of hikers in Denali National Park and Preserve, Alaska.
Photograph by Sam Hooper, National Park Service.

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Natural Resource Report NPS/DENA/NRR—2016/1223

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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 eligible wilderness in Denali National Park and Preserve (DENA).

A set of indicators and measures was identified by DENA staff to capture the impacts to the five qualities of wilderness character (natural, untrammeled, undeveloped, solitude or primitive and unconfined recreation, and other features of value). 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 DENA staff to reflect its importance in relation to other measures. Maps were generated for each of the five qualities of wilderness character, which were added together to produce the composite wilderness character map for DENA.

The DENA 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 DENA was determined to possess wilderness character whose qualities are relatively undiminished from optimal conditions. This map will be used as a baseline representing the existing conditions of each tangible quality of wilderness character in DENA, and future assessments of wilderness character can be updated with new and improved data as they become available. Therefore, future reruns of the map with updated datasets will allow for identifying areas where wilderness character is changing over time. Wilderness character within DENA is applied to both federally designated and eligible wilderness lands that include 99% of DENA.

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This report is dedicated to Tom Meier, Denali's late Wolf Biologist. Tom knew wolves and wildness well. He was a wonderful colleague, friend, and neighbor to many at Denali.

Many thanks all around to the project team and advisors. We must thank retired DENA Wilderness Coordinator Joe Van Horn whom helped set this project in motion and left it for his successors to enjoy and work through. Special thanks to Paul Anderson and Don Striker (former and current DENA superintendents) for encouraging and supporting this project. Additional thanks goes to Jon Paynter, GIS specialist, who brought together, processed, and mapped much of the data that contributed to the wilderness character map. Thanks to Sandee Dingman, Chad Dawson, and Zach Babb for their thoughtful reviews and comments on the report. Plus a big thanks to all the DENA staff and other individuals involved with the project, for their passion and commitment to protecting the wilderness resource of Denali National Park and Preserve, and for supporting the wilderness ideal.

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. Denali National Park and Preserve (DENA) is now part of a second wave of NPS wilderness areas that have developed a wilderness character map.

The total size of DENA (Figure 1) is 6,075,030 acres, of which roughly one third of the landscape is designated wilderness. The Denali Wilderness (2,124,783 acres) was designated in 1980 as part of the Alaska National Interest Lands Conservation Act (ANILCA), which also expanded and changed the name from the original Mount McKinley National Park as well as expanding public lands and designating wilderness across Alaska.

A large majority of the additional park and preserve lands are considered suitable/eligible to be designated wilderness as documented in the DENA General Management Plan (NPS 1986), and thus are managed as wilderness. The term 'backcountry' refers to "all park and preserve lands, except the park road corridor and adjacent development zones and backcountry day use areas…" (DENA Backcountry Management Plan [BCMP]; NPS 2006). This can be restated to mean all designated and eligible wilderness will be managed to protect the wilderness character of DENA (both shades of green areas in Figure 2).

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

- Show the current the condition of each of the five qualities of wilderness character, both singularly and in aggregate, and how it varies across the ~6 million acres of designated and eligible wilderness of Denali National Park and Preserve.

- 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. Similarly, this map can be used in the future to analyze the effects of site-specific projects on wilderness character.
- Allow park staff to evaluate existing backcountry spatial data and consider whether new or better data would be needed for future planning and analyses of effects 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 six primary benefits described above, other potential benefits of the wilderness character map include identifying specific areas where actions could be taken inside the wilderness to improve wilderness character or areas where actions should not be taken because they would degrade wilderness character. In addition, the map would help identify specific areas outside the wilderness where actions are currently affecting or might pose a significant threat of degrading wilderness character inside wilderness.

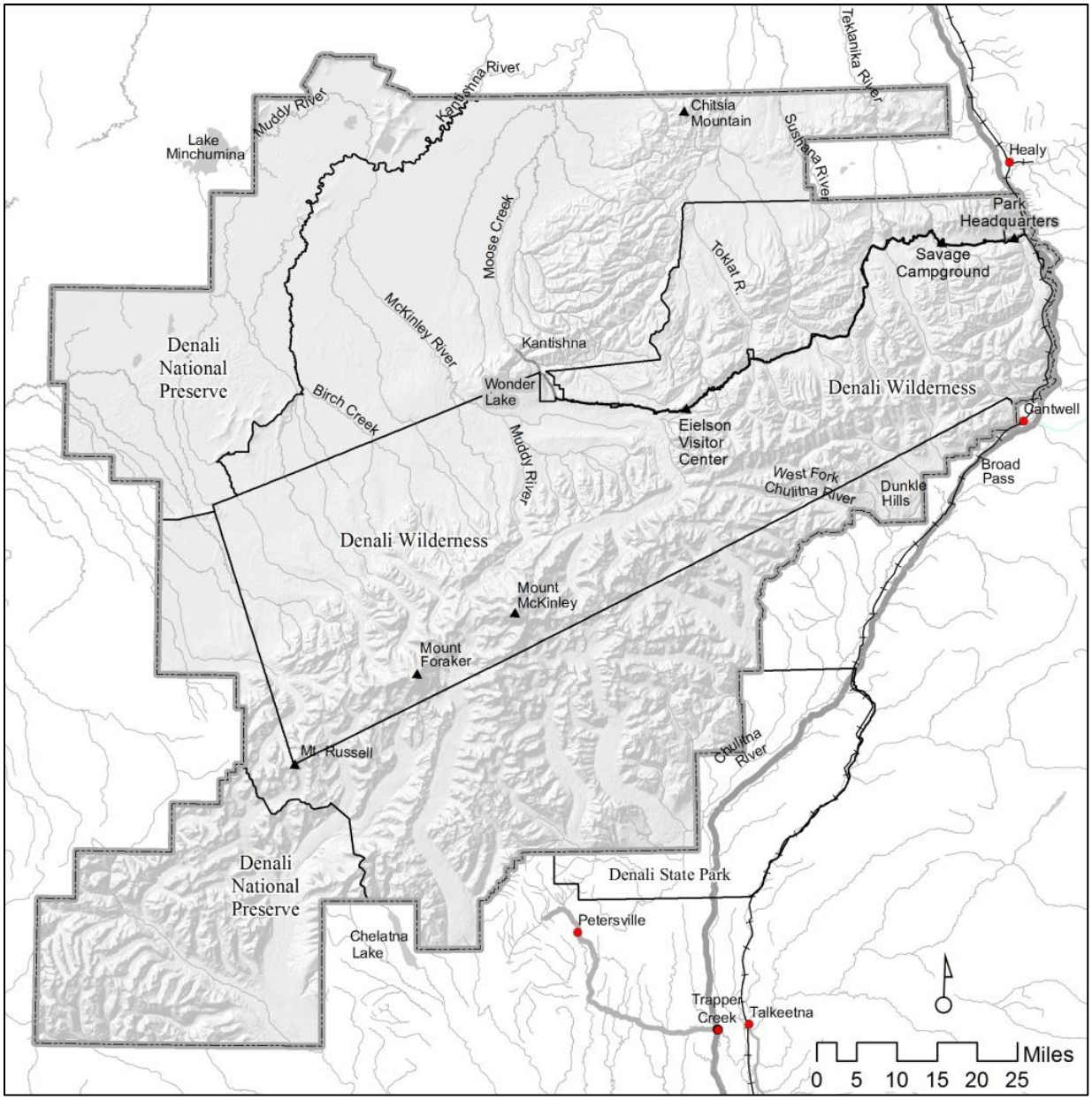

Figure 1. Denali National Park and Preserve. Areas north and south of the wilderness boundaries are National Park.

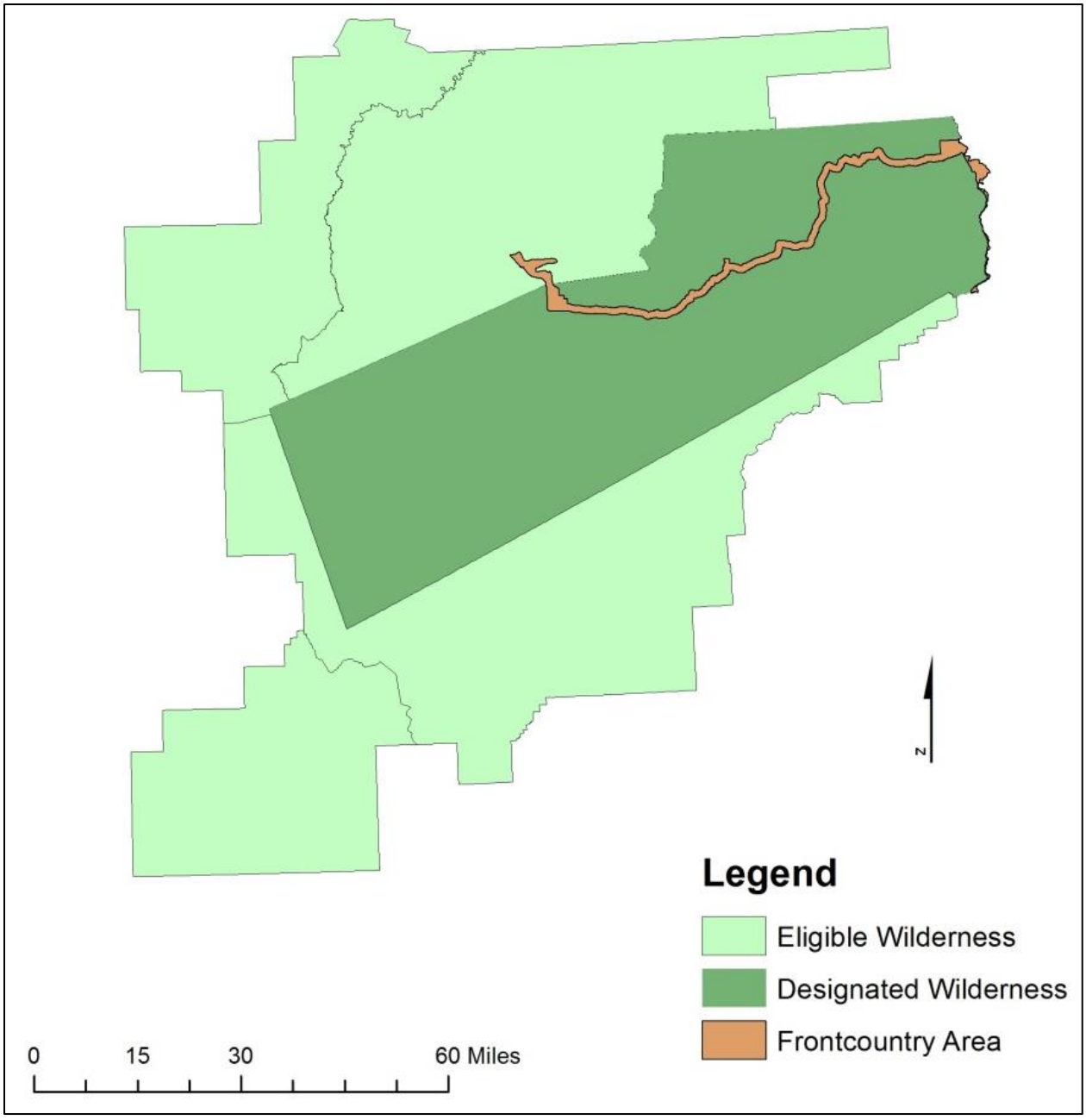

Figure 2. Denali National Park and Preserve backcountry and frontcountry areas as defined in Denali's Backcountry Management Plan (NPS 2006). The frontcountry area in brown depicts the "Frontcountry Developed Area" which includes 0.5 mile on either side of the Denali Park Road. However, the wilderness boundary is 150 feet off the centerline of the Denali Park Road in most areas, thus the frontcountry area is exaggerated along the road corridor in these maps.

There are a number of potential concerns and cautions about producing the wilderness character map. Despite these concerns, these maps are one of the best available metrics we have and have been useful in other national parks (e.g., Death Valley, Olympic, Sequoia and Kings Canyon).

Specific cautions are described under each measure. Major cautions about this overall effort include:

- *Creating inappropriate 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.
- *Avoid 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 wilderness is unique, and the map for each wilderness is built with data for that wilderness and no others.
- *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 and where they were descriptive of the five qualities of wilderness character. 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 cannot describe the full complexity, richness, or depth of wilderness character, nor the experiences of people in wilderness or around their ideas, values, and emotions about wilderness.
- *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 existing conditions and/or 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 DENA, tapping the experience and knowledge of the staff who work at the park (see page ix for a full list of staff involved). Together, the team and advisors have more than 200 person-years of on-the-ground experience in and with the DENA backcountry. 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 of DENA's backcountry only.[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. In addition to these four qualities, a fifth quality was used, called other features, based on the last clause of Section 2c in the 1964 Wilderness Act, that a wilderness "may also contain ecological, geological, or other features of scientific, educational, scenic or historical value" (Landres et al. 2012). The framework with five qualities is now summarized for NPS staff in "Keeping It Wild in the National Park Service: A User Guide to Integrating Wilderness Character into Park Planning, Management, and Monitoring" (Landres et al. 2014).

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

[1] The analysis was run for the entire park. The frontcountry 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.

assigned and weighted under an appropriate indicator. These measures represent impacts to wilderness character within the study area: designated and eligible wilderness, hereon referred to as DENA in this report. The multiple indicators for each quality were combined to produce a map representing the condition of that quality. The five maps, one for each quality, were then combined together to create an overall map of the current condition of wilderness character in DENA (Figure 3).

Over 100 datasets were used for measuring and delineating wilderness character in DENA and comprise local, regional, and national spatial data at varying scales, accuracy, and completeness (as is often the case with geospatial datasets). 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 for data quality and availability.

The datasets represent features, conditions, and actions that degrade wilderness character. The baseline map of DENA'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 by the presence of non-native plants. However, there are actions or features in wilderness that have a positive influence on wilderness. Displaying positive and negative impacts simultaneously on a single map would make it difficult to discern the overall effect on wilderness character. Therefore, DENA staff decided to adopt a negative mapping approach, in that the measures only record where wilderness character is degrading. Lastly, the standardized values of certain measures were adjusted based on DENA staff input – these exceptions are described in the methods section.

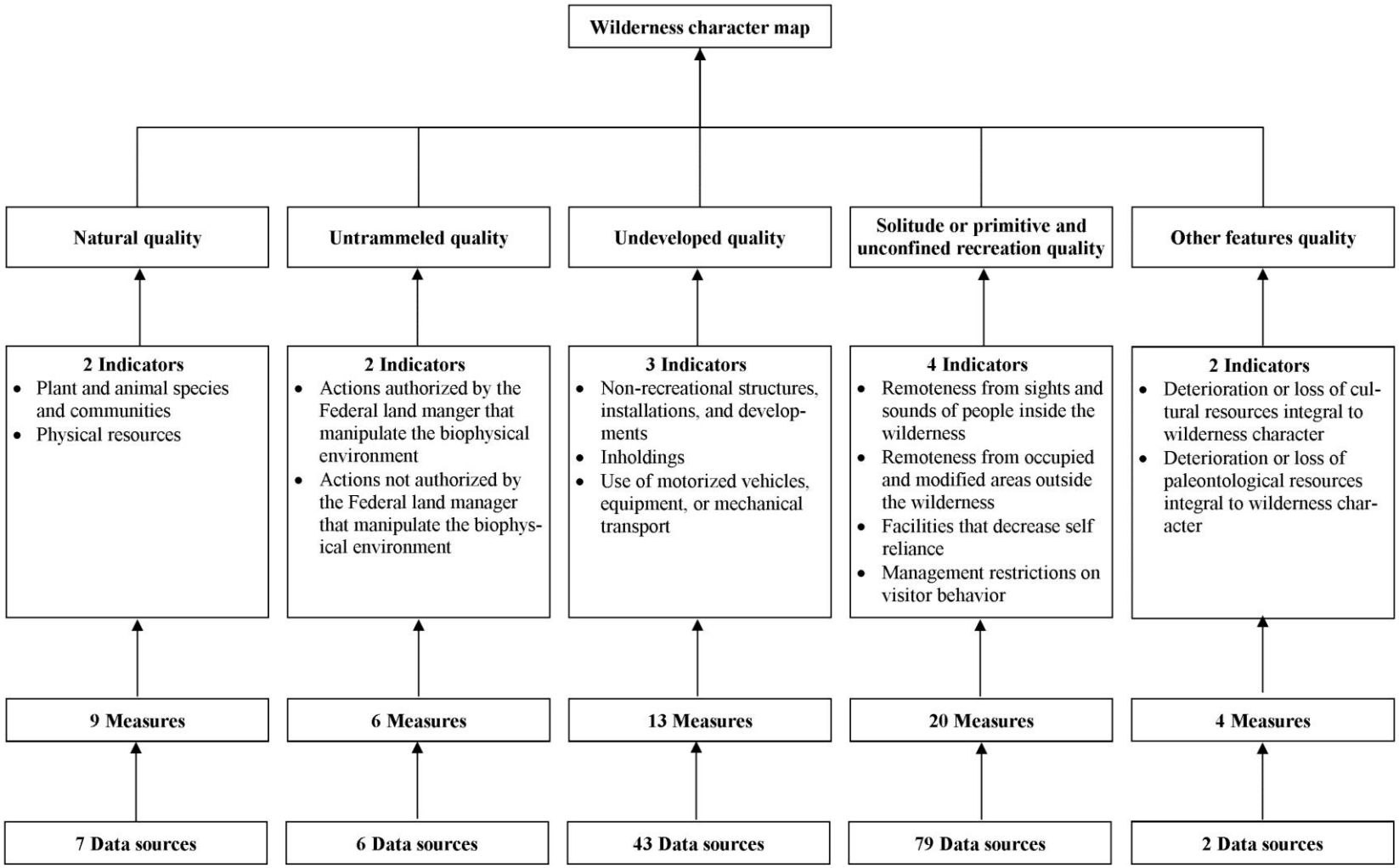

Figure 3. Flow chart for developing the wilderness character map.

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 effects on fire regime maps use different units of measure (decibel vs. low, medium, and high) and cannot be directly compared without normalization. Higher values of normalized measures represent "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 100 meters (m). Although using a 100 x 100 m pixel size may be deemed too coarse for many small point or linear features in DENA. The area of features such as rebar installations and trails will be over represented by the 100 meter resolution, but the sheer size of the DENA Backcountry meant that choosing a finer spatial scale 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, 2014, and Figure 3) was used to sort each measure under its appropriate wilderness character quality. For example, under the natural quality of wilderness character, the magnitude non-native plant invasion is informed by the "non-native plants" 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.

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

The assigned values of the measures under each indicator were weighted using a consensus-determined weighting regime based on expert judgments of DENA 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 2, 4, 7, 11 and 13.) The weighted measures were combined to produce the indicator maps. The indicator maps were then added under their respective qualities to produce five maps showing the condition of each quality of wilderness character. These five maps were then added together to produce a single composite map of wilderness character for DENA.

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[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

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 five 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 Denali National Park and Preserve boundary[6], with additional buffer zones extending beyond the boundary to 15 and 30 km respectively for running the travel time and viewshed models. These buffer zones are necessary to account for edge effects[7] from visible human features and points of access immediately outside the park. Metadata were utilized or 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 NPS Alaska Region's spatial data server, a centrally-located geospatial repository that is accessible to park staff via the NPS Theme Manager;
- 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 Alaska Albers 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 DENA had insufficient or non-existent data. DENA 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 (ESRI 2011) before they were used as measures to create the wilderness character map. Values were assigned to the

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

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

vector[8] datasets to represent their spatial impact in DENA. The vectors were then converted to raster layers at 100m resolution, whereby their extent was represented by the assigned values; the rest of the park, where no degradation occurs, was 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 "Effects on wildfire regime" has a value of 1 for 'low' areas, a value of 2 for 'moderate' areas and a value of 3 for 'high' areas, and the rest of the park is classed as 0. 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 DENA 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 actions authorized indicator, the following weights are applied: radio collaring (27%), exotic plant control (9%), fire management (27%) harvest of ungulate populations (27%), and fluvial process trammeling (9%). The high weights for the radio collaring, fire management and ungulate harvest measures reflect the extent and impact that they have on the authorized actions indicator throughout the entire wilderness. The relative low weights for the exotic plant control and fluvial process trammeling measures implies that these 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 DENA 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 green and degraded areas of wilderness character as brown.

Natural Quality

The natural quality defines wilderness as containing ecological systems that are substantially free from the effects of modern civilization. This quality is degraded by the intended or unintended

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

[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).

effects of modern people on the ecological systems inside the wilderness since it was designated in 1980 (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 following indicators, with their measures and relevance to the natural quality, were used:

Indicator: Plant and Animal Species and Communities

- Climate change: Woody vegetation advance – advance of woody vegetation has been documented in repeat photographs. Species dependent on open habitats are likely to be affected.
- Threats to wolves – All areas outside of the DENA boundary are open to hunting and trapping under state regulation, with open seasons and bag limits (i.e., the number of wolves that could be harvested per person) managed by the Alaska Department of Fish and Game. Subsistence and sport hunting and trapping are permitted in the preserve portions of DENA, but only subsistence hunting and trapping is allowed in specific areas of the national park. From 2000 to 2010 a "buffer zone" prohibiting wolf hunting and trapping was in place in areas adjacent and outside of the eastern and northeastern boundaries of DENA. The buffer zone was removed in 2010 and there has been concern that wolves that frequent the Denali Park Road corridor are accustomed to people and thus may be more vulnerable to trapping and shooting.
- Threats to grizzly bears – Recent authorizations by the State of Alaska's Board of Game have liberalized predator hunting practices in many areas. This includes national preserves, which are managed in the same manner as national parks, but by law are open to sport hunting. Liberalized predator hunting intended to manipulate natural population dynamics conflicts with NPS law and policy. National park areas are managed to maintain natural ecosystems and processes, including wildlife populations and their behaviors. While sport hunting is consistent with the purposes for which national preserves were established in Alaska, NPS policies prohibit reducing native predators for the purpose of increasing numbers of harvested species.
- Threats to black bears – Same as threats to grizzly bears.
- Effects of harvest on salmon runs – salmon spawning runs come up into some streams in DENA, but are not well mapped. Runs are vulnerable to the effects of harvest, climate change, disease, and pollution in the Gulf of Alaska, Bering Sea, and contributing river systems.
- Non-native plants - non-native plants have potential to spread, particularly in river valleys and areas disturbed by fire.

Indicator: Physical Resources

- Climate change: Permafrost decrease - permafrost areas in and around DENA are retreating as a result of anthropogenic caused climate change and natural climate cycles/variation. The proportion of each cause is unknown but the anthropogenic proportion is acknowledged.
- Climate change: Effects on wildfire regime - climate change can affect natural fire regimes through changes in temperature and humidity, season length, forest insect and disease outbreak.
- Climate change: Loss of glacier area from 1950s to 2010 – Glaciers in DENA are retreating as a result of both anthropogenic and natural forcings on global and regional climate. The proportion of each cause is unknown but the anthropogenic proportion is acknowledged by including all glacier area mapped from1950s aerial photography. Almost all of the glaciers in DENA have retreated and/or had thinning ice since the 1950s, and this time period is an important baseline to compare against glacier conditions documented in 2010 (Loso et al. 2014).

