Mapping Wilderness Character in Olympic National Park

Final Report

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EXECUTIVE SUMMARY

The recent development of an interagency strategy to monitor wilderness character allows on-the-ground managers and decision-makers to assess whether stewardship actions for an individual wilderness are fulfilling the mandate to "preserve wilderness character." By using credible data that are consistently collected, one can assess how wilderness character changes over time and evaluate how stewardship actions affect trends in wilderness character. As most of these data depict spatial features in wilderness, a GIS-based approach was developed to identify the state of wilderness character for the Olympic Wilderness in Olympic National Park (OLYM).

A set of indicators and measures were identified by OLYM staff to capture the impacts to the five qualities of wilderness character. These measures were derived from a variety of spatial datasets and were formatted onto a common relative scale. Each measure was "weighted" by OLYM 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 wilderness character map for OLYM.

The wilderness character map delineates the range in quality of wilderness character in the Olympic Wilderness. A histogram of the map reveals that the majority of wilderness character in OLYM is of high quality. The map will serve as a baseline for wilderness character quality in OLYM, in which future reruns of the map with updated datasets will allow for identifying areas where wilderness character is changing over time. In addition, the map is intended to be used by OLYM staff to evaluate the spatial impacts of the different planning alternatives during the development of the OLYM Wilderness Stewardship Plan.

ACKNOWLEDGEMENTS

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We also greatly appreciate the willingness of the following people to share their time and expertise to help develop the wilderness character map: M. Barna (NPS Air Resources Division), J. Vaughan (Washington State University), D. Mennitt and K. Fristrup (NPS Natural Sounds and Night Skies Division), K. Sherrill (NPS I&M Program), K. Hutten (University of Washington), S. Carver and J. Washtell (University of Leeds), C. Copass (OLYM Botanist and Pacific West Region Vegetation Mapping Coordinator), B. Baccus (OLYM Physical Scientist), L. Lack (OLYM Trails Foreman), B. Hertel (OLYM Trails), M. Tetreau (OLYM Wilderness Resources, Data Manager), B. Micha (OLYM Wilderness Resources), T. Rankin (OLYM Fire/Fuels Management), P. Happe (OLYM Wildlife Biologist), S. Gremel (Pacific West Region Wildlife Biologist – Northern Spotted Owls).

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INTRODUCTION

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

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

The Olympic Wilderness was established November 16, 1988 when President Ronald Reagan signed the Washington Park Wilderness Act. A total of 876,447 acres or 95% of Olympic National Park (OLYM) was designated as wilderness and became a part of the National Wilderness Preservation System, wherein wilderness character would be preserved. The purpose of this project was to develop an approach that spatially depicts the condition of Olympic's wilderness character qualities and how they vary across the Olympic Wilderness (Figure 1). This map of wilderness character will:

- Show the current overall condition of wilderness character and how it varies across the 876,447 acres of the Olympic Wilderness.
- Allow analysis of different planning alternatives being considered in the OLYM Wilderness Stewardship Plan and their effects on wilderness character by varying different factors that affect the map. Similarly, this map could be used for project planning to analyze the effects of proposed actions on wilderness character.
- Provide a baseline from which future monitoring could show the trend in wilderness character over time.
- Allow park staff to evaluate existing park spatial data and consider whether new or better data would be needed for future planning and analyses of effects on wilderness character.
- Help park staff and the public understand the idea of wilderness character.