Indicator: Biophysical Processes (no measures were identified for this indicator).
The following additional measures are considered data gaps, which were considered but not included at this time due to inadequate data:

- Threats to migratory birds - there are threats to birds outside of DENA such as migration interference and habitat loss. The problem is complex and dependent on species and there is currently insufficient data available.
- Exotic animal species and zoonotic diseases - this includes possible future conditions such as exotic mammal species introduction, lice infestations on wolves, and other possible pests.
- Anthropogenic effects on the hydrologic regime - this could include effects from climate change or more localized effects from such things as micro-hydro projects or gravel harvest. Some gravel harvest actions are already included with the untrammeled quality measures.
- Air quality related values - at present anthropogenic effects are considered negligible.

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 small variation in scale, mostly medium levels of accuracy, and medium to high levels of completeness (Table 1).

Subsistence harvest of animals (hunting/trapping) was considered, since by federal law subsistence harvest is an allowed use of federal lands, it would be internally consistent to account for the effects. However, the number of animals harvested is thought by DENA staff to be small and there is a lack of data. Plus, staff is reluctant to consider subsistence harvest as degradation against wilderness character, because people have been engaged in a subsistence way of life on this landscape for thousands of years thus exerting an ecological pressure that is considered natural in this landscape.

Table 1. Natural quality datasets.

Measures	Source	Type	Scale/ Resolution	Accuracy	Completeness
Climate Change: Woody Vegetation Advance	USGS National Elevation Dataset	Digital Elevation Model Raster	60 m	Medium	High
Threats to wolves	Alaska Department of Fish and Game Wildlife Harvest Data	Point and Polygon	100m	Medium	Medium
Threats to grizzly bears	Alaska Department of Fish and Game Wildlife Harvest Data	Point and Polygon	100m	Medium	Medium
Threats to black bears	Alaska Department of Fish and Game Wildlife Harvest Data	Point and Polygon	100m	Medium	Medium
Effects of harvest on salmon runs	Anadromous Waters Catalog	Line	100 m	Medium	High
Non-native plants	DENA EPMT database	N/A	N/A	N/A	N/A
Climate change: Permafrost decrease	Natural Resources Conservation Service Denali permafrost map	Raster	1:1,000	Medium	High
Climate change: Effects on wildfire regime	DENA wildfire	Raster	2ac.	Medium	High
Climate change: Loss of glacier ice	Glaciers 1950s	Polygon	100m	Medium	High

Climate change: Woody vegetation advance

- Sources: US Geological Survey National Elevation Dataset for Alaska. Discussed this measure with Carl Roland, DENA plant ecologist. Shrub encroachment impacting alpine plant diversity is likely to occur between 3,500 and 5,000 feet, with south slopes more affected than north slopes.
- Processing: Reclassed the 3,500–5,000 foot elevation band in the DEM to 1, and all other elevations 0. Ran ASPECT for the DEM, and multipled by reclassed DEM to isolate slope of the desired elevation band. Reclassed north, northwest and southwest 1, and all other directions 2. Raster values were normalized to 0–255.
- Cautions: This is based on broad elevation bands only and not on mapped vegetation.

Threats to wolves

- Sources: Alaska Department of Fish and Game Wildlife harvest data. Worked closely with Bridget Borg, DENA wildlife biologist, to capture the threat to wolves from hunting pressures adjacent to park boundary.
- Processing: The following methodology was developed for this measure:

- We divided the park into three geographical wolf sub-populations (GSPs) using the Alaska Department of Fish and Game uniform coding units (UCUs). The UCUs are a subunit of game management units. The following UCU's were used to delineate the three sub-populations: East (601, 603, 607, 605, 3001, 108), Central (503, 502, 901, 1001), and West (504, 505, 2202, 2301, 1604, 1601, 1501).
- We developed an 'exposure' measure for wolf packs based on how often they are out of the park for each GSP (using wolf location data 2006–2011)
  - We determined which UCU the pack was located in most often as the UCU with the maximum number of locations during the time period.
  - Based on the UCU that the pack was located in most often, we classified the pack as West (GMU 19 UCUs: 2202, 1603, GMU 20 UCUs: 505, 504), Central (GMU 20 UCUs: 502,503) or East (GMU 20 UCUs: 605, 607).
  - For each pack, we estimated the percent of time out of the park by the percent of locations outside of the park or preserve during the time period.
  - Average the percent time out of the park for each pack in each GSP. East packs averaged 40.6% time outside of the park, Central packs 10.7%, and West packs 23.5%.
  - We scaled the percent time outside of the park to an "Exposure" measure:

    0–10.0%: 1

    10.1–20.0%: 2

    20.1–30.0%: 3

    30.1–40.0%: 4

    40.1–50.0%: 5

    50.1% or greater: 6
  - Exposure for East packs = 5, Central = 2, and West = 3.
- We developed a 'severity' measure based on average number of wolves sealed per UCU. We averaged yearly harvest numbers from 2006 to 2011 for each UCU and summed the averaged harvest numbers for all UCUs in the GSP. We divided by number of UCUs for that GSP. Severity for East packs = 2.2, Central = 0.9 and West = 0.2
- We multiplied the exposure grid by the severity grid and normalized the raster values to 0–255 (Figure 4).

- Cautions: This is a complex and sensitive issue. Creating a quantitative depiction of a measure of threat to DENA wolves to harvest is a novel approach that was developed for this map.

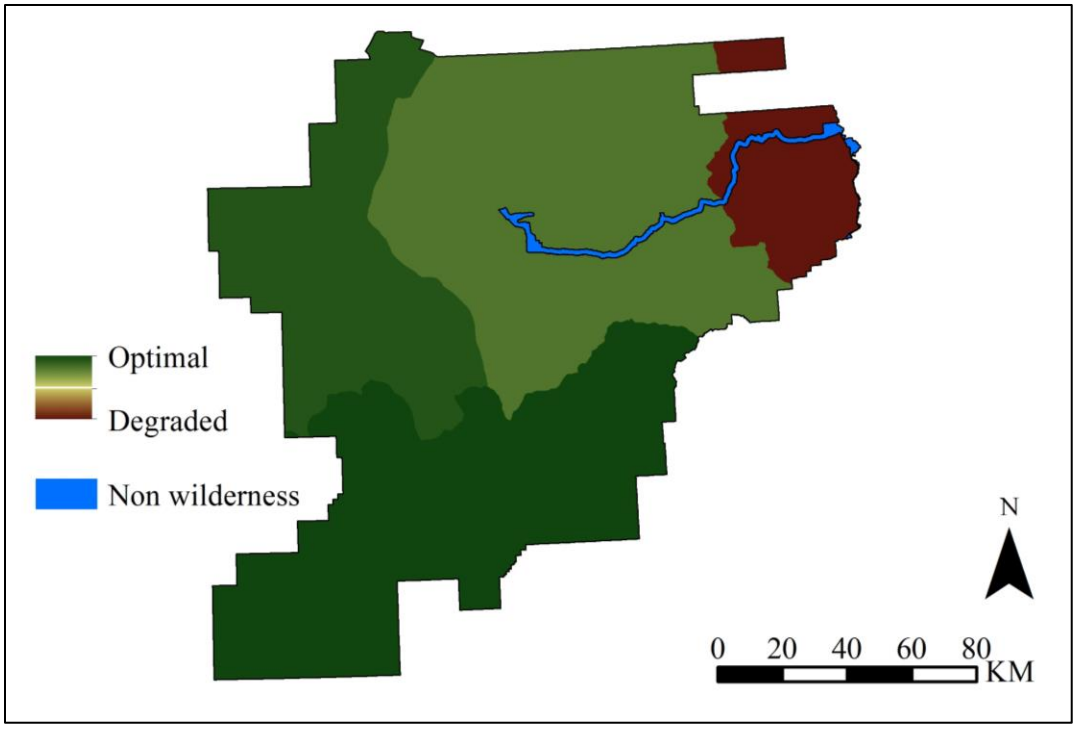

Figure 4. Threats to wolves.

Threats to grizzly bears

- Sources: Alaska Department of Fish and Game Wildlife harvest data. US Geological Survey National Elevation Dataset for Alaska. Worked closely with Pat Owen, DENA wildlife biologist, to capture the threat to grizzly bears from hunting pressures adjacent to park boundary.
- Processing: The following methodology was developed for this measure:
    - Determined the threat level per major drainages based on UCU average takes (2006–2011) and professional judgment (a number of UCUs intersecting the park with low or no takes, but were 'sandwiched' between UCUs with higher takes, received upgraded threat levels).
    - Clipped the above UCUs to a buffer zone in from the park boundary. This was done to represent bear range within the park that might overlap outside the boundary. This buffer zone was determined using average ranges based on collar locations, which is 344 km². The hypotenuse for 'two sides' of this range is used as the buffer distance, which is 27 km.
    - All lands above 1200 m were removed as this is the height limit of grizzly bear habitat.
    - Raster values were normalized to 0–255.
- Cautions: Repeating this measure would be difficult, owing to the professional judgment used to upgrade the lower-take UCUs surrounded by high-take UCUs.

Threats to black bears

- Sources: Alaska Department of Fish and Game Wildlife harvest data. Worked closely with Pat Owen, DENA wildlife biologist, to capture the threat to black bears from hunting pressures adjacent to park boundary.
- Processing: The following methodology was developed for this measure:
    - Determined the threat level per major drainages based on UCU average takes (2006–2011) and professional judgment (a number of UCUs intersecting the park with low or no takes, but were 'sandwiched' between UCUs with higher takes, received upgraded threat levels).
    - Clipped the above UCUs to a buffer zone in from the park boundary. This was done to represent bear range within the park that might overlap outside the boundary. This buffer zone was determined using average ranges based on collar locations, which is 64 km². The hypotenuse for 'two sides' of this range is used as the buffer distance, which is 11 km.
    - All lands above 1100 m were removed as this is the height limit of black bear habitat.
    - Raster values were normalized to 0–255.
- Cautions: Repeating this measure would be difficult, owing to the professional judgment used to upgrade the lower-take UCUs surrounded by high-take UCUs.

Effects of harvest on salmon runs

- Sources: Anadromous Waters Catalog polyline dataset.
- Processing: Anadromous water bodies in DENA were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: These effects are very generalized since these waters are not well mapped and the threats to salmon are not specifically quantified for this layer.

Non-native plants

- Sources: DENA Exotic Pest Management Team (EPMT) database. This dataset records both non-native plant surveys and treatments.
- Processing: Queried database for where no treatments for exotics were prescribed ("Control_ef" = 'none') – this excluded areas that had been surveyed but no exotics were found. Then, queried dataset for where treatments had occurred ("Management" Like '%reatment%'). Finally, erased the areas of the first query using the areas of the second query, which left existing locations of non-native plants. These locations were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: At this time there are no known exotic plants within the backcountry area, only the frontcountry area.

Climate change: Permafrost decrease

- Sources: Natural Resources Conservation Service permafrost map based on soils survey, 2004.
- Processing: Queried "permafrost' field for continuous, discontinuous, and sporadic permafrost and assigned these areas a value of 1. Layer was converted to raster and values were normalized to 0–255. Since permafrost is affected by unknown proportions due to both natural and anthropogenic climate changes this was symbolized by reducing the stretched value (255) by half (127).
- Cautions: Permafrost loss and change has been sampled with limited spatial coverage and large areas are inferred based on only a few sites.

Climate change: Effects on wildfire regime

- Sources: Landcover – DENA (Update v. 2008)
- Processing: Based on fire prone vegetation types, assigned the following values to risk of fire rating: Low = 1, Moderate = 2, and High = 3. Raster values were normalized to 0–255.
- Cautions: Layer is current to 2008 so it may not reflect 2012 conditions in all locations due to fires in that time period. Subject errors and uncertainties of the landcover layer.

Climate change: Loss of glacier ice

- Sources: Glaciers1950s_polygon. Included all area of glaciers since climate change is likely effecting all elevations (not just the terminus). Used the 1950s extent because some of the retreat since then can be attributed to anthropogenic changes, and area covered then but absent of ice now will be represented.
- Processing: Queried all locations with ice, and assigned value of 1. Raster values were normalized to 0–255.
- Cautions: It is extremely difficult to discern between natural and anthropogenic-induced glacier loss.

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 2). 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 rerun of the wilderness character map.

Table 2. Indicators and measures for the natural quality with weights and rationale

Indicator	Measure	Weight	Rationale
Plant and animal species and communities	Climate Change: Woody Vegetation Advance	11	Advance of woody vegetation has been documented in repeat photographs. Species dependent on open habitats are likely to be affected.
	Threats to wolves	22	The ability for visitors to see wolves from the Park Road is an important issue for many. Also "buffer zones" were recently removed from NE park periphery. Park Road corridor wolves are accustomed to people and thus may be more vulnerable to trapping and shooting.
	Threats to grizzly bears	20	State of Alaska has recently increased emphasis on intensive management and predator control regulations for grizzly bears on preserve and adjacent state lands can affect park bear populations that move across boundaries.
	Threats to black bears	16	State of Alaska has intensive management and predator control regulations on preserve and adjacent state lands can affect park bear populations that move across boundaries.
	Effects of harvest on salmon runs	16	Salmon spawning runs come up into some streams in DENA, but are not well mapped. Runs are vulnerable to the effects of harvest, climate change, disease, and pollution.
	Non-native plants	16	Non-native plants are not known to have made it into the backcountry yet but have potential to spread, particularly in river valleys and areas disturbed by fire.
Physical resources	Climate change: Permafrost decrease	40	Permafrost is likely the most sensitive physical resource to climate change
	Climate change: Effects on wildfire regime	30	Climate change can affect natural fire regimes through changes in temperature and humidity, season length, forest insect and disease outbreak.
	Climate change: Loss of glacier ice	30	Glaciers are a sensitive indicator of climate change in high elevation areas.
	Total weight	**200**	

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 and physical resources (Figure 5). After these indicator maps are created, the raster calculator was used to add the two indicator maps together to create the natural quality map (Figure 6).

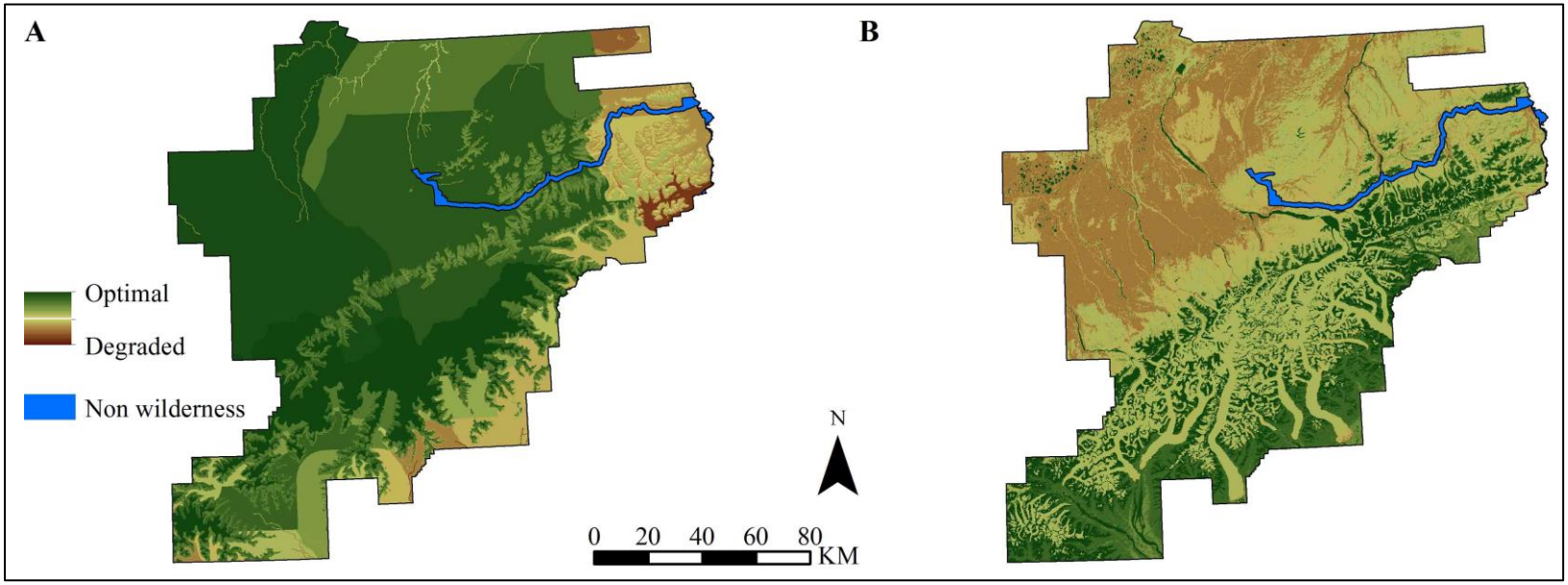

Figure 5. Indicator maps for (A) plant and animal species and communities and (B) physical resources. Green depicts optimal quality and brown depicts degraded quality.

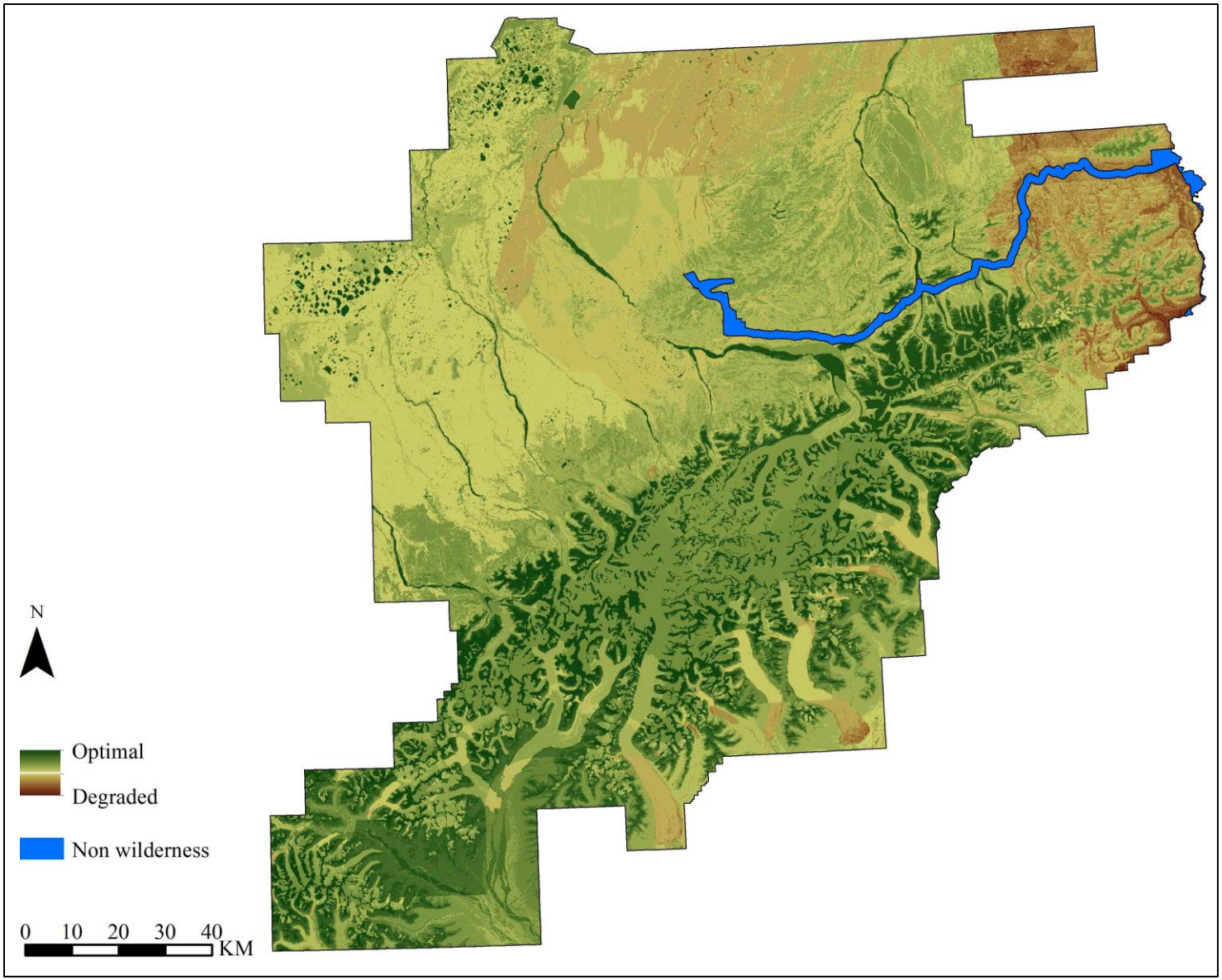

Figure 6. Natural quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.

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. 2008b).

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 DENA baseline map we provided a cumulative summary for all trammeling that has occurred from 2007 to 2012, as per staff decision. When this was not possible, the most recent complete datasets were used.

Indicators and Measures

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

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

- Capture of animals for radio collaring - the action of collaring animals is a widespread trammeling action approved by the NPS for monitoring and research.
- Exotic plant control - removing plants that have migrated and established themselves manipulates natural processes.
- Fire management (suppression, fuels reduction, prescribed fires) – actions to control wildfire are very limited in DENA and include only localized project work to reduce fuels adjacent to backcountry cabins. This includes thinning, hand piling, and burning the piles. If a fire were to threaten a historic cabin then localized suppression may take place to protect the structure from wildfire.
- Harvest of ungulate populations – sport hunting is allowed on preserve lands and primarily subject to state hunting regulations (when in line with federal land management priorities). DENA staff chose to draw a distinction between sport and subsistence hunting of moose, caribou and sheep on preserve and surrounding lands, thus data from sport hunting only was used.
- Fluvial process trammeling – river processes are trammeled by actions as gravel harvest/mining, road bridges and causeways, and dams/micro-hydroelectric projects. The major impacts are in a frontcountry area (Toklat Camp area) however, these impacts are translated both upstream and downstream into the Wilderness.

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

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

Data Sources, Processing and Cautions

The untrammeled quality map is composed of six measures, reflecting the small number of modern human actions impacting the untrammeled quality of the DENA wilderness, which are all represented by vector data, of mostly high scale, and have mostly high accuracy and medium to high completeness (Table 3).

Table 3. Untrammeled quality datasets

Measures	Source	Type	Scale/ Resolution	Accuracy	Completeness
Capture of animals for radio collaring	DENA and USGS capture records	Point	100m	High	Medium
Exotic plant control	DENA EPMT database	Polygon	100m	High	Medium
Fire management	Fire_History, cabins	Point and polygon	100m	Medium	High
Harvest of ungulate populations	Park_boundary	Polygon	100m	High	High
Fluvial process trammeling	DENA gravel harvest folder	Point and polygon	30m	High	High
Poaching and illegal collection	Ranger Case Incident Reports	Point	30m	High	Medium

Capture of animals for radio collaring

- Sources: Capture records for bear (2010–12), wolf (2009–12) and caribou (2011–12). All are point datasets.
- Processing: Capture locations in DENA were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Moose were not included in this dataset.

Exotic plant control

- Sources: DENA Exotic Pest Management Team (EPMT) database. This dataset records both non-native plant surveys and treatments.
- Processing: Queried dataset for where treatments had occurred. Locations of all treatments in DENA were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: No action has been taken to date in the backcountry.

Fire management

- Sources: GPS fire perimeter polygons as recorded in the DENA fire history database and cabins point dataset.
- Processing: Locations of fire perimeters with some level of control/suppression and 'fire-wising' around backcountry cabins were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: It is difficult to establish where fires are fought inside the fire perimeter. Instead of including the entire burn area of the fire, only the fire perimeter was used to represent the general locations where suppression actions would have taken place.

Harvest of ungulate populations

- Sources: NPS boundary polygon dataset.
- Processing: Locations where harvest of ungulate populations occur (the preserve areas) were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Hunting does not occur everywhere in these zones, but hunting pressures are assumed to move and disturb the animals in and around preserve and park areas.

Fluvial process trammeling

- Sources: DENA gravel harvest folder point and polygon datasets drawn by the park geologist.
- Processing: Locations where trammeling of fluvial processes occurs were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Most of this measure technically won't show up on map because gravel harvest in braided gravel floodplains and terrestrial borrow pits occur outside wilderness. Downstream impacts from the Toklat River gravel harvest are extremely difficult to quantify at this time. However, an upstream trammeling of the Toklat River from the infrastructure of the Denali Park Road and bridge causeway is possible to document and included. Note that the impacts from the Park Road decrease as one moves upstream, but that the area impacted is symbolized on the map with a uniform value.

Poaching and illegal collection

- Sources: Ranger Case Incident Reports (consisting of cut trees, gut piles, resource impacts and rock/veg damage). All are point datasets.
- Processing: All locations where poaching and illegal collection occurred were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: This measure is far from complete, as there are likely cases not detected by rangers.

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 4). The "weighted" measures under each indicator total 100.

Table 4. Indicators and measures for the untrammeled quality with weights and rationale.

Indicators	Measures	Weight	Rationale
Authorized actions	Capture of animals for radio collaring	27	Since this practice affects a relatively widespread area and is a frequent practice the weighting is relatively high.
	Exotic plant control	9	This is not a widespread problem.
	Fire management	27	This is not a widespread practice and has had only localized actions, but the symbolic impact is high.
	Harvest of ungulate populations	27	Alaska State hunting regulations and limits are not based in ecosystem management.
	Fluvial process trammeling	10	Occurs or may occur in the future in only a few localized cases.
Unauthorized actions	Poaching and illegal collection	100	Such actions do not fit within management schemes for conservation and thus if unchecked could be quite harmful to the populations of organisms and ecosystem.
	Total Weight	**200**	

Maps

The weighted measures for each indicator are added together using a raster calculator to create maps for authorized and unauthorized actions (Figure 7). 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 8). Please note that although the maps appear completely green, very small areas of trammeling do exist but are difficult to see at this broad scale.

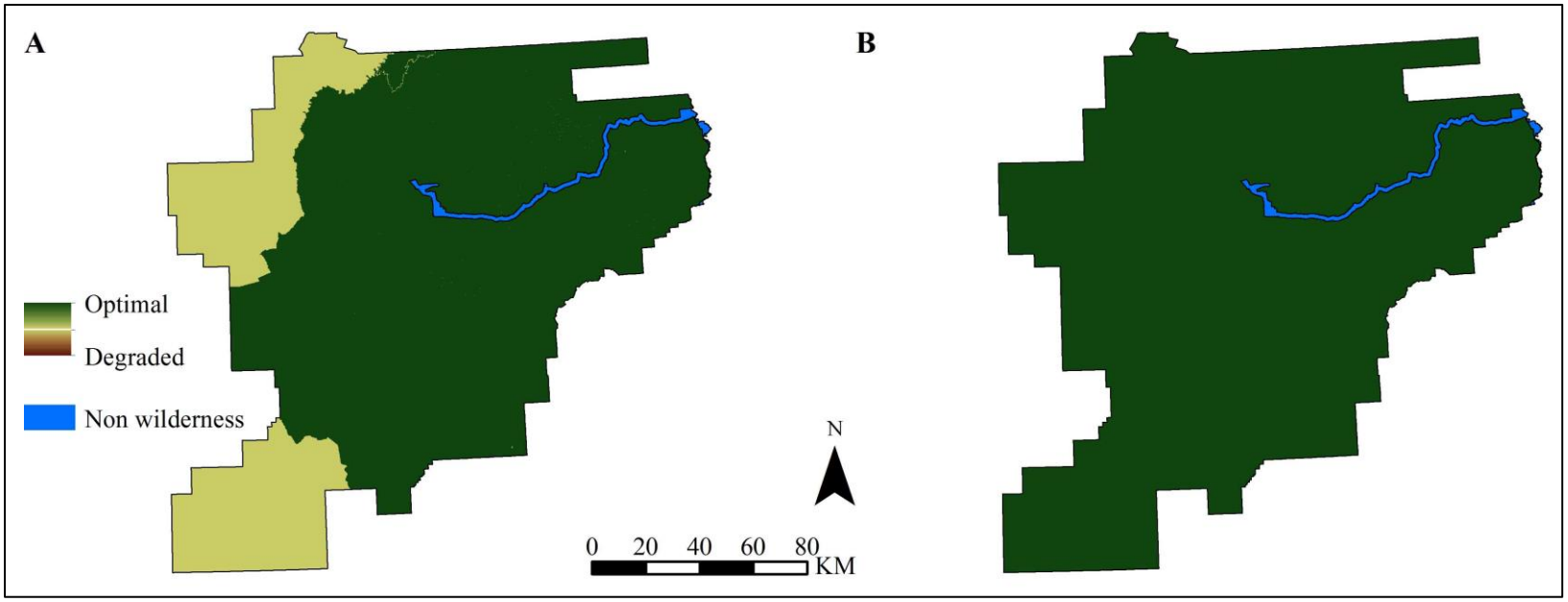

Figure 7. Indicator maps for (A) authorized actions and (B) unauthorized actions. Green depicts optimal quality and brown depicts degraded quality

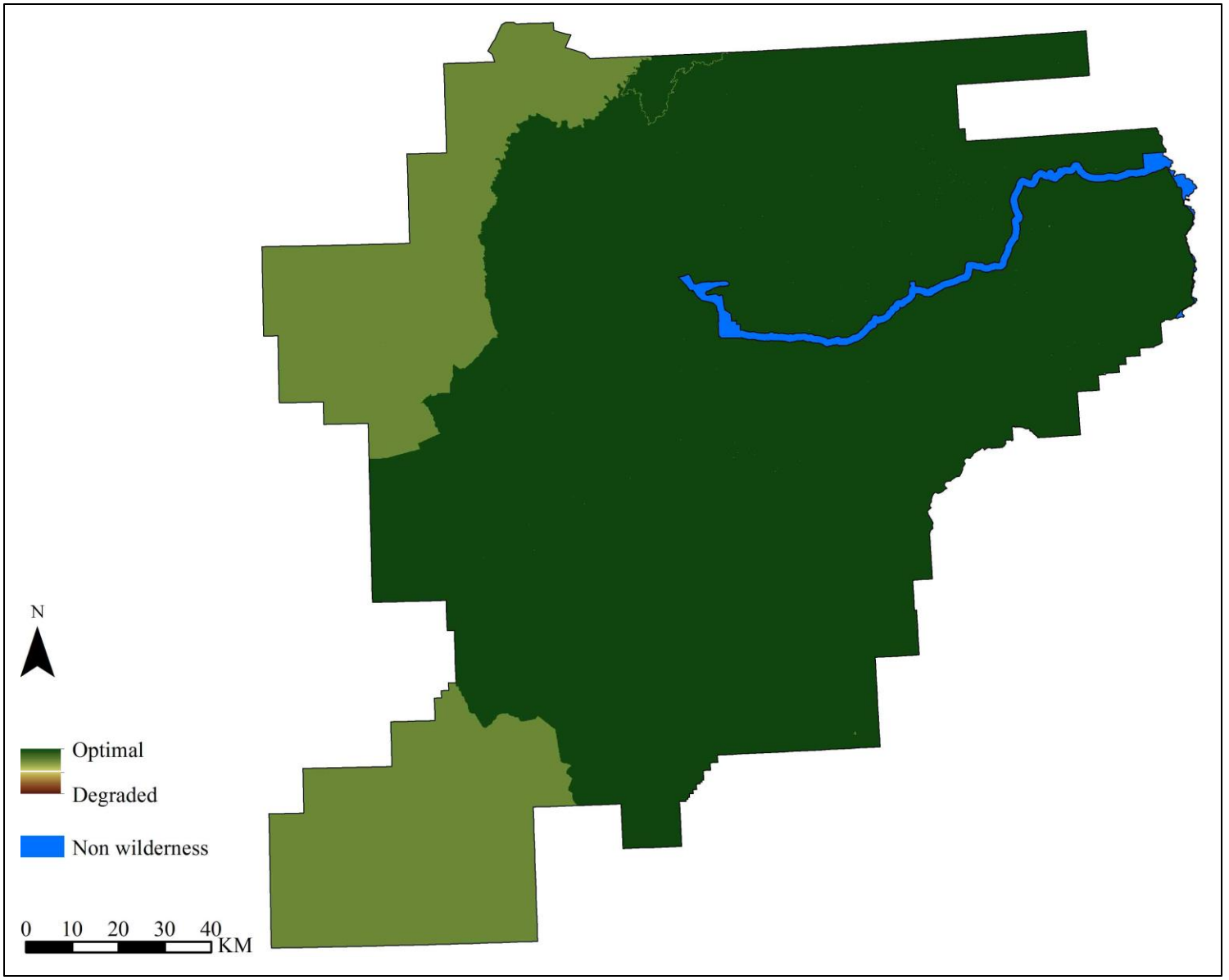

Figure 8. Untrammeled quality of wilderness character. Green depicts optimal quality brown depicts degraded quality.

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.

- Unauthorized installations and developments (improved airstrips, illegal ATV trails, squatter cabins) - these weren't planned for, and had no public review and vetting for compliance with applicable laws (National Environmental Policy Act, National Historic Preservation Act, Wilderness Act, etc.).
- Abandoned and closed mines – these pre-date park expansion and wilderness designation in 1980, and had no planning or compliance with applicable laws. Some require major clean up and have toxic chemical contamination of soil and water.
- Radio collars – the impact of capturing and collaring animals is recorded in the untrammeled quality, however the impact of having "roving installations" on animals could not be ignored because they are so often visible in visitor wildlife sightings.
- Administrative installations and developments (communication equipment, NPS historic cabins, NPS and non-NPS science equipment and markers, boundary (including cadastral) markers, bridges, NPS helispots, NPS-improved airstrips, power lines) – such installations and structures are pervasive, well-funded and the NPS has more direct control over them. These are often more durable and visible impacts.
- Subsistence (private cabins and camps, trap lines, designated ORV trails) – subsistence is considered part of the fabric of wilderness character but the activity results in some development.
- Public roads and associated structures (parks highway, park road, Dunkle Road, Rex Road, Stampede Road, 17B) and railroads - durable and visible, provides access for more impacts, roads are the quintessential development.

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

- Development of inholding (combines acres and actual development level) - includes Tokositna and Kantishna, and mines and their associated developments.

- Structures and developments for access to inholdings – may include trails, bridges, roads, or other impacts.

Indicator: Use of motor vehicles, motorized equipment, or mechanical transport. This includes aircraft (planes and helicopters) that have landed in the backcountry but not those flying overhead. Noise from aircraft overflights is accounted for in the solitude or primitive and unconfined quality (next section).

- Administrative use - research and monitoring, Visitor and Resource Protection (VRP) ranger patrol reports (CIR-Case Incident Reports, including summer and winter), trail crew use, generators, access for maintenance of radio repeaters, fire crew use - all plane landings and other mechanized uses.
- Emergency use - all plane landings and other mechanized use that are done to respond to an emergent situation without advance planning (search and rescue, fire, law enforcement incident).
- Commercial use – includes air tour landings, land-based tours (monster trucks) and water-based tours.
- Private recreational use - includes motor boats, ATVs, bikes, fixed wing aircraft landings, and snowmobiles.
- Subsistence use - ATVs, snowmobiles, boats, and chainsaws.

Data Sources, Processing and Cautions

The undeveloped quality datasets are all vector data, of mostly fine scale, and have varying levels of accuracy and completeness (Table 5).

Unauthorized installations and developments

- Sources: CntwlORV_Unauth and Stampede_ORV_incursions_july62010 polyline datasets and landing_sites_a point dataset
- Processing: Locations of incursions and landing sites were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: These are the installations and incursions that have been reported – many more may exist.

Abandoned and closed mines

- Sources: USGS Alaska Resource Data Files point dataset
- Processing: Locations of abandoned and closed mines were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Quite a few of the sites have many small features that are difficult to see. Some of the prospects are probably very small indeed and may not have any mining impacts (e.g., someone staked a claim but never did any work on it). Conversely, some of the larger Kantishna placer mines are probably represented by only one point.

Table 5. Undeveloped quality datasets.

Measures	Source	Type	Scale/ Resolution	Accuracy	Completeness
Unauthorized installations and developments	CntwlORV_Unauth, Stampede_ORV_incursions_july62010, landing_sites_a	Point and polyline	100m	Medium	Medium
Abandoned and closed mines	USGS Alaska Resource Data Files	Point	100m	Low	Medium
Radio collars	Collar locations (bears, caribou and wolves)	Point	30m	High	Medium
Administrative installations and developments	See table 6.	N/A	N/A	N/A	N/A
Subsistence	Subsistence/Minchumina/Lines, CntwlORVTradUseTrails, CntwlORVTradUseRtes, and subsistence_cabins	Point and polyline	1000m	Medium	Medium
Public roads and associated structures	Roads_de, rails_de, and dunkle_row	Polyline	30m	High	High
Development of inholding	Private_property	Polygon	30m	High	High
Structures and developments of access to inholding	kant_rds, skyline_drive and dunkle_row	Polyline	30m	High	High
Administrative	VRP CIRs, SS_lines_motor, 2012_Helo_Landings_from_AFF_data, glacierLandings, VRP fixed-wing and helicopter landings	Point and polyline	100m	Medium	Medium
SAR, emergency	Fire_Management	Point from polygon	1000m	Medium	Medium
Commercial	Portals, dunkle_row	Polyline and polygon	12000m	Low	Low
Private recreational	Ss_lines_motor, ss_polygons	Polyline and polygon	12000m	Low	Low
Subsistence	CntwlORVTradUseTrails	Polyline	30m	High	High

Radio collars

- Sources: Collar locations for bears (1999–2000; representing 1845 locations from 82 collared individuals), caribou (1986–2008; representing 23072 locations from 310 collared individuals) and wolves (2001–2008; representing 5701 locations from 149 collared individuals). The frequency at which the individuals of all species were located varies from daily to over several months between successive locations.
- Processing: A utilization distribution was calculated for each species using home range analysis tools created by the NPS Alaska Regional Office GIS Team (Alaska Pak Version 3.0.0.0, NPS 2010). The kernel bandwidth of the bivariate kernel used to create the UD was calculated for each species using the reference bandwidth (adjusted by 0.8 for a normal distribution, see Worton 1995). The bandwidth used for each species was as follows (measurements given in meters): bears = 5,800.6, caribou = 5,740.9, and wolves = 10,050.4. The output for all species were normalized to 0–255, added together in a raster calculator and then re-normalized to 0–255.
- Cautions: For this analysis we used a sample of all collared animal locations, and as such there are potential issues with spatial and temporal autocorrelation of the locations. Spatial and temporal autocorrelation violate the assumptions of independence of samples, biasing the resulting utilization distribution. No moose data.

Administrative installations and developments

- Sources: See Table 6.
- Processing: Locations of administrative installations and developments are ranked on a scale of 1–10 according to their footprint/presence in the wilderness and then converted to rasters. Rasters were added together and values were normalized to 0–255.
- Cautions: Not a complete dataset.

Subsistence

- Sources: Subsistence/Minchumina/Lines and CntwlORVTradUseTrails polyline datasets, CntwlORVTradUseRtes polygon datasets and subsistence_cabins point dataset.
- Processing: Locations were subsistence developments occur were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: None

Public roads and associated structures

- Sources: Roads_de, rails_de, dunkle_row polyline datasets.
- Processing: Locations of roads and railroads were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Few of these are located in the backcountry.

Table 6. Administrative installations and developments datasets.

Features	Value	Source	Type	Scale/ Resolution	Accuracy	Completeness
BLM Cadastral	1	BLM_Mon_GCBD, BLM_MON_SDMS	Point	30m	High	High
Boundary marking	2	Bndy_marking folder	Point	30m	High	Low
Installations/ Communications	7	Communications_Installations	Point	30m	High	High
Installations/ Glaciers	2	DENA_glacier_installations	Point	30m	High	High
Installations/ Instrumentation (weather, acoustics, etc.)	5	Instrumentation_Installations	Point	30m	High	High
Installations/ Marker installations	2	Marker_installations	Point	30m	High	High
Installations/ NOAA weather stations	7	NOAA_weatherStation	Point	30m	High	High
Monitoring/Gauges	2	Denagauge	Point	100m	Medium	High
Monitoring/ Denaifds – Municipal and Industrial Facility Water Discharges	2	Denaifds	Point	100m	Medium	High
Monitoring/Water quality	2	Denawq, Lterplot – queried water quality	Point	100m	Medium	High
Monitoring/Sound	5	Lterplot – queried sound	Point	30m	High	High
NPS airstrips & portals	8	NPS&portal_airstrips	Point	100m	Medium	High
Utilities	9	Utilities_de	Point	30m	High	Low
Patrol cabins & climbing camps	10	Patrol_cabins, climbing_camps	Point	100m	Medium	High

Development of inholding

- Sources: Private_property polygon dataset.
- Processing: Ranked locations of private properties on a scale of 1–3 according to level of development. Layer was converted to raster and values were normalized to 0–255.
- Cautions: No inholdings in designated wilderness

Structures and developments of access to inholding

- Sources: kant_rds, skyline_drive and dunkle_row polyline datasets
- Processing: Locations of access roads to inholdings were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: The Slate Creek Road was missing from the original kant_rds dataset and has since been added.

Administrative

- Sources: VRP CIRs and SS_lines_motor polyline datasets (the latter dataset was heads-up digitized by Roger Robinson and Coley Gentzal), 2012_Helo_Landings_from_AFF_data, glacierLandings, VRP fixed-wing and helicopter landing point datasets (Matt Smith).
- Processing: Locations of administrative motorized use were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: These impacts are highly temporal and short time duration but give an indication of the type and location of administrative motorized use in DENA. Some search and rescue related helicopter landings may be in this data.

Search and rescue (SAR), emergency

- Sources: Fire management dataset.
- Processing: Queried all fires since 1999 that received motorized observations (helicopter and fixed wing aircraft). The center points of these polygons were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: These impacts are can vary widely from year to year. During the period the map represents the primary emergency response was related to fires and no search and rescues are represented. Helicopter landings related to SARs were not differentiated from other administrative use and may be represented in the Administrative Installations and Developments layer.

Commercial

- Sources: Portals polygon dataset and dunkle_row polyline dataset
- Processing: Locations of portals and roads used for commercial motorized use were given a value of 1. Layer was converted to raster and values were normalized to 0–255.

- Cautions: Does not capture all air taxi landings which can occur anywhere in the 1980 additions lands.

Private recreational

- Sources: Ss_lines_motor polyline and ss_polygons polygon datasets heads-up digitized by Roger Robinson and Coley Gentzal.
- Processing: Locations of private recreational use were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Not all incursions are likely to be documented.

Subsistence

- Sources: CntwlORVTradUseTrails polyline dataset
- Processing: Locations of subsistence motorized use were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Subsistence motorized use may occur in other parts of the park but no data exists.

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	Unauthorized installations and developments	9	Few of these are known to exist and they tend to be unobtrusive.
	Abandoned and closed mines	18	These have potentially harmful effects on surrounding biota and human health.
	Radio collars	10	Weight lowered because the impact associated with capturing and collaring is already counted.
	Administrative installations and developments	27	Widespread (low density), well-funded, durable and visible.
	Subsistence	9	Lower weighting because this is a traditional activity.
	Public roads and associated structures	27	Durable and visible, provides access for more impacts, roads are the quintessential development
Inholdings	Development of inholding	75	Inholdings have the potential for highly visible and durable impacts.
	Structures and developments of access to inholding	25	NPS has more influence in mitigating impacts.

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

Indicator	Measures	Weight	Rationale
Use of motor vehicles, motorized equipment, or mechanical transport	Administrative	20	All use is appropriate for minimum requirements and management area.
	SAR, emergency	20	All use is appropriate for minimum requirements and management area.
	Commercial	20	All use is appropriate to management area regulations and ANILCA.
	Private recreational	20	Most use is appropriate to ANILCA and management area with some illegal incursions
	Subsistence	20	All use is appropriate to management area and ANILCA.
	Total Weight	**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 9). 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 10).