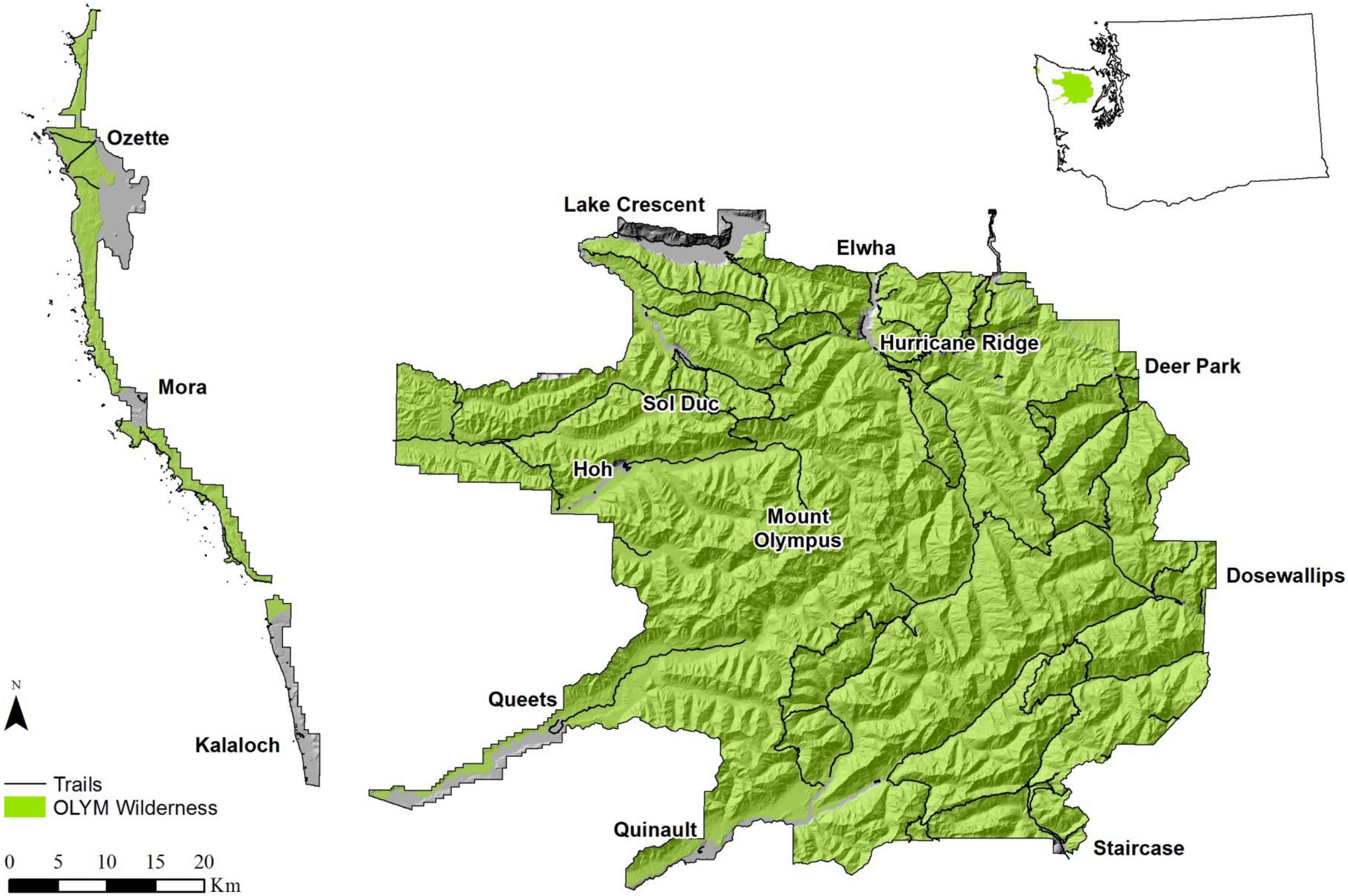

Figure 1. Olympic National Park.

In addition to the five 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. The map would also help identify specific areas outside the wilderness where actions taken there might pose a substantial risk of degrading wilderness character inside wilderness.

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

- *Creating sacrifice zones* - the map may facilitate inappropriate creation of "sacrifice zones" within the wilderness, directly contravening Congressional and agency mandates to preserve wilderness character across an entire wilderness. For example, if the map shows that some areas are "better" or of "higher quality" than others, the tendency may be to focus efforts on preserving wilderness character only in these specific areas while allowing wilderness character to degrade in "lower quality