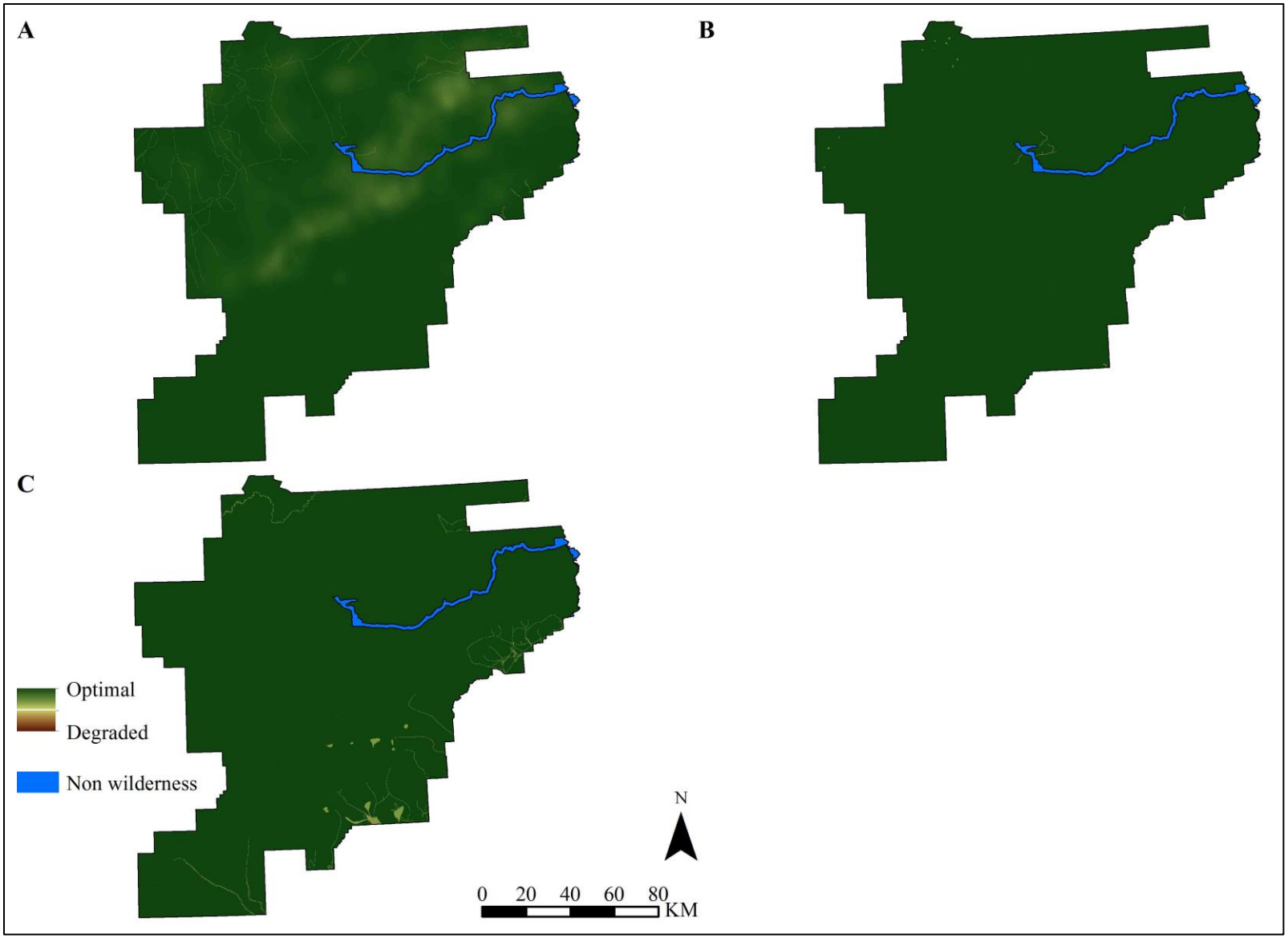

Figure 9. Indicator maps for (A) non-recreational structures, installations, and developments; (B) inholdings; and (C) use of motor vehicles, motorized equipment, or mechanical transport. Green depicts optimal quality and brown depicts degraded quality.

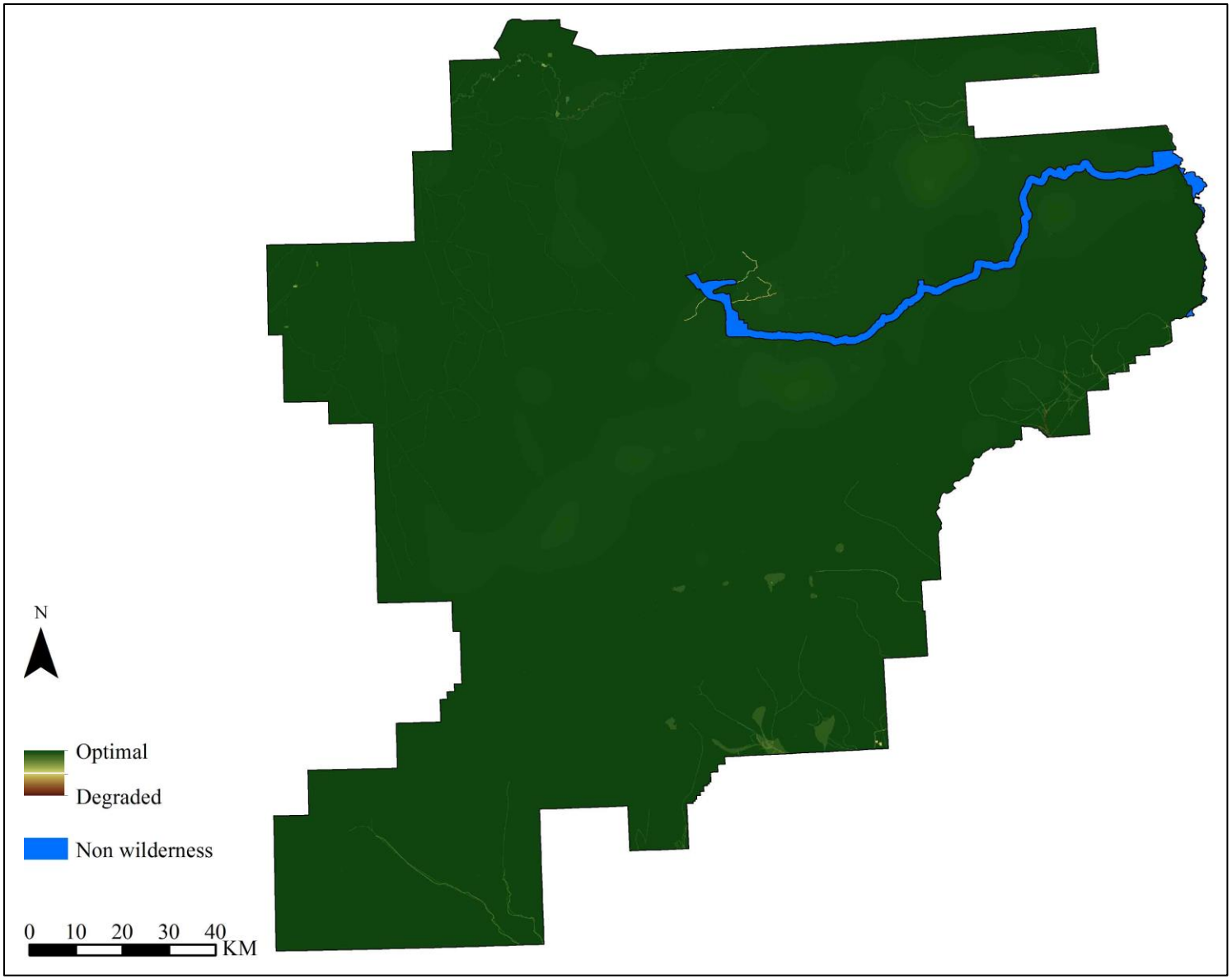

Figure 10. Undeveloped quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.

Solitude or Primitive and Unconfined Quality

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

Seasonal differences at DENA strongly influence the solitude quality. The long, mild days of the summer months (roughly mid-May through mid-September) are when the majority of people visit the park. This is also the time of year when the 92-mile park road is open, which parallels the Alaska Range to the north, and affords a unique opportunity for visitors to access and experience the wilderness. Summer also sees the majority of flightseeing and air taxi landings for climbing, hunting, and other recreation. In winter, the onset of snow, extreme temperatures and short days sees the park road close, the tourism industry shut down and visitor numbers drop dramatically. However, the park is still accessible for those who are proficient in winter travel, whether it be on foot (skiing, skijoring, snowshoeing), dogsled and portions of the 1980 park additions to snowmobiles.

As a consequence, it was essential to analyze this quality seasonally, and produce maps for both summer and winter. The measures that are affected by seasonal changes are denoted with an asterisk in Tables 9 & 10. Additionally, seasonal changes to measures are described in Table 10 in the rationale section.

Indicators and Measures

Measures were selected for each of the four indicators recommended in Keeping it Wild (Carver et al. 2013). The following indicators, with their measures and relevance to the solitude or primitive and unconfined quality, were used:

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

- Travel time model – calculates the time it takes for a person to travel across the landscape using the most common mode of travel from various access points (paved roads), taking into account cost surfaces[10] (elevation and land cover) and barrier features (steep ground and water). Most areas are for a person of average fitness level to travel on foot, however some areas of the new park additions allow motorized travel and those speeds are included. Seasonal differences are important as well.
- Viewshed model – calculates the line-of-sight impacts (using distance decay) of modern human features both inside and outside the wilderness.
- Interactive administrative contacts – visitors have a range of attitudes toward encountering a ranger in the backcountry from genuine interest and gladness to strong dislike. Patrols and other administrative visits (trail work, research, etc.) are factors that are within NPS purview.

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

- Administrative motorized use of the backcountry (snowmobiles, ATVs, boats) – NPS rangers/staff will often use the method of transport that visitors are allowed to use in a given management area.
- Non-motorized use of the wilderness (NPS discovery hikes, MSLC hikes, dog mushing patrols, summer backcountry ranger patrols, research, VIP, mountaineering patrols, trail crews, long-term NPS camps, and visitor use (hiker density maps) – non-motorized use is most aligned with ideal wilderness travel, but seeing people is still a degradation to opportunities for solitude.
- Encounter rate with hiking parties and with large groups (6 or larger) – this measure also accounts for a degradation to opportunities for solitude but uses a BCMP indicator that was surveyed for in 2010 (Fix and Hatcher 2011).
- Private motorized recreational use (boats, ATVs, bikes, snowmobiles) – most visitors will follow the rules and regulations for such use but this also contains some incursions. This is also used for the undeveloped quality but here is considered as remoteness from the sounds of people.
- Trash (administrative, recreational, non-NPS, non-historic) – although often small in spatial area affected the aesthetic effect is considered as such encounters affect a feeling of remoteness from signs of people. This is also a BCMP indicator.

Indicator: Remoteness from occupied and modified areas outside the wilderness

- Soundscape (inside and outside) – DENA's soundscape monitoring program detects motorized noise from aircraft flying overhead. An impact which significantly affects remoteness from the sights and sounds of people. Three BCMP indicators also apply to this.

Indicator: Facilities that decrease self-reliant recreation

- Authorized trails, bridges and signs (maintained, ORV, winter routes, climbing gear (e.g., fixed lines, anchors, rescue caches), and climbing routes) – Staff, public guidance, and management plans value keeping the number and extent of formal trails to a minimum in DENA, so much so that except for a few identified areas the BCMP has a "no formal trails" policy. This policy attempts to protect visitor's ability to choose their own route to discover the landscape for themselves with minimal guidance.
- Social trails, found campsites, and fire rings - decrease self-reliant recreation by providing some amenities, albeit rough and informal.
- Commercial developments (AAA-Backside Lake basecamp hiking, Mountain House, guided hunting camps) – these decrease self-reliant recreation.
- NPS mountain camps, private camps (hunter camps unguided), cabins (subsistence cabins) – these decrease self-reliant recreation.
- Non-NPS roads (Dunkle, Stampede, Kantishna Hills) – these decrease self-reliant recreation by providing a hardened and defined route to access more remote areas.

Indicator: Management restrictions on visitor behavior

- Backpacking and non-climbing permits – backcountry permits are required for visitors camping in the backcountry.
- Restrictions for backcountry visitors – rules and regulations restrict desired visitor behavior to protect other qualities. Such restrictions include zoning and quotas that limit the number of people in any given area, summer prohibition of pets, food storage, firearms use, fire use, and motorized use. All restrictions are lumped together.
- Wildlife closures – hard restriction, no people are allowed to enter the area.
- ANILCA allows consumptive use – subsistence hunting and gathering is allowed in some areas of the park and preserve, but it is an exclusive use to a relatively small group of people.
- Non-ANILCA consumptive use restrictions (primarily for hunting) – rules and regulations restrict desired visitor behavior to protect the natural and untrammeled qualities.
- Road access restrictions – restricted private vehicle access along the Denali Park Road. After the first 15 miles, visitors must take a bus to access the backcountry from the road.

Travel Time and Viewshed Modeling

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

Travel Time

Travel time is modeled in DENA based on a GIS implementation of Naismith's rule[12] (Naismith 1892), with Langmuir's correction[13] (Langmuir 1984). Terrain and land cover information are used to delineate the relative time necessary to travel into a roadless area from the nearest points of road or airplane access, taking into account the effects of distance, relative slope, ground cover, and barrier features such as very steep ground. Travel methods used in DENA include hiking in the summer and skiing, snowshoeing, mushing, and snowmachines in the winter (see below and Appendix A for more

[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 (1984) 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.

details). The travel time (or "remoteness") model, developed by Carver and Fritz (1999), assumes a person can walk at a speed of 5 km/hr over flat terrain and adds a time penalty of 30 minutes for every 300 m of ascent and 10 minutes for every 300 m of descent for slopes greater than 12 degrees. When descending slopes between 5 and 12 degrees, a time bonus of 10 minutes is subtracted for every 300 m of descent. Slopes between 0 and 5 degrees are assumed to be flat. 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 traveling speeds according to ground cover (e.g., Naismith's 5 km per hour on the map can be reduced to 1 km 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 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

[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.

- 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 National Elevation Dataset 60 meter DEM was resampled to a 100m resolution/pixel size and provides terrain elevation. A 25-class landcover map was created by NPS DENA using Landsat TM and SPOT XS satellite data supported with field data, modeling, aerial photography, and fire mapping from 1985 to 2008 information sources. Additionally, DENA road, trail, river and lake datasets are used to supplement the land cover layer.
- 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:
    - Source grid: SUMMER - this is taken to be the paved road network in and around the park that is open to public vehicles, and the commercial air portals in the south of the park (Pika, SE Kahiltna, Ruth and Eldridge glaciers).

      WINTER – the road network outside the park remains open but the drivable portion within the park is shortened to the park headquarters entrance. Portals are not included for winter because the amount of use is substantially less than in summer.
    - Cost surface*:* SUMMER - impedance values are assigned to the various land cover classes when traveling off trail in DENA. The majority of shrubland is difficult to travel through in DENA and is generally estimated to be 0.4–0.8 km/hr. Stunted spruce and low shrub spruce are estimated to be slightly faster at 1.6 km/hr. More open classes, such as open spruce, broadleaf and bare ground are set at 2.4 km/hr. (For a full list of land cover impendence values that represent off-trail travel, see Appendix A). Additional features not found in the land cover data are used to amend the base cost surface for a more accurate depiction of the DENA terrain. Trails are overlaid onto the cost surface at 5km/hr, due to their low resistance to movement. Rivers are numerous in DENA and can be dangerous to cross (there are no bridges in the backcountry). Backcountry rangers recommend a high degree of caution when crossing rivers: take the time to ascertain the water depth, find a braided section to cross, use poles or sticks for balance, etc. Therefore, rivers are factored into the cost surface at DENA, with the majority of rivers set to take 15 minutes to cross. The larger rivers in DENA are a different proposition and are generally considered barrier features considering their size and strength. These rivers include: on the Southside - Chulitna, Ohio, Tokositna, Kahiltna, Lake and Yentna rivers; and on the Northside – all rivers between the McKinley and Tonzona. However, with good knowledge of the local area and/or using packrafts these rivers may be crossable. Hence, considering the planning and time needed to cross these rivers, they were given a crossing time of 2 hours. Lastly, the park road is "hardwired" onto the cost surface at 40 km/hr to represent the speed the buses travel at as they head towards Wonder Lake.

WINTER – cold temperatures and snowfall result in significant changes to the terrain in winter. Vegetation impedance, trails and roads are no longer an issue as the landscape is blanketed in snow. And the colder temperatures freeze the rivers making them easy to cross. Therefore, the most important factor to consider for winter travel is the mode of transport. To evaluate this, the DENA staff split the park into three zones: north, wilderness and south. The north zone is set to 8 km/hr, as the majority of visitors will either mush or use snowmobiles. Winter trails[16] in this zone are set to 24 km/hr, which is the fastest average speed snowmobile users are likely to travel. The wilderness zone is set to 1.6 km/hr as no motorized transport is allowed. Winter trails in this zone are set to 6.4 km/hr, which is the fastest average speed dog mushers can travel. Finally, the south zone is set to 24 km/hr as the majority of visitors will be on snowmobiles. There are no winter trails in this zone. Outside the park, the areas adjacent to the north and wilderness zones are set to 8 km/hr and the area adjacent to the south zone are set to 24 km/hr. (See Appendix A for a winter travel speeds map.)

- Barriers to movement: SUMMER - these include all lakes and any areas where slope angles exceed 40 degrees.

  WINTER – lakes are removed (they will be frozen and easy to travel across) but any areas where slope angles exceed 40 degrees remain as barrier features.

  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 11).

- Cautions: Naismiths's rule and the model used to implement it here assumes the person "travelling the landscape" is a fit and healthy individual and does not make allowances for load carried, weather conditions, snow conditions, or navigational skills.

[16] Winter trails are created by park staff and the public to facilitate quicker travel by avoiding time consuming obstacles such as unpacked snow, steep slopes, vegetation protruding above the snow, sharp corners, etc. Winter trails created by park staff are demarcated with temporary marked poles in some places.

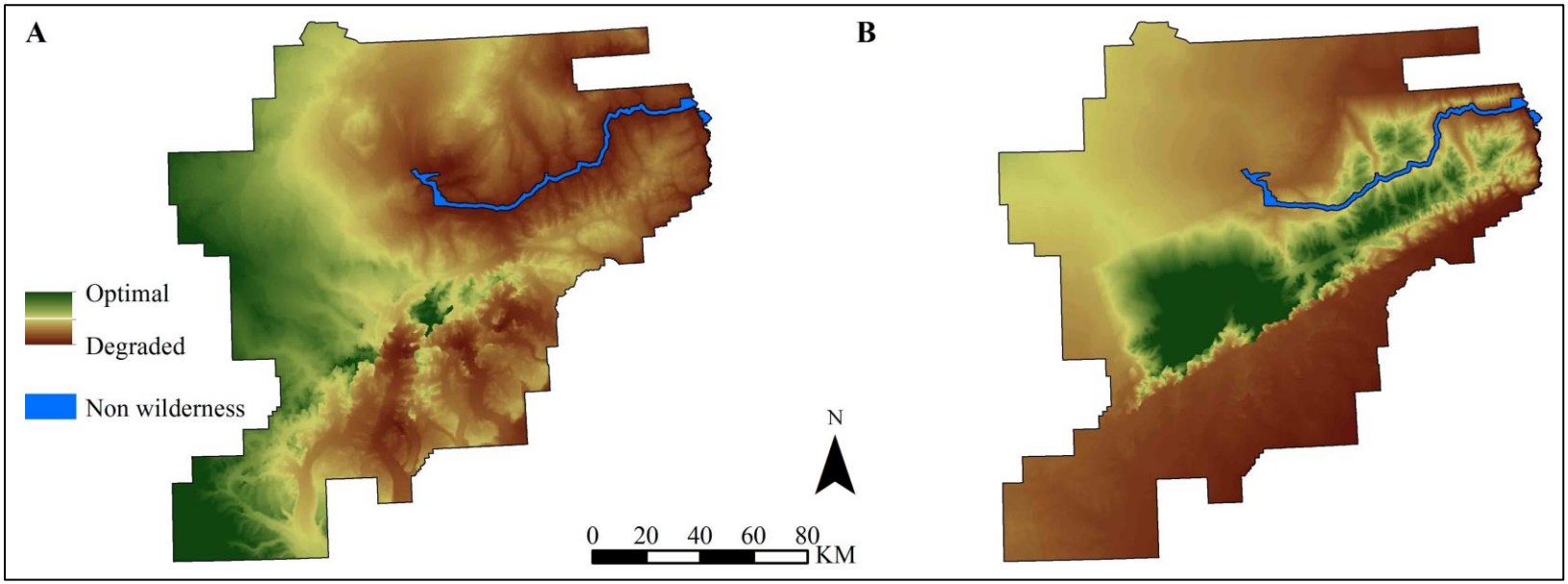

Figure 11. Travel time model for (A) summer travel and (B) winter travel. This map depicts the fastest route it would take a person to walk to every pixel in DENA from the source grid (paved road network) and portals. Brown indicates the pixels that are within quicker reach and therefore we assume that these pixels represent a lower opportunity for solitude, and green represents pixels that will take longer to reach and therefore represent greater opportunity for solitude. (Map is displayed using standard deviations.)

Viewshed

The visual impacts of modern anthropogenic features in DENA are modeled using a custom-built software tool. The software tool calculates the visibility of a feature with given properties from the perspective of a person on any point on a landscape to any other point on the landscape. The presence of these artificial features, which may be located within or adjacent to DENA, is assumed to detract from a sense of solitude by the hypothetical person on the ground. 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[17].

- Sources: Visibility analysis and viewshed calculations rely on the ability to calculate "line-of-sight" from one point on a landscape to another. It has been shown that the accuracy of viewsheds produced in GIS is strongly dependent on the accuracy of the terrain model used and the inclusion of intervening features or "terrain clutter" in the analysis (Fisher 1993). While previous studies have made use of a digital surface model (DSM) for obtaining "terrain clutter" (Carver et al. 2008), the extent of DENA and relative lack of features allows feature information to be collated and formatted manually (Table 9). A resolution of 100 m for feature inputs was considered adequate for this analysis. Viewshed distance and height information were determined for each feature by the working group. The USGS NED DEM was used to provide terrain elevation data. Finally, a number of features will not be visible in winter due to snow cover (these features are denoted with an asterisk in Table 9). Therefore, the analysis is run twice to depict both the summer and winter viewshed in DENA.
- 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[18] 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

[17] 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.

[18] A voxel is a volumetric pixel.

model utilizing only moderate computing resources. This "viewshed transform" approach represents a maturation of traditional cumulative viewshed techniques (Carver et al. 2008) and is used to:

1. calculate the viewshed for every single feature;
2. incorporate estimates of the proportional area of each visible feature; and
3. run separate viewshed calculations for each of the different categories of features listed in Table 9, which can then be combined together to create the viewshed map.

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

Table 9. Human features impacting viewshed.

Feature type	Data source	Viewshed distance	Height	Accuracy	Completeness
Denali Park Road*	Park_road	15km	6m	High	High
Parks Highway	Parks_highway	15km	4m	High	High
Railroad	Railways	15km	5m	High	High
Headquarters area	Buildings_de	5km	6m	High	High
C-camp & maintenance area	Buildings_de	15km	15m	High	High
Denali Visitor Center Wilderness Access Center, Concessions buildings, Murie Science and Learning Center	Buildings_de	5km	15m	High	High
Medium structures (backcountry cabins, shelters)	Buildings_de & cabins	5km	3m	High	High
Large structures/Inholdings	Buildings_de	15km	8m	High	High
Radio repeaters	DENA_structures	15km	3m	High	High
Weather stations	DENA_structures	5km	3m	High	High
Installations	Other_instruments	5km	3m	High	High
Cell phone towers	Cell_towers	5km	25m	High	High
Campgrounds	Buildings_de	5km	4m	High	High
Parking lots (Mtn vista, Savage River, Eielson, etc.)*	Fc_roads	5km	4m	High	High
Major mountaineering camps*	Ss_points	5km	2m	Medium	High

* Denotes feature that can't be seen in winter, and were excluded from the winter analysis

Table 9 (continued). Human features impacting viewshed.

Feature type	Data source	Viewshed distance	Height	Accuracy	Completeness
Trails*	Trails_de	5km	2m	High	High
Landing strips*	Landing_sites	5km	1m	Medium	Medium
Grande Denali	Grande_DENA	15km	8m	High	High
Southside communities	Ss_communities	5km	8m	Medium	High
Powerlines	Utilities	15km	10m	High	Medium
Intertie	Intertie	15km	35m	High	High
Mine disturbance*	Mines & ss_polygons	15km	3m	Medium	Medium
Toklat road camp	Toklat_roadcamp	15km	5m	High	High
Toklat rest area & tent	Toklat_rest	15km	5m	High	High
Eielson Visitor Center	Buildings_de	15km	4m	High	High
The Igloo	Igloo	15km	12m	Medium	High
Gravel pits*	DENA gravel harvest	5km	3m	High	High
Clear Air Force base	Clear_airbase	30km	25m	Medium	Medium
Healy power plant	Healy_dev	30km	25m	Medium	High
Healy coal mine	Healy_dev	15km	50m	Medium	Medium
Minchumina airport base	Minchumina_light	30km	20m	Medium	High

* Denotes feature that can't be seen in winter, and were excluded from the winter analysis

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

1. The cell resolution was limited to 100 m for all features;
2. A "pessimistic" re-sampling was done to generate the 100 m feature inputs guaranteeing that features smaller than this area were included[19] and that the viewsheds produced an accurate representation of the visual impacts of these features;
3. The landscape was split into a number of overlapping tiles such that they could be simultaneously analyzed by a cluster of desktop computers;

[19] Re-sampling of feature layers in GIS is normally carried out on a "majority class" basis wherein the value of a grid cell takes on the value of the largest feature by area that it contains. Using this rule, a 10 x 10 m building in a 100 x 100 m grid cell that was otherwise not classified as a feature would not be recorded on re-sampling. The "pessimistic" re-sampling used here operates on presence/absence basis such that any grid cell containing a human feature will be classified as such even though the actual area or footprint of the feature may not cover the majority of the grid cell.

4. The viewshed analysis was run for 5 km, 15 km and 30 km maximum viewshed distances.
5. The analysis is repeated for the winter landscape, excluding features that will be covered by snow.

The model outputs for the different viewshed distances per season were combined together using the MINIMUM function in ArcGIS to produce grids of viewshed impacts for features both inside and adjacent to DENA. 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 12).

- Cautions: Categorizing the anthropogenic features in DENA 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 wooden backcountry cabins are largely unnoticeable from distance because they are difficult to pick out against a spruce forest and/or tundra backdrop, and thus are assigned a maximum viewshed distance of 5 km. Larger and more prominent structures situated in easily visible areas (such as the Eielson Visitor Center) are assigned a higher viewshed distance of 15 km.

  Depending on the angle of view, a road can be largely unnoticeable once past a short distance. However, roads are set at a height of 5 m in anticipation of traffic, especially for traffic traveling at night with their lights on. 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 5 m high "wall" when in reality these features only consist of poles and powerlines. These are limitations of the model and should be considered when interpreting 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.

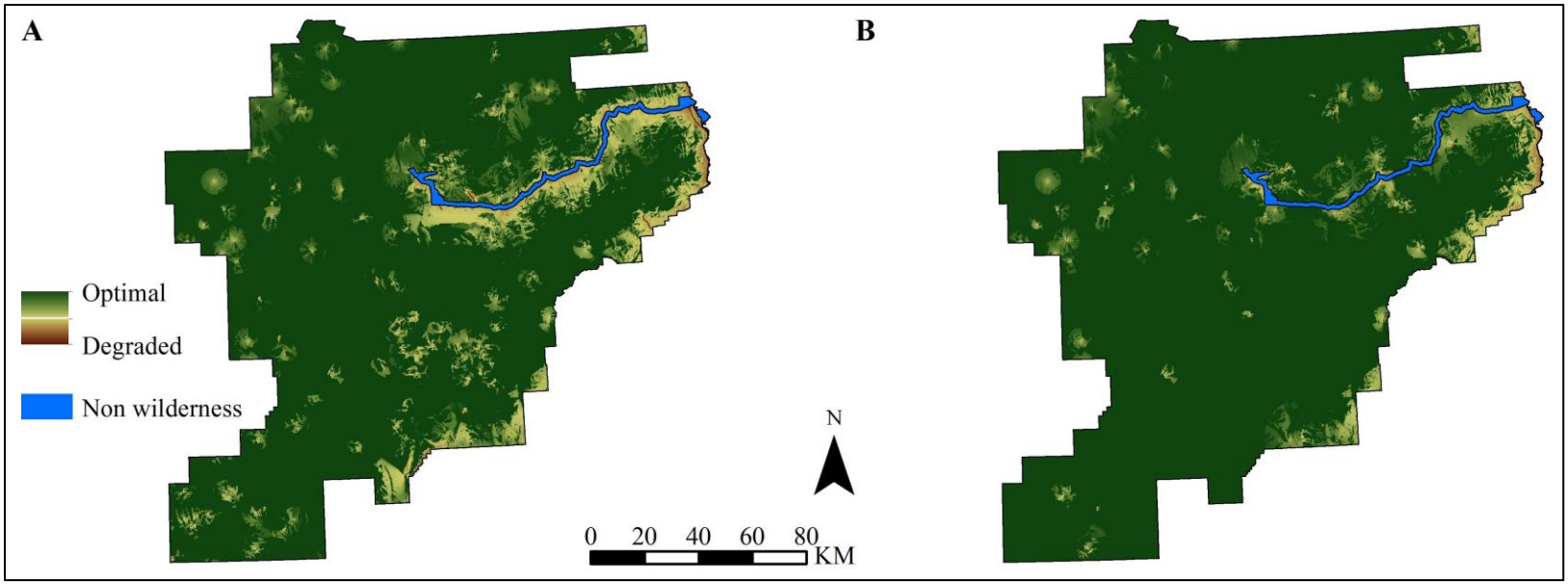

Figure 12. Viewshed impacts in (A) summer and (B) winter. Green depicts optimal quality viewshed and brown depicts degraded quality viewshed.

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.

Interactive Administrative contacts

- Sources: SUMMER = NPS data: compliance, visitor_contact and Denali_westbutt point datasets; and WINTER = NPS data: winter_contacts point dataset.
- Processing: Locations of administrative contacts were given a value of 1. Layers were converted to rasters and values were normalized to 0–255.
- Cautions: This dataset provides a snapshot of contacts over the course of three years. Outside of the West Buttress mountaineering route, where such contacts are highly predictable, other areas of the park have few contacts. This is because of sparse backcountry ranger patrols in a landscape mostly without trails, where visitors are encouraged to disperse and find their own routes.

Administrative motorized use of the wilderness

- Sources: SUMMER = VRP CIRs; and WINTER = VRP CIRs and SS_lines_motor polyline datasets (the latter dataset was heads-up digitized by Roger Robinson and Coley Gentzal).
- Processing: Polylines are buffered to a distance of 1km to represent the noise emitted from the motorized use. These locations of motorized use were given a value of 1. Layers were converted to rasters and values were normalized to 0–255.
- Cautions: Motorized use is highly temporal, but these locations serve as a proxy for yearly use.

Non-motorized use of the wilderness

- Sources: SUMMER = VRP CIRs, Disco_hikes (2009–2010), AK_GEO (2009–2010) polyline datasets and Denali SUA polygon dataset; WINTER = VRP CIRs and winter_patrols polyline datasets.
- Processing: Used kernel density to evaluate these datasets (cell size set to 100m, kernel radius to 1km and set the population field to group size). Finally, the Denali SUA was entered at the highest value of the kernel density output as this area has consistent high use during the summer months.
- Cautions: Using kernel density is a novel approach for evaluating these datasets, but the DENA staff found that the results were in line with their on-the-ground understanding of the impacts to this measure.

Table 10. Solitude and primitive and unconfined quality datasets

Measures	Source	Type	Scale/ Resolution	Accuracy	Completeness
Travel time model*	DEM and land cover Park_road, Parks_highway, rail, rivers, lakes	Raster, line	100m	Medium	High
Viewshed	See Table 9				
Interactive Administrative contacts*	Compliance, visitor_contact, Denali_westbutt and winter_contacts	Point	100m	Medium	High
Administrative motorized use of the wilderness*	VRP CIRs and SS_lines_motor	Polyline	1000m	Medium	Medium
Non-motorized use of the wilderness*	VRP CIRs, Disco_hikes (2009–2010), AK_GEO (2009–2010) Denali SUA, winter_patrols	Polyline & polygon	1000m	Medium	Medium
Encounter rate with hiking parties and with large groups*	Fix and Hatcher (2011), estimates from mountaineering patrols, NPS data on Triple Lakes Trail.	Line	1000m	Low	Medium
Private motorized recreational use*	priv_summer, priv_winter, snowmobile_route and SS_lines_motor and ss_polygons	Polyline & polygon	1000m	Low	Low
Trash	VRP CIRs, roger_trash, CIR_12_0177_6-7_WP_lumberandtrash, climbing_cache, nps_trash_litter, historic litter, non_nps_total, and ohio_creek_crash_site1995	Point	100m	Medium	Medium
Soundscape	DENA_Parkwide_DerivedData2012formap and DENA_Soundscapes_Winter_Unconstrained_Event_Rate 04 16 2013	Point	100m	Medium	Medium
Authorized Trails, bridges and signs	Trails_de, West_butt_route, and trails_mushing	Polyline	30m	High	High
Social trails, found campsites and fire rings	Inf_trails and impact_site	Point & polyline	100m	Medium	Low

* Indicates seasonal differences

Table 10 (continued). Solitude and primitive and unconfined quality datasets

Measures	Source	Type	Scale/ Resolution	Accuracy	Completeness
Commercial Developments	Airstrips, hunt_camps, PntInter, comm_devs and mountain_house	Point & polygon	100m	Medium	Medium
NPS mountain camps, private camps, cabins	Historic_cabins, subsistence_cabins and camps_ss	Point	100m	Medium	High
Non-NPS roads	Dunkle_road	Polygon	100m	Medium	High
Backpacking and non-climbing permits	Bc_unit_restrict_summer	Polygon	100m	High	High
Restrictions	Bc_unit_restrict_summer and bc_unit_restrict_winter	Polygon	100m	High	High
Wildlife closures	Closures	Polygon	100m	Medium	High
ANILCA allows consumptive use	Park_boundary	Polygon	30m	High	High
Non-ANILCA consumptive use restrictions	Park_boundary	Polygon	30m	High	High
Road access restrictions	Bc_unit_restrict_summer and bc_unit_restrict_winter	Polygon	100m	High	High

* Indicates seasonal differences

Encounter rate with hiking parties and with large groups

- Sources: Fix and Hatcher (2011), NPS data on mountaineering routes and Triple Lakes Trail, backcountry unit boundaries.
- Processing: Fix and Hatcher (2011) surveyed backcountry visitors, asking them to draw on a map where they hiked and if they saw other hiking parties (among other questions about BCMP indicators). Encounters by overnight hikers were summarized spatially by backcountry unit. Encounters by day hikers had data that allowed creation of a hiker density map (line density). The hiker density informed where to draw boundaries for busier areas with encounter rates attributed to these encounter rates. Air taxi and commercial air tour portals encounter rates were informed by anecdotal ranger accounts. Polygons describing an area of uniform encounter rates were assigned the actual numerical encounter rate. The layer was converted to raster, and the values were normalized to 0–255
- Cautions: The reliability of visitor observations is not confirmed.

Private motorized recreational use

- Sources: SUMMER = priv_summer polyline dataset; and WINTER = priv_winter, snowmobile_route and SS_lines_motor polyline datasets (the latter dataset was heads-up digitized by Roger Robinson and Coley Gentzal), and ss_polygons polygon dataset.
- Processing: Polylines are buffered to a distance of 1km to represent the noise emitted from the motorized use. These locations of motorized use were then given a value of 1. Layers were converted to rasters and values were normalized to 0–255.
- Cautions: Motorized use is highly temporal, but these locations serve as a proxy for yearly use. Snowmachines can disperse in many areas on the south side of the Alaska Range with use levels uncertain in some areas. In addition, depending on snow conditions, use can be highly temporal.

Trash – visitor litter, admin trash, and historical trash

- Sources: VISITOR LITTER = backcountry_litter, m_smith_litter and roger_trash point datasets; ADMIN TRASH = CIR_12_0177_6-7_WP_lumberandtrash, climbing_cache and nps_trash_litter point datasets; and NON_NPS_TRASH = historic litter, non_nps_total, and ohio_creek_crash_site1995 point datasets. Trash is only noticeable in summer, there is no trash measure for winter.
- Processing: The 3 categories are assigned values (out of 10) based on their impact to the trash measure: VISITOR LITTER = 5, ADMIN TRASH = 7, and NON_NPS_TRASH = 8. Layers were converted to rasters, added together, and their values were normalized to 0–255.
- Cautions: The visitor litter points are where rangers have picked up litter. However, these points are usually at informal campsites or along travel corridors and thus serve as a proxy for typical amounts of visitor litter found in the backcountry.

Soundscape

- Sources: SUMMER = DENA_Parkwide_DerivedData2012formap spreadsheet. WINTER = DENA_Soundscapes_Winter_Unconstrained_Event_Rate 04 16 2013 spreadsheet.
- Processing: A point dataset was created from the coordinates of soundscape monitoring stations (in the spreadsheet), including both the summer and winter sampling locations. The IDW (Inverse distance weighted) interpolation tool then uses 'events per day' value for each station to create interpolated grids for summer and winter. Additional features with average noise event values were then overlaid onto this grid for completeness: Denali Park Road (75 events per day), George Parks Highway (250 events per day) and railway (7 events per day). This process was the same for both the summer and winter measures, except the Denali Park Road was excluded from the winter analysis (Figure 13).
- Cautions: DENA has an active soundscape inventorying and monitoring program, which is coordinated by their own soundscape scientist. The datasets generated by this program provide an important record of how human-generated noise is impacting the wilderness soundscape. However, the park has never attempted to interpolate these data into a continuous grid. Working closely with the soundscape scientist, a number of methods were tested and tweaked to produce grids that interpret the raw data. These methods may appear coarse, but the park staff was in agreement that the grids were satisfactory for the intents of this mapping project. Long after the map had been finalized it was suggested that future efforts should map the noise free interval (NFI) instead of events per day. The NFI is essentially the typical amount of time until the next noise event, and better representation of the experiential manifestation of the event rate. Furthermore, NFI and noise events have an inverse exponential relationship and thus NFI drops very quickly with the addition of a few noise events, but very slowly when event rates are high. Using NFI would resolve the issue of the George Parks Highway washing out the scale for the rest of the wilderness, (250 events per day is an extreme value compared to those over and adjacent to the rest of the wilderness. The winter map has significant spatial data gaps as compared to the summer and the summer estimate for events per day used for winter is probably too high.

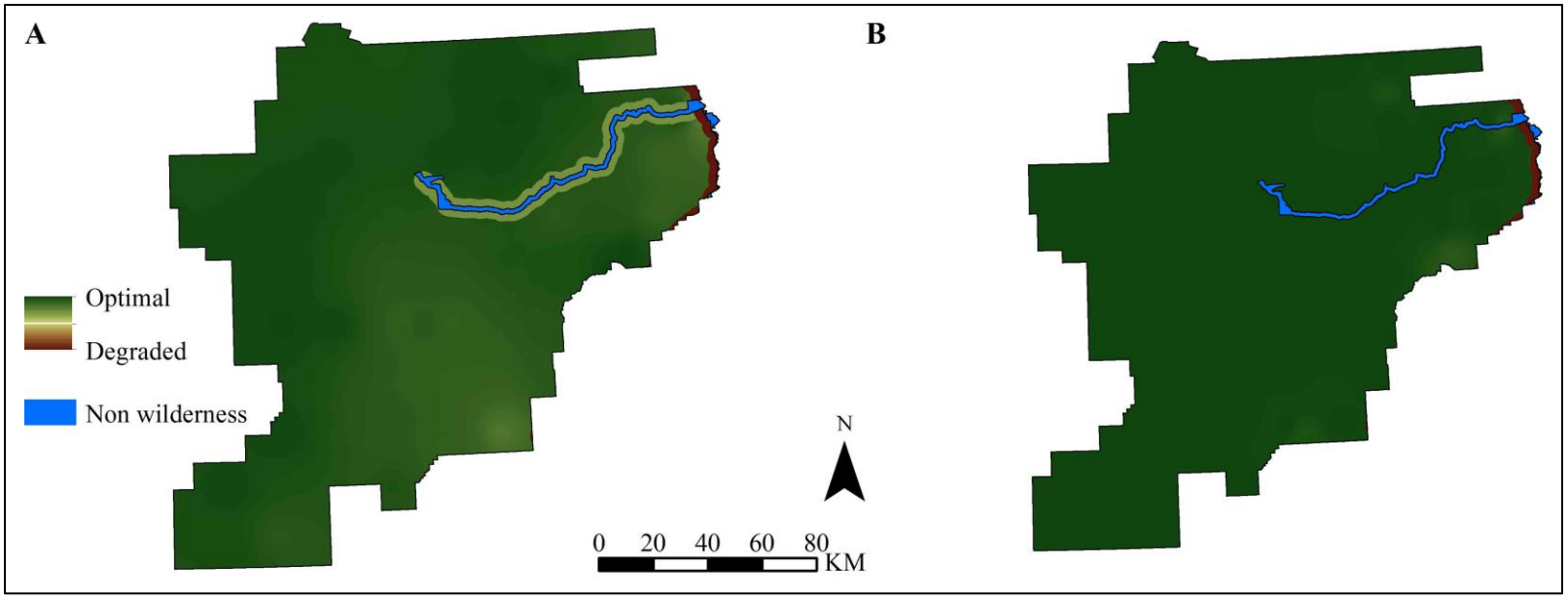

Figure 13. Soundscape impacts in (A) summer and (B) winter. Green depicts optimal quality and brown depicts degraded quality.

Authorized trails, bridges and signs

- Sources: SUMMER = Trails_de and West_butt_route polyline datasets and WINTER = trails_mushing polyline datasets.
- Processing: Locations of authorized trails, bridges and signs were given a value of 1. Layers were converted to rasters and values were normalized to 0–255.
- Cautions: None

Social trails, found campsites and fire rings

- Sources: Inf_trails polyline dataset and impact_site point dataset. Social trails and impacted sites are only noticeable in summer.
- Processing: Locations of informal trails and impacted sites were given a value of 1. Layers were converted to raster and values were normalized to 0–255.
- Cautions: Use in this map does not distinguish the level of impact at each trail or site.

Commercial developments

- Sources: Airstrips, hunt_camps and PntInter point datasets and comm_devs and mountain_house polygon datasets.
- Processing: Locations of commercial developments and associated infrastructure were given a value of 1. Layers were converted to raster and values were normalized to 0–255.
- Cautions: May not capture all guided hunting camps.

NPS mountain camps, private camps, cabins

- Sources: Historic_cabins, subsistence_cabins and camps_ss point datasets.
- Processing: Locations of hunting camps were given a value of 1 (these are temporary structures with less impact than permanent structures) and locations of historic and subsistence cabins were given a value of 2. Layer was converted to raster and values were normalized to 0–255.
- Cautions: None

Non-NPS roads

- Sources: Dunkle_road polygon dataset
- Processing: Locations of non-NPS roads were given a value of 1. Layer was converted to rasters and values were normalized to 0–255.
- Cautions: None

Backpacking (non-climbing) permits

- Sources: Bc_unit_restrict_summer polygon dataset
- Processing: Locations requiring backpacking permits were given a value of 1. Layer was converted to raster and values were normalized to 0–255.

- Cautions: None

Restrictions

- Sources: SUMMER = bc_unit_restrict_summer polygon dataset; and WINTER = bc_unit_restrict_winter polygon dataset.
- Processing: Values were assigned to backcountry units based on the number of restrictions. Layers were converted to rasters and values were normalized to 0–255.
- Cautions: None

Wildlife closures

- Sources: Closures polygon dataset.
- Processing: Locations of closures are given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Many localized closures are highly temporal depending on locations of nesting birds and denning wolves.

ANILCA allows consumptive use

- Sources: Park_boundary polygon dataset.
- Processing: Locations that don't allow ANILCA consumptive use were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: None

Non-ANILCA consumptive use restrictions

- Sources: Park_boundary polygon dataset.
- Processing: Locations that don't allow non-ANILCA consumptive use were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: None

Road access restrictions

- Sources: SUMMER = bc_unit_restrict_summer polygon dataset; and WINTER = bc_unit_restrict_summer polygon dataset.
- Processing: Backcountry units that don't have vehicular access were given a value of 1. Layers were converted to rasters and values were normalized to 0–255.
- Cautions: Road access by motor vehicles varies by season. During the main visitor season (mid-May to mid-September) road access is most restricted from mile 15–92. Between those dates access is open to mile 30 until snow and ice conditions dictate the road be closed.

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. The summer and winter measures are assigned the same weights, which allows the reader to focus on the seasonal differences between the measures in the resultant maps. Although data for winter encounter rates, trash and commercial developments 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 a rerun of the wilderness character map. The revised weights for indicators with missing data are recorded in brackets in Table 11.

Table 11. Indicators and measures for the solitude quality with weights and rationale

Indicator	Measure	Summer Weight	Winter Weight	Rationale	Seasonal Change
Remoteness from sights and sounds of people inside the wilderness	Travel time model	10	10	Quantifies the time to travel across the landscape using the most common mode of travel for a given area and season. Lightly weighted because visitor use is relatively low particularly in more remote areas.	Different - The park road is closed in winter, which significantly reduces access. Further, winter generally makes travel faster in DENA, using skis, dogsleds in the Old Park, and snowmobiles in the New Park (which is factored into the model).
	Viewshed model	21	21	Installations and structures both inside and outside of the park that are visible from inside are more heavily weighted because many people are sensitive to being able to see human intrusion in wilderness.	Different - What is not covered by snow is more visible and has higher contrast with the surrounding landscape.
	Interactive Administrative contacts	21	21	Visitors have a range of attitudes toward encountering a ranger in the backcountry from genuine interest and gladness to strong dislike. More heavily weighted to reflect the more negative sentiment that may be more common to Alaska.	Different - There are fewer visitors and NPS presence in the winter hence fewer contacts.
	Administrative motorized use of the wilderness	8.5	8.5	More lightly weighted because such use is heavily scrutinized by NPS management and reduced as much as possible. Also factored into undeveloped.	Different – less use in the winter.
	Non-motorized use of the wilderness	6	6	More lightly weighted because such use is consistent with traditional modes of wilderness travel.	Different – less use in the winter.
	Encounter rate with hiking parties and with large groups	10	Data gap (10)	Lightly weighted because such use is consistent with traditional modes of wilderness travel.	Different – no data currently exists for winter encounters, but they happen occasionally.

Table 11 (continued). Indicators and measures for the solitude quality with weights and rationale

Indicator	Measure	Summer Weight	Winter Weight	Rationale	Seasonal Change
Remoteness from sights and sounds of people inside the wilderness (continued)	Private motorized recreational use	8.5	8.5	Lightly weighted because summer/fall is short duration ORV subsistence use and medium duration snowmachine use. It would be ideal to weight the winter use higher but winter weights were chosen to be the same as summer.	Different – Use is more widespread in winter with snowmobiles as well as incursions are more common in winter by snowmobiles.
	Trash	15	Data gap (15)	Moderately weighted because trash carries a larger aesthetic and symbolic impact even though it is often associated with a small spatial scale.	This is a data gap for the winter but litter is a perennial problem in popular visitor use areas, though it may be less noticeable in the winter due to snow cover.
Remoteness from occupied and modified areas outside the wilderness	Soundscape	100	100	This is the single measure which captures the majority of impacts from outside the wilderness…motorized noise from aircraft over head and adjacent roads and highways.	Different – Low-altitude commercial aircraft use, the major impact to soundscape condition in Denali, is greatly reduced during the winter months. High-altitude commercial aircraft may also be reduced across seasons, but not nearly as dramatically. Snowmachine use is only present in winter months. Caution: the winter map has more spatial data gaps than the summer map.
Facilities that decrease self-reliant recreation	Authorized Trails, bridges and signs	25.6	25.6	Such facilities guide a backcountry traveler instead of the skill, focus, and awareness necessary off a trail and hence reduce the need for self-reliance. These facilities are permanent and lasting and hence more heavily weighted.	Different – Some may still be used in winter, but are often snow covered and not as apparent or useful for travel. Most signs will still be visible because of relatively thin snowpacks on the north side of the range.

Table 11 (continued). Indicators and measures for the solitude quality with weights and rationale

Indicator	Measure	Summer Weight	Winter Weight	Rationale	Seasonal Change
Facilities that decrease self-reliant recreation (continued)	Social trails, Found Campsites, fire rings, cairns	14.6	Data gap (14.6)	Such impacts guide a backcountry traveler instead of the skill, focus, and awareness necessary off a trail and hence reduce the need for self-reliance. These provide some amenity but are still quite primitive and hence more lightly weighted.	Different – social trails that may be used in the summer may not be visible in the winter, however temporary winter trails may function in similar manner. Winter informal trails, campsites and fire rings are not as common, more transitory, and were not mapped hence a data gap.
	Commercial Developments	17.6	Data gap (17.6)	Such facilities guide a backcountry traveler instead of the skill, focus, and awareness necessary off a trail and hence reduce the need for self-reliance.	Different – a data gap in winter because there is currently limited use.
	NPS mountain camps, private camps, cabins	24.6	24.6	Such facilities guide a backcountry traveler instead of the skill, focus, and awareness necessary off a trail and hence reduce the need for self-reliance. Facilities that are maintained and thus are strongly weighted.	Different: only cabins used in winter, the mountaineering camps are taken down after the climbing season.
	Non-NPS roads	17.6	17.6	These are usually not maintained and often brushier or rougher than a maintained road and hence not as heavily weighted.	Same - Still useful in winter because they hold snow and provide a travel corridor.
Management restrictions on visitor behavior	Backpacking and non-climbing permits	25	25	In areas where permits are required this can be a time consuming process taking up to an hour.	Same – but obtaining a permit is less time consuming for winter use.
	Restrictions	21	Data gap (21)	Restrictions are an important symbolic impact on unconfined recreation, particularly in Alaska; hence this is weighted moderately high.	Different – most restrictions are relaxed or not applicable in winter, but this could change over time.
	Wildlife closures	16	Data gap (16)	These are hard closures to protect Natural and Untrammeled qualities and thus moderately weighted.	Not used in winter - Closures are not in effect in the winter, but could be in the future.

Table 11 (continued). Indicators and measures for the solitude quality with weights and rationale

Indicator	Measure	Summer Weight	Winter Weight	Rationale	Seasonal Change
Management restrictions on visitor behavior (continued)	ANILCA allows consumptive use	11	11	Relatively low weighting because this is subsistence related, but it is an exclusive use to a relatively small group of people.	Same summer and winter.
	Non-ANILCA consumptive use restrictions	11	11	NPS has more restrictions on sport hunting than Alaska state regulations, but low weighting because they are designed to protect the Natural and Untrammeled qualities.	Same summer and winter.
	Road access restrictions	16	16	The Denali Park Road is the only road with restricted access which is a limiting factor to people accessing the backcountry. This measure is equally weighted with general restrictions and wildlife closures because these are designed to protect other qualities of wilderness character and/or the visitor experience on the park road.	Different. In summer the Denali Park Road is closed to private vehicles at mile 15 and concessionaire bus, administrative, and inholder traffic is regulated. After mid-September the road is open to the general public to mile 30. When snow/ice conditions dictate the road is gated at mile 3 until mid-March when it incrementally opens up to mile 30 to the general public as it is plowed. In mid-May the road falls into summer use patterns.
	Total	**400**	**305.8 (348.4)**		

Maps

The weighted measures for the summer and winter indicators are added together using a raster calculator to create separate maps for remoteness from sights and sounds of people inside the wilderness, remoteness from occupied and modified areas outside the wilderness, facilities that decrease self-reliant recreation, and management restrictions on visitor behavior (Figure 14 & 15). The first two indicators are added together to depict opportunities for solitude inside wilderness and the latter two indicators are added together to depict opportunities for primitive and unconfined recreation inside wilderness (Figure 16). Finally, the raster calculator is used to add the four indicator maps for summer and winter together to create the solitude or primitive and unconfined quality map (Figure 17 & 18).

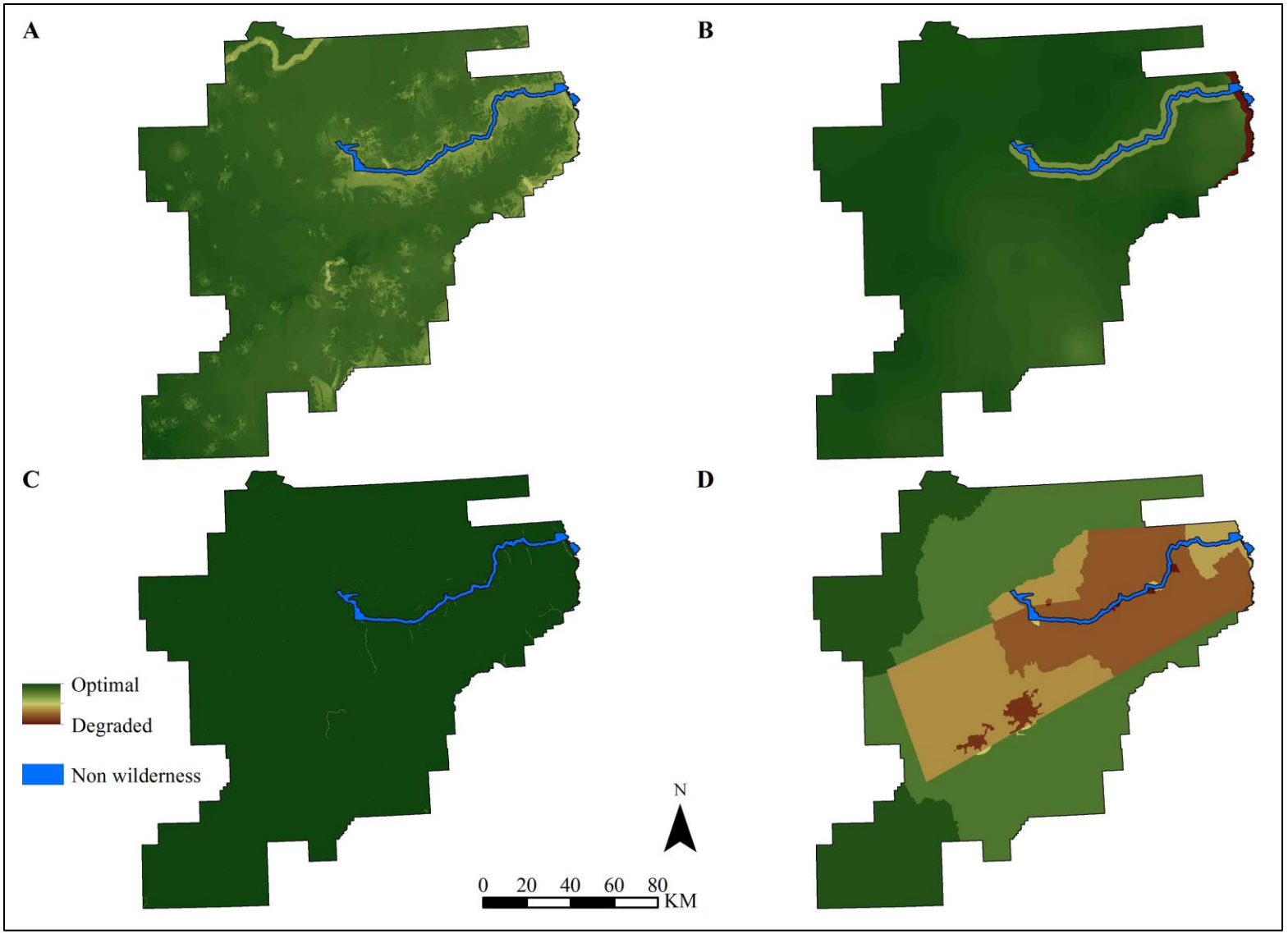

Figure 14. Summer indicator maps for (A) remoteness from sights and sounds of people inside the wilderness, (B) remoteness from occupied and modified areas outside the wilderness, (C) facilities that decrease self-reliant recreation, and (D) management restrictions on visitor behavior. Green depicts optimal quality and brown depicts degraded quality.

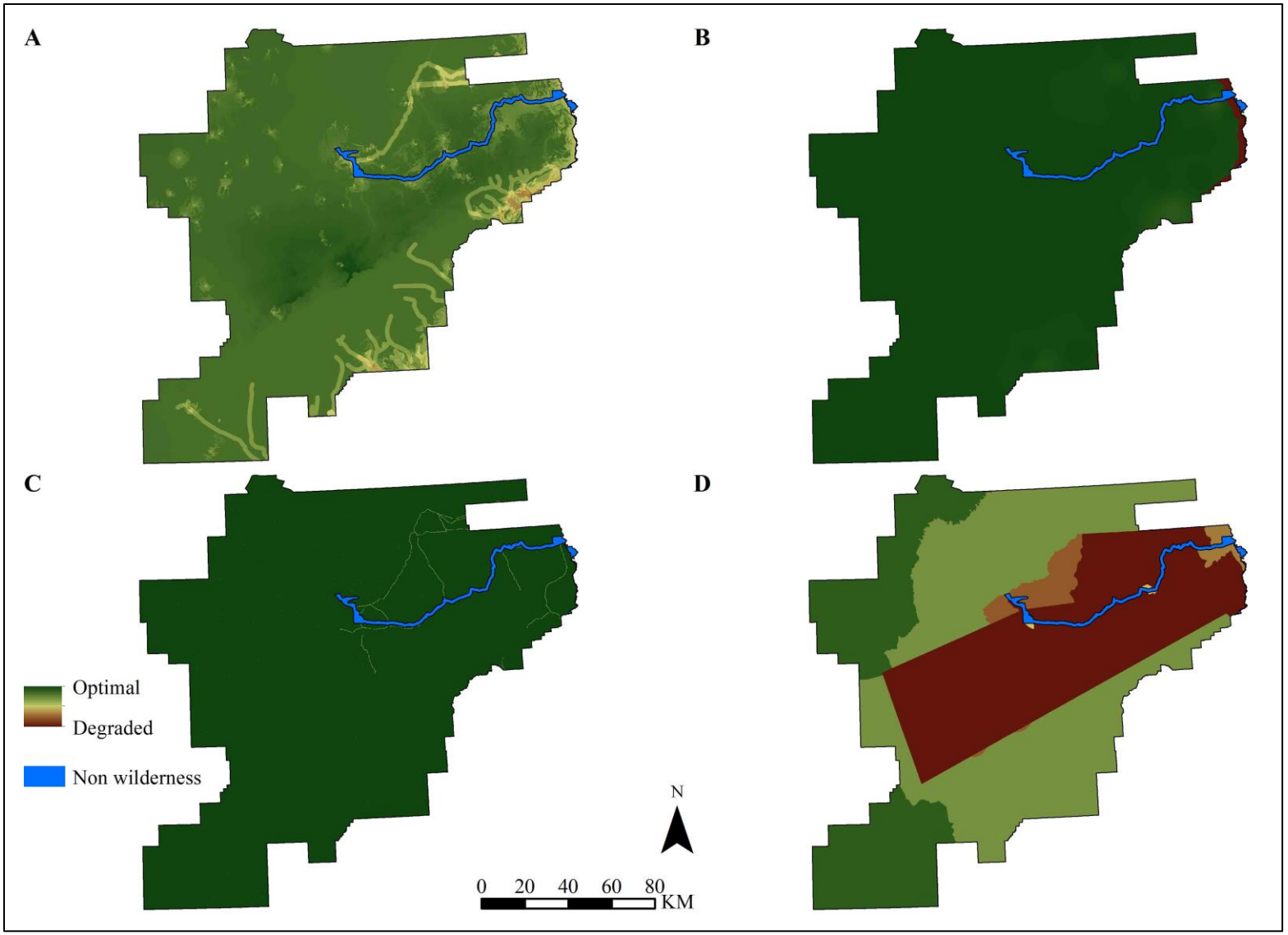

Figure 15. Winter indicator maps for (A) remoteness from sights and sounds of people inside the wilderness, (B) remoteness from occupied and modified areas outside the wilderness, (C) facilities that decrease self-reliant recreation, and (D) management restrictions on visitor behavior. Green depicts optimal quality and brown depicts degraded quality.

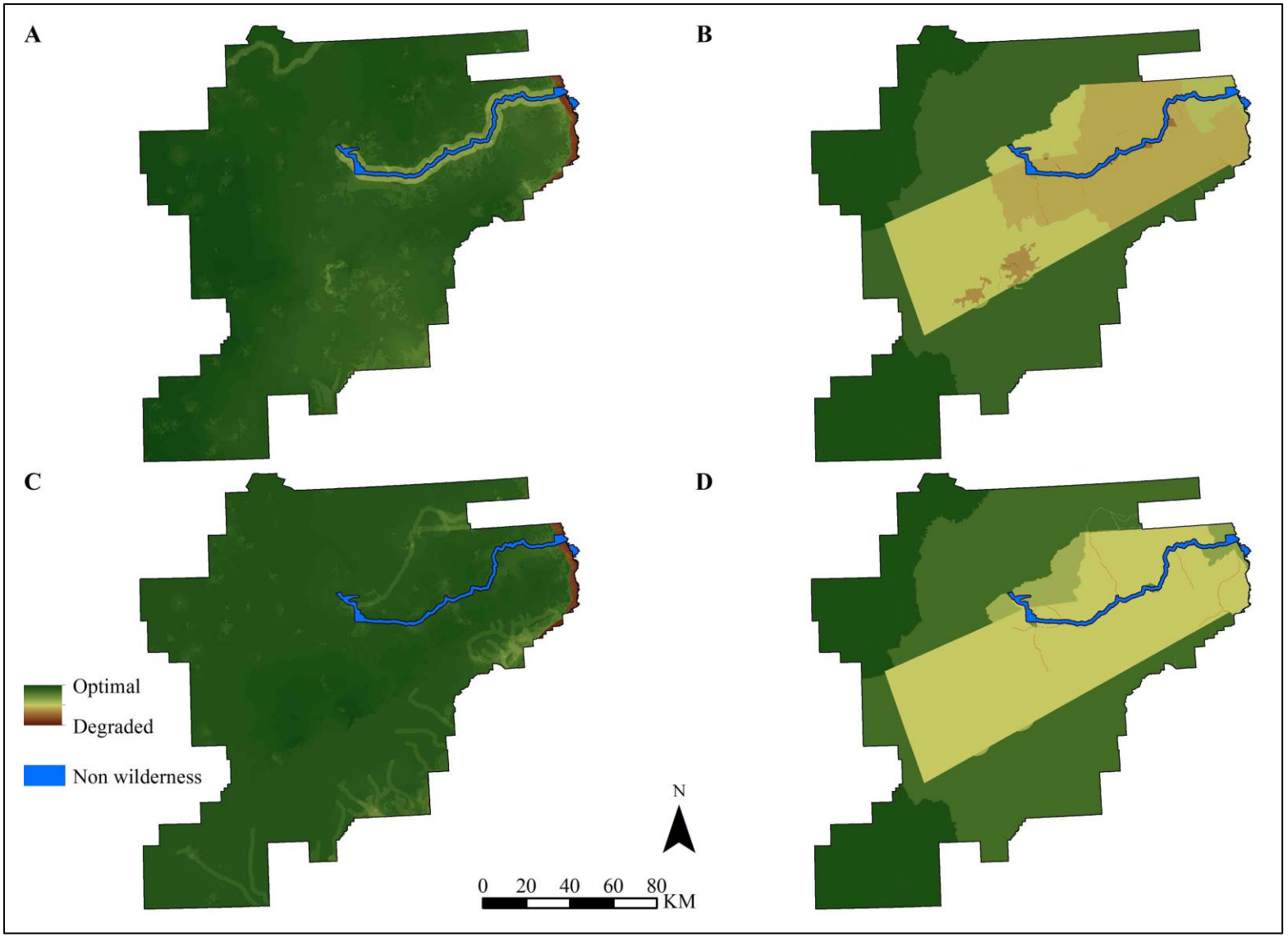

Figure 16. Combined indicator maps for (A) opportunities for solitude inside wilderness in summer, (B) opportunities for primitive and unconfined recreation inside wilderness in summer, (C) opportunities for solitude inside wilderness in winter, and (D) opportunities for primitive and unconfined recreation inside wilderness in winter. Green depicts optimal quality and brown depicts degraded quality.

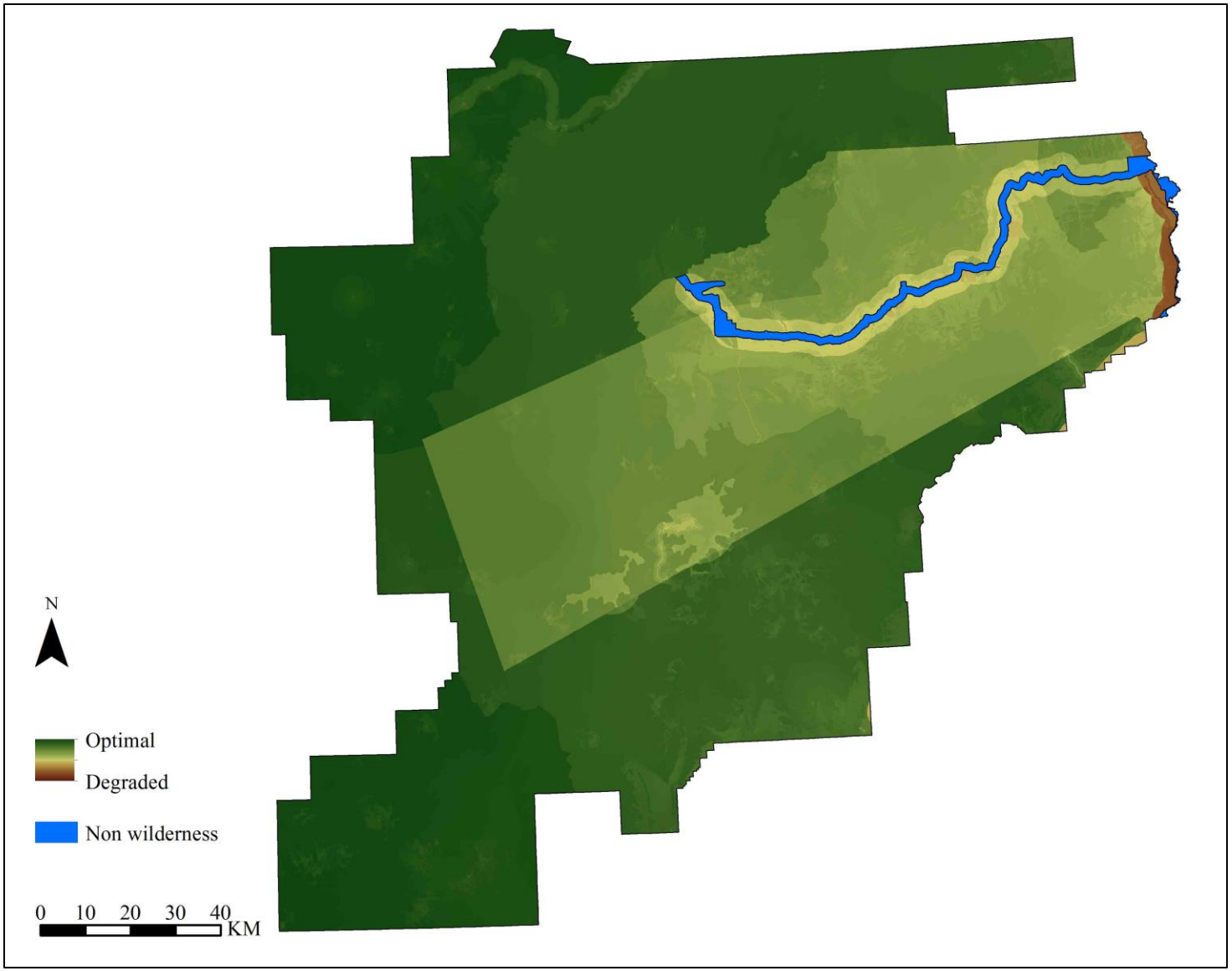

Figure 17. Solitude or primitive and unconfined quality of wilderness character in summer. Green depicts optimal quality and brown depicts degraded quality.

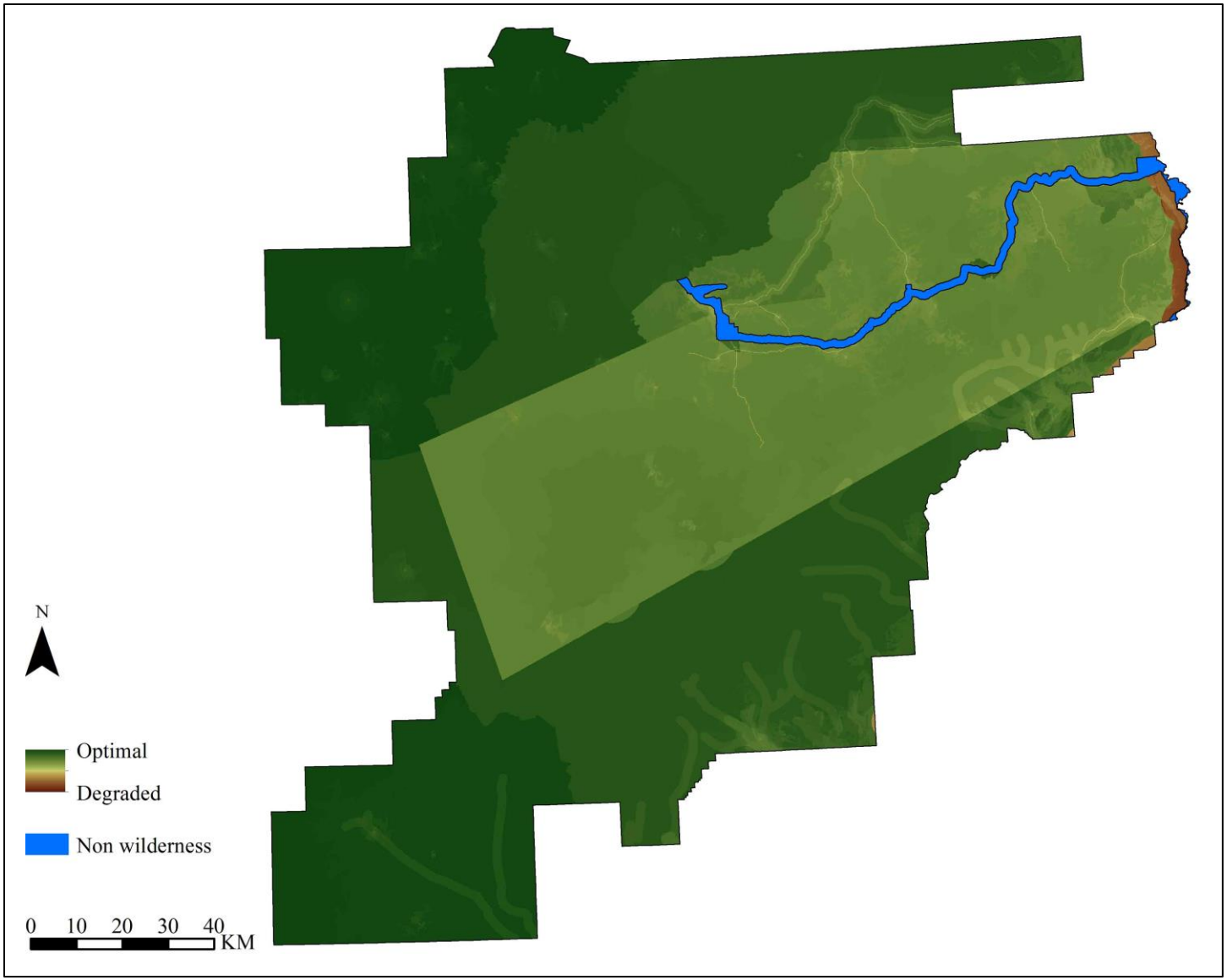

Figure 18. Solitude or primitive and unconfined quality of wilderness character in winter. Green depicts optimal quality and brown depicts degraded quality.

Other Features of Value

Unlike the preceding four qualities that apply to every wilderness, this fifth quality has unique measures for an individual wilderness based on the features that are inside that wilderness. These features typically occur only in specific locations within a wilderness and include cultural resources, historical sites, paleontological sites, or any feature not in one of the other four qualities that has scientific, educational, scenic, or historical value (Landres et al. 2012). Loss or impacts to such features degrade this quality of wilderness character.

Indicators and Measures

Measures were selected for the indicators recommended in Keeping It Wild in the National Park Service (Landres et al. 2014). The following indicators, with measures as their relevance to other features, are used:

Indicator: Deterioration or loss of cultural resources integral to wilderness character.

- Unauthorized actions that result in disturbances to cultural resources (looting, trespass activities, non-compliance with National Historic Preservation Act) – certain cultural resources have scientific, educational, scenic, and/or historical value. Deterioration or loss to these features is considered a degradation of wilderness character.
- Authorized actions that result in disturbances to cultural resources (visitor and commercial use such as catholes, trampling, hearths, aircraft landings, etc.); findings of adverse effect for projects and operations) – certain cultural resources have scientific, educational, scenic, and/or historical value. Deterioration or loss to these features is considered a degradation of wilderness character. Authorized actions are weighted less because they are often done knowingly with mitigations.

Indicator: Deterioration or loss of paleontological resources integral to wilderness character.

- Unauthorized collection of paleontological resources – paleontological resources in the DENA Wilderness have scientific, educational, and scenic value. Deterioration or loss to these features is considered a degradation of wilderness character.
- Authorized collection of paleontological resources – paleontological resources in the DENA Wilderness have scientific, educational, and scenic value. Deterioration or loss to these features is considered a degradation of wilderness character. Authorized actions are weighted less because they are often done knowingly with mitigations. Removal of fossils is done for scientific and educational purposes.

Data Sources, Processing and Cautions

The other features quality datasets are all vector data, of mostly high spatial resolution, and have varying levels of accuracy and completeness (Table 12).

Table 12. Other features quality datasets.

Measures	Source	Type	Scale/ Resolution	Accuracy	Completeness
Authorized actions that result in disturbances to cultural resources	CulturalSiteDisturbances	Point	111m	Medium	Medium
Unauthorized actions that result in disturbances to cultural resources	CulturalSiteDisturbances	Point	111m	Medium	Low
Authorized collection of paleontological resources	Paleo_auth_collected	Point	30m	High	High
Unauthorized collection of paleontological resources	N/A	N/A	N/A	N/A	N/A

Authorized actions that result in disturbances to cultural resources

- Sources: CulturalSiteDisturbances point dataset
- Processing: Locations were ranked 1–5 based on level of threat or disturbance. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Very few cultural sites are known, and have not been surveyed for over much of the area, for example as of 2012 less than 1% of the park had been surveyed for archeological resources.

Unauthorized actions that result in disturbances to cultural resources

- Sources: CulturalSiteDisturbances point dataset
- Processing: Locations were ranked 1–5 based on level of threat or disturbance. Layer was converted to raster and values were normalized to 0–255.
- Cautions: Knowledge of cultural sites across the park is very limited thus disturbances can easily go undetected.

Authorized collection of paleontological resources

- Sources: Paleo_auth_collected point dataset
- Processing: Locations where authorized paleontological collecting has occurred were given a value of 1. Layer was converted to raster and values were normalized to 0–255.
- Cautions: None

Unauthorized collection of paleontological resources

- Sources: DATA GAP
- Processing: N/A

- Cautions: No incidents have been recorded but it is likely there have been some unauthorized collections.

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 13). The "weighted" measures under each indicator total 100. Although data for unauthorized collection of paleontological resources are unavailable; this "missing" measure is still assigned a weight. In the future, should the data improve or become available, this measure can be added to a rerun of the wilderness character map. The revised weights for the indicator with missing data are recorded in brackets in Table 13.

Table 13. Indicators and measures for the other features quality with weights and rationale

Indicator	Measure	Weight	Rationale
Deterioration or loss of cultural resources integral to wilderness character	Authorized actions that result in disturbances to cultural resources	40	When an action is authorized to disturb a resource then its importance is not lost and may be magnified. Such actions are done carefully, with purpose, and documented.
	Unauthorized actions that result in disturbances to cultural resources	60	This has a higher weight because unauthorized actions result in a loss of the knowledge of importance and other benefits of the resource.
Deterioration or loss of paleontological resources integral to wilderness character	Authorized collection of paleontological resources	100 (40)	When an action is authorized to disturb a resource then its importance is not lost and may be magnified. Such actions are done carefully, with purpose, and documented.
	Unauthorized collection of paleontological resources	Data gap (60)	This has a higher weight because unauthorized actions result in a loss of the knowledge of importance and other benefits of the resource. There likely have been unauthorized collections, but none are known.
	Total	**200**	

Maps

The weighted measures for each indicator are added together using a raster calculator to create separate maps for deterioration or loss of cultural resources and deterioration or loss of paleontological resources (Figure 19). After these indicator maps are created, the raster calculator is used to add the two indicator maps together to create the other features quality map (Figure 20).

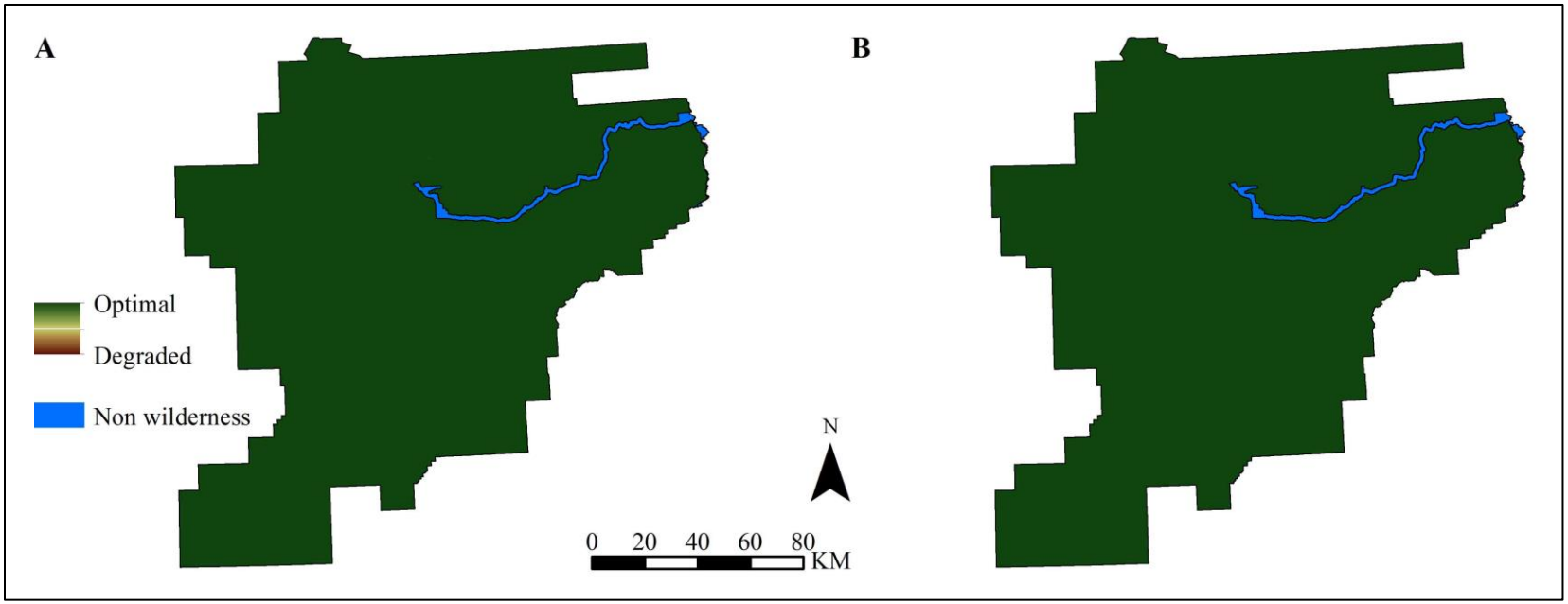

Figure 19. Indicator maps for (A) deterioration or loss of archeology integral to wilderness character, and (B) Deterioration or loss of constructed environments integral to wilderness character. Green depicts optimal quality and brown depicts degraded quality.

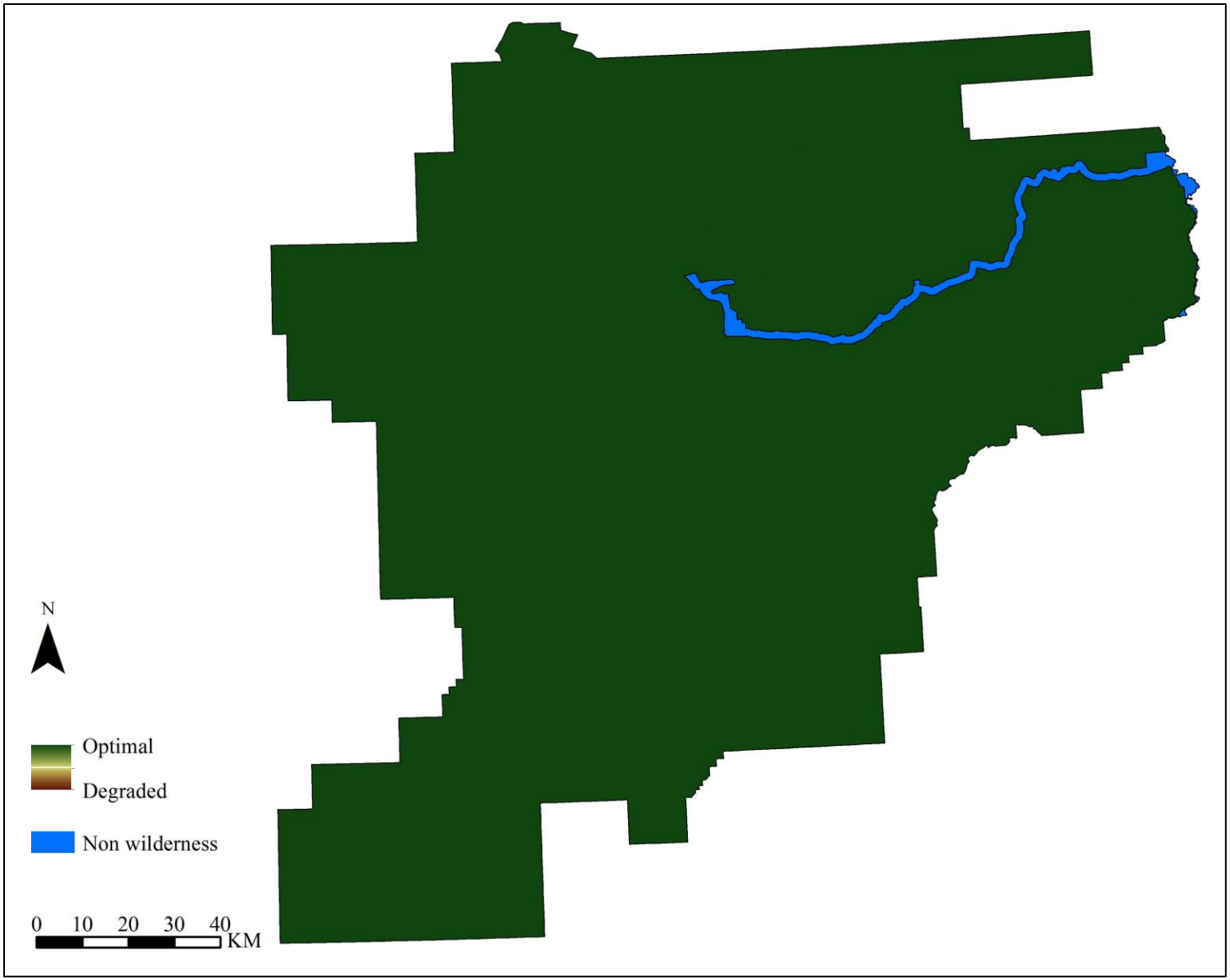

Figure 20. Other features quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.

The Wilderness Character Map

The methodology described produces five maps, one for each of the qualities of wilderness character as presented in the previous sections. These maps are then combined to produce a single map of overall wilderness character quality in DENA. Because all five qualities are equally important and none is held in higher or lower regard than the other, the five qualities are added together equally (Figure 21 & 22).

Interpreting and discussing these maps requires a clear understanding of the methods used and the many limitations when creating the map products. For example, it is noticeable that the natural and solitude maps are distinctly different in appearance to the untrammeled, undeveloped and other features 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. The maps represent a grid of values (approximately 2.4 million pixels at 100 m 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[20] of the wilderness character map was performed to assess the range of values of all the pixels into a scale of 1–100%. These percentages are then split into ten equal categories (i.e., 0–10%, 11–20%, 21–30%, and so on). All pixels, now allocated to one of the ten categories, identify the current status of wilderness character at DENA (Figure 23 & 24). For the summer map, pockets of the highest quality category (91–100%) are mostly found in the southwest preserve. (Interestingly, the majority of these pockets occur outside the designated wilderness, but they are the most remote.) The largest category in the summer map (81–90%) covers large swathes of the northern, western and southern parts of DENA (and comprises over 50% of the park and preserve). The six smallest categories occur mostly in the eastern border of the park (which is adjacent to the Parks highway and railway line) and along the park road.

For the winter map, the pockets of the highest quality category (91–100%) diminish slightly in the extreme southwest preserve when compared to the summer map. However, the next two categories (71–80% and 81–90%) cover almost 85% of DENA. The remaining 7 categories are mostly confined to the eastern border of DENA and along winter travel corridors (especially in the south of the park).

The differences between the summer and winter maps are due to the changes in the seasonal solitude maps. The impacts of measures such as viewshed, soundscape, visitor restrictions and encounters are greatly reduced from summer to winter – particularly in the designated wilderness. However, winter also results in greater and easier access to the interior of the park, and the amount of private

[20] 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)

motorized use increases. The overall trend for DENA between the seasons is the designated wilderness sees the most visitor use and subsequent impacts through the summer months; whereas the winter months see a noticeably reduced focus on impacts to the wilderness as visitor use becomes more spread out through the wilderness, park and preserve lands. As the park and preserve lands constitute twice the size of the designated wilderness, the winter histogram indicates that impacts to wilderness character have a wider impact to the whole of the park than in the summer months (where the majority of impacts tend to occur in the designated wilderness). Looking at the histograms of the distribution of pixel values for the summer and winter maps (Figure 25), it is clear that the majority of DENA has mostly high quality wilderness character.

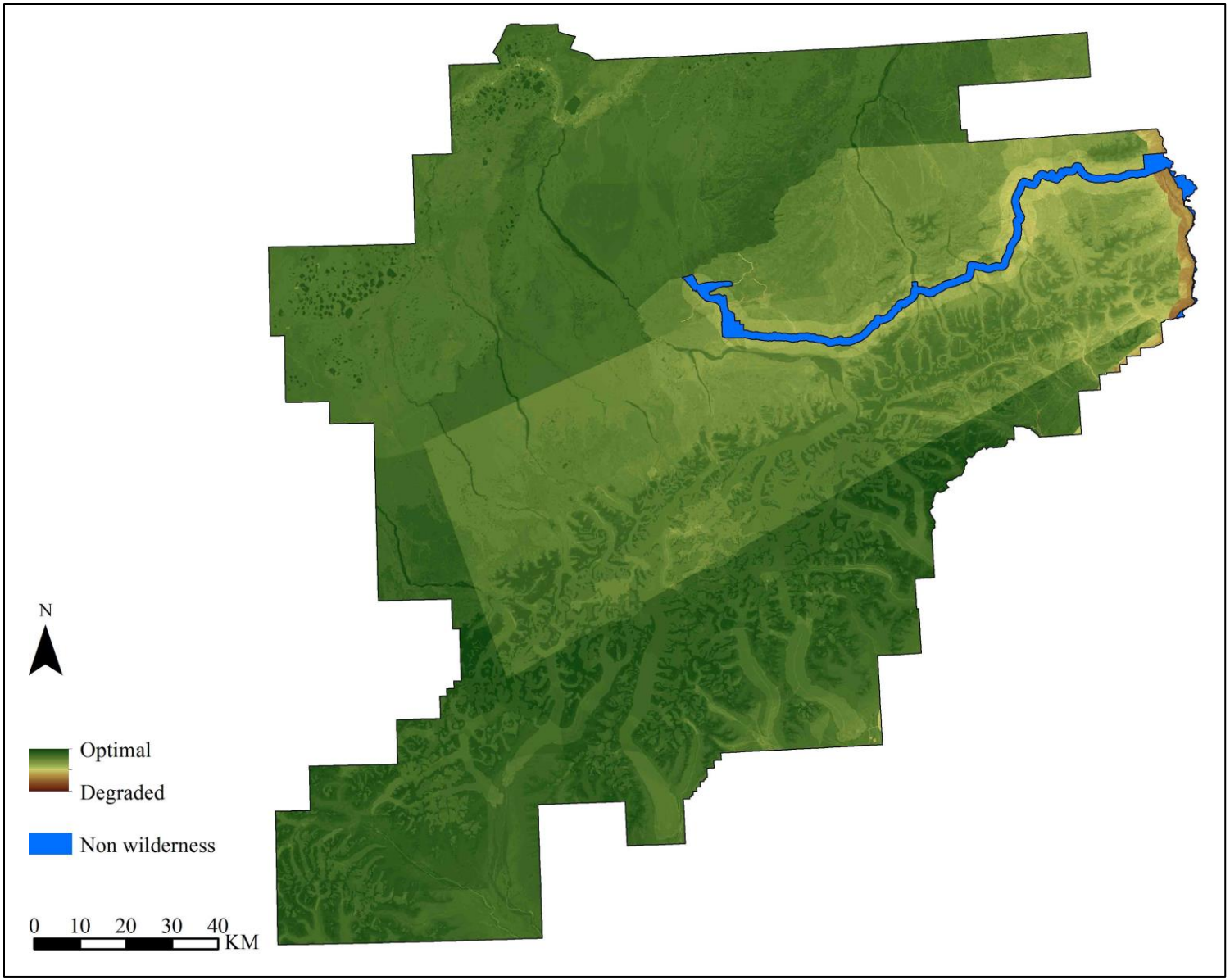

Figure 21. Summer map of wilderness character in DENA. Green depicts optimal quality and brown depicts degraded quality.

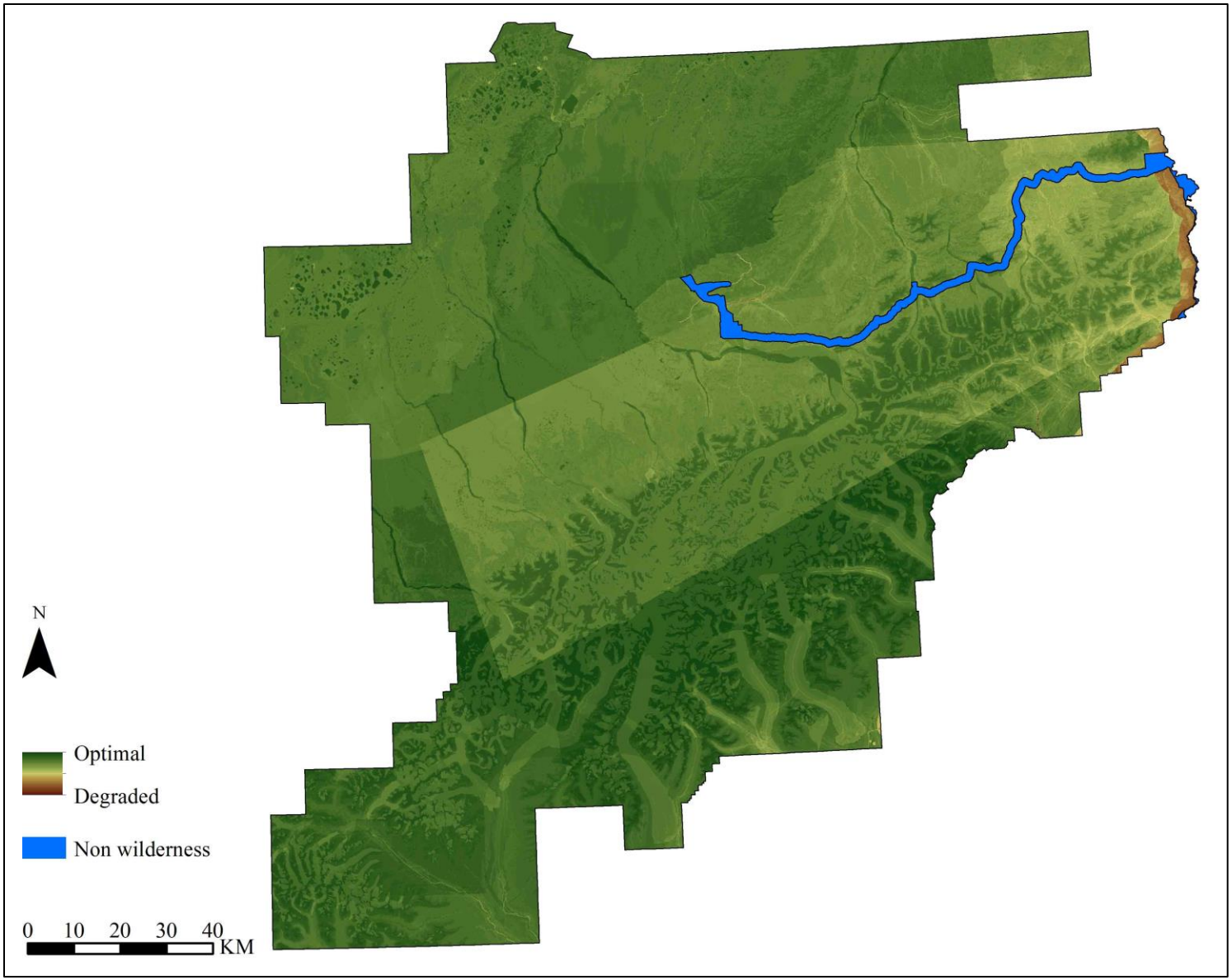

Figure 22. Winter map of wilderness character in DENA. Green depicts optimal quality and brown depicts degraded quality.

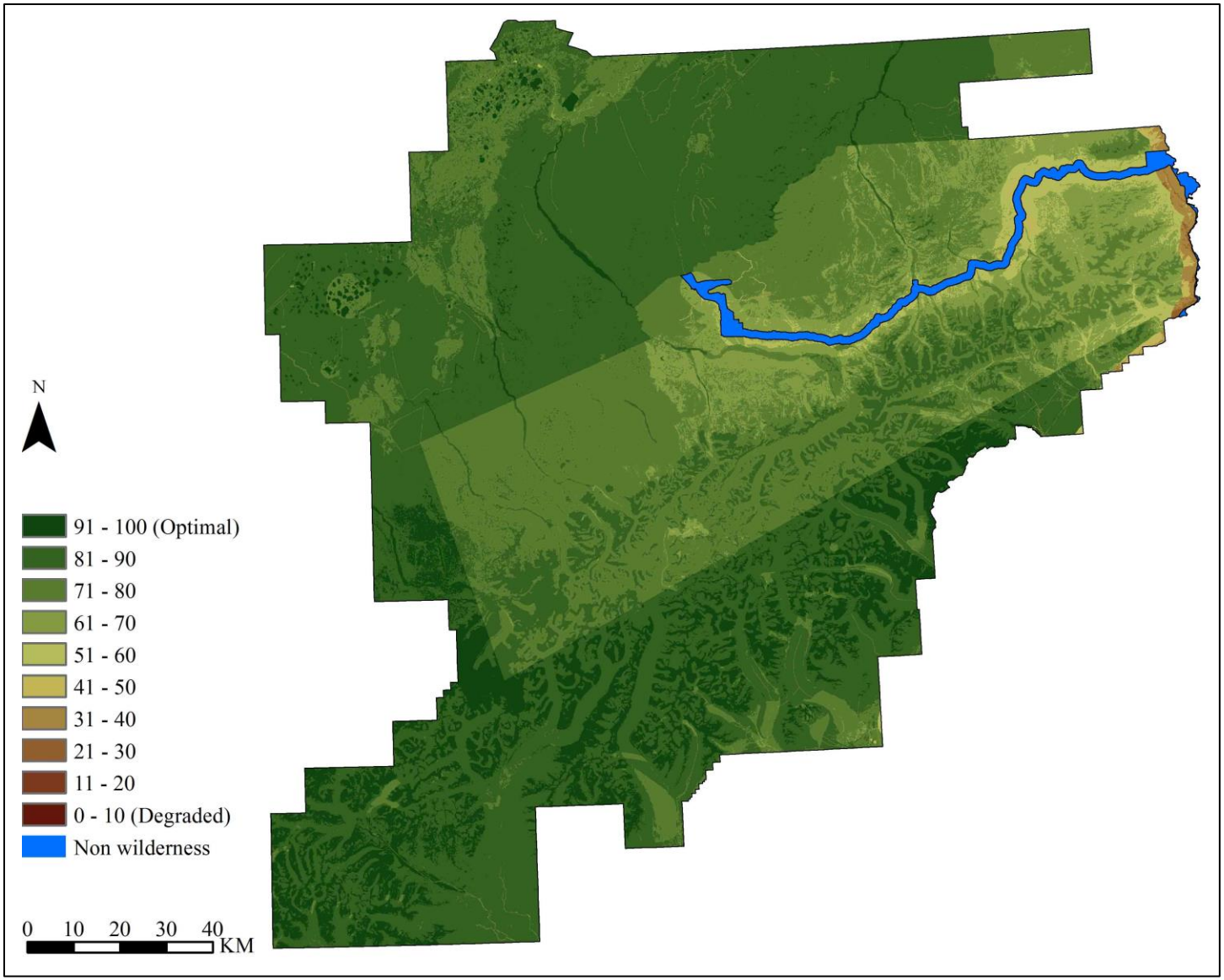

Figure 23. Summer map of wilderness character in DENA reclassified into ten equal categories. Green depicts optimal quality and brown depicts degraded quality.

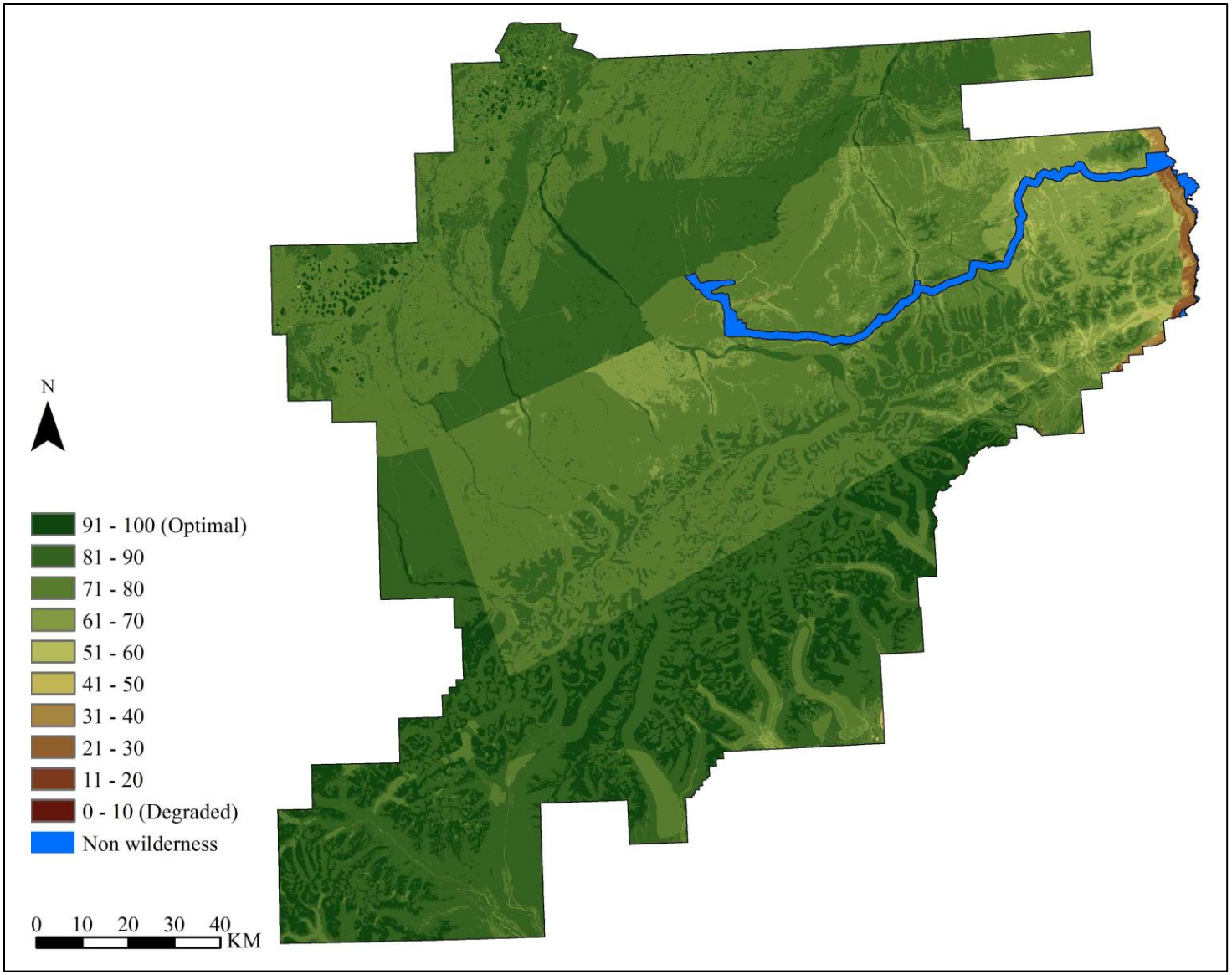

Figure 24. Winter map of wilderness character in DENA reclassified into ten equal categories. Green depicts optimal quality and brown depicts degraded quality.

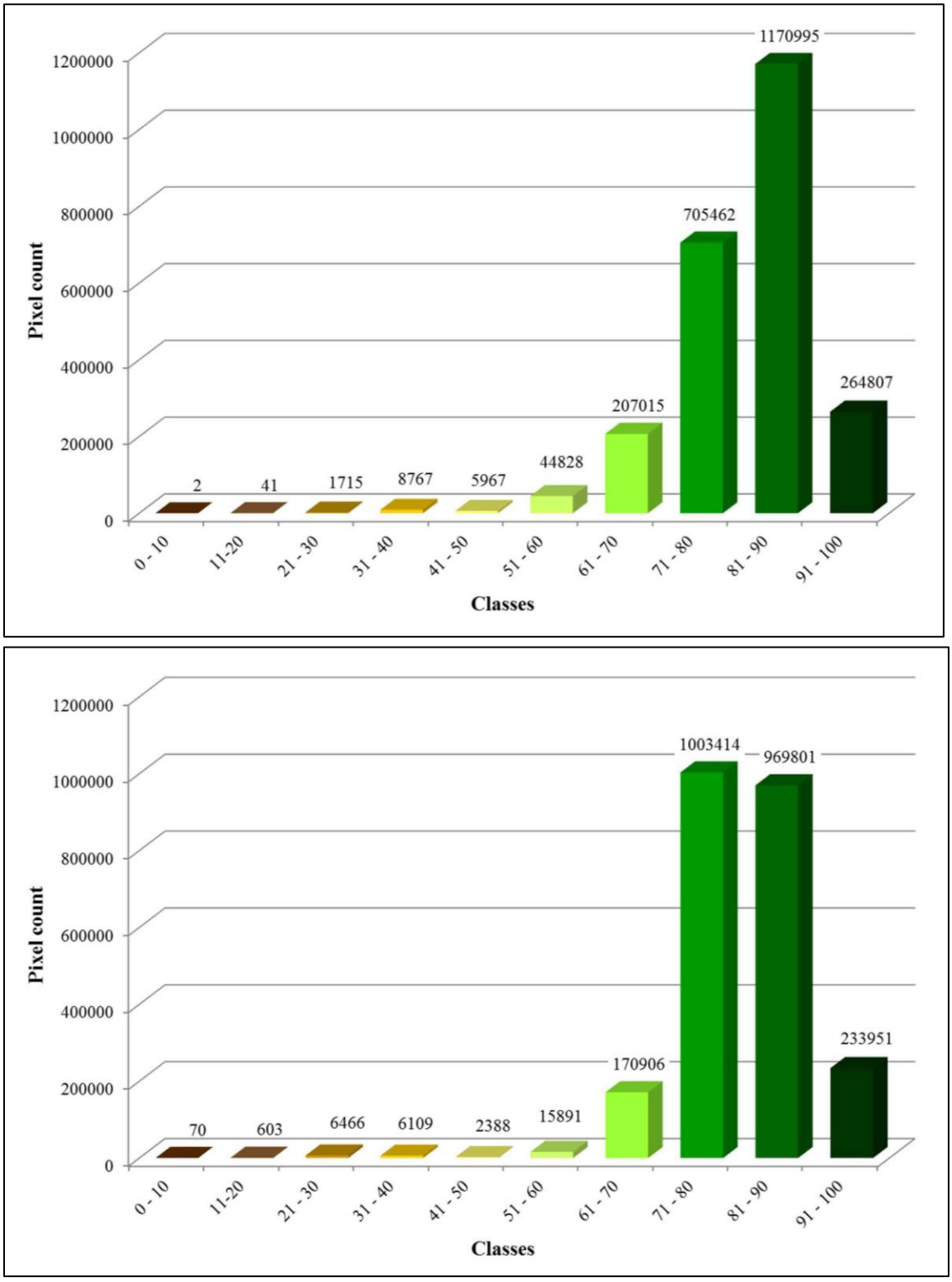

Figure 25. Histograms of the wilderness character map values for summer (top) and winter (bottom).

Improvements

The map products presented in this document could be improved in a number of 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, future versions of the maps will improve. Again, the availability of improved land cover maps and a higher resolution Digital Surface Model would increase the accuracy and effectiveness of the travel time and viewshed models.

The NPS Alaska Region's spatial data server, Theme Manager, was helpful in providing data and metadata for the wilderness character map. This includes park-specific data such as administrative facilities, vegetation, and management areas layers, as well as region-wide layers including topography, hydrography, boundaries, etc. Denali has several additional databases that incorporate spatial information. However, it also identified the need to organize other data in a more structured format. For example, data from observations made by backcountry rangers were moved into a Microsoft Access database that also stores and associates waypoint and tracklog data to patrol observations.

Data management can be further improved by creating awareness and promoting training among new park staff to correctly record observations and spatial information gathered in the field. Park staff with wilderness experience, but who do not enter field observations into databases themselves should continue to be encouraged to meet regularly with a GIS specialist to transfer their knowledge into spatial datasets. Field staff should 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.

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, DENA should continue to improve communication with external and NPS researchers. For example by promoting and regularly updating NPS Alaska Region's Science in Wilderness installations database. It is important to develop and maintain agreements and lines of communication between projects, teams, units, etc. that address reliability and precision in data collection and storage.

With optimal interaction between park staff and researchers, and between park staff of different work groups and disciplines, the accuracy and extent of information in databases and available to park management can be improved resulting in more effective and efficient stewardship of DENAs wilderness character.

A risk in the approach of mapping degradation is to become overly focused on impacts to wilderness character and let impacts overshadow summarizing and promoting the benefits and value added features of wilderness. DENA staff grappled with and deferred to include "positive features" into the mapping scheme for the reasons of incompatibility with the current mathematical construct of the map. This was the same decision of Sequoia and Kings Canyon National Parks staff for their wilderness character map (Tricker et al. 2014).

One approach to promote positive features independent of the wilderness character map would be to create outreach products, a spatially explicit example is a story map (e.g., ESRI 2015) that shows areas in which an active effort was made to improve long-term wilderness character, such as trash clean-up projects or habitat restoration. A similar approach could be used for mapping benefits, such as the route that an educational group hiked to learn about and discuss the wilderness or the protected habitat provided for threatened/endangered species. Such maps would be qualitative ways to focus on value added to and/or the benefits of wilderness character.

Conclusion and Final Concerns about Mapping Wilderness Character

The purpose of this project was to develop an approach that spatially depicts the condition of DENA's wilderness character qualities and how they vary across Denali's Backcountry. 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). The maps:

- Shows the current the condition of each of the five qualities of wilderness character, both singularly and in aggregate and how it varies across the ~6 million acres of designated and eligible wilderness of Denali National Park and Preserve.
- 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. Similarly, this map can be used in the future to analyze the effects of site-specific projects on wilderness character.
- Allow park staff to evaluate existing backcountry spatial data and consider whether new or better data would be needed for future planning and analyses of effects 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.

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.

Use of the final maps (wilderness character, quality, indicator, or measure) for decision making should be done carefully. Tulloch et al. (2015) discuss the benefits of using threat maps as part of a structured decision making (SDM) process. In a SDM the objective is to maximize outcomes for the focal problem and other related issues (there are often multiple competing objectives related to social, political, economic, conservation, and preservation outcomes). The danger lies in having the single objective of reducing or avoiding threats, regardless of whether actions taken would have any effect, which could waste time, funding, and/or resources or have perverse outcomes. Within the NPS there are SDM processes that a wilderness character map could be integrated into such as Value Analysis and NEPA document processes (e.g., environmental impact statements). However, to increase the utility of the wilderness character map an interactive interface needs to be developed so that the effects of different action alternatives can be evaluated quickly and easily.

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Appendix A. Travel impedance for land cover classes

Summer travel speeds:

Table A-1. Summer travel speeds are modeled to vary by land cover type. The impedance column provides walking speeds (in kilometers per hour) for each land cover type, according to their perceived impedance when 'walking' through the landscape. The land cover classes correspond to those in in the NPS DENA landcover GIS layer.

Land cover class	Impedance (km/hr)
Dense-Open Spruce	2.4
Open-Woodland Spruce	2.4
Stunted Spruce	1.6
Broadleaf	2.8
Spruce-Broadleaf	2.4
Alder	0.4
Willow	0.8
Closed Low Shrub Birch	1.6
Low Shrub Birch-Ericaceous-Willow	0.8
Low Shrub-Sedge	0.8
Peatland	0.8
Herbaceous-Shrub	0.4
Dwarf Shrub	2.0
Dwarf Shrub-Rock	3.2
Dry-Mesic Herbaceous	3.2
Wet Herbaceous	0.4
Aquatic Herbaceous	0.4
Sparse Vegetation	3.2
Bare Ground	2.4
Snow-Ice	1.6
Shadow-Indeterminate	1.6
Silty Water	0.4
Clear Water	0.4
Burn	0.4

Winter travel speeds:

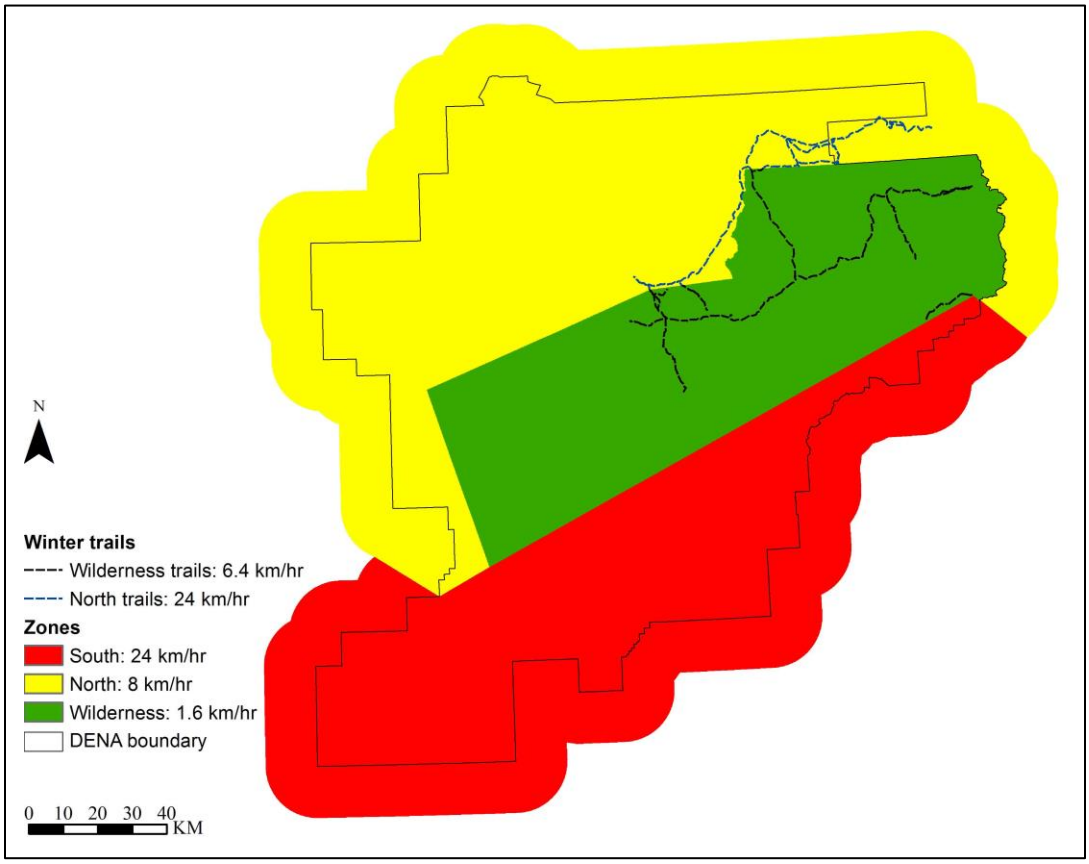

Figure A-1. Travel speeds in winter based on common modes of transportation used. The north zone is set to 8 km/hr, as the majority of visitors will either mush or use snowmobiles. Winter trails[21] in this zone are set to 24 km/hr, which is the fastest average speed snowmobile users are likely to travel. The wilderness zone is set to 1.6 km/hr as no motorized transport is allowed. Winter trails in this zone are set to 6.4 km/hr, which is the fastest average speed dog mushers can travel. Finally, the south zone is set to 24 km/hr as the majority of visitors will be on snowmobiles. There are no winter trails in this zone. Outside the park, the areas adjacent to the north and wilderness zones are set to 8 km/hr and the area adjacent to the south zone are set to 24 km/hr.

[21] Winter trails are created by park staff and the public to facilitate quicker travel by avoiding time consuming obstacles such as unpacked snow, steep slopes, vegetation protruding above the snow, sharp corners, etc. Winter trails created by park staff are demarcated with temporary marked poles in some places.

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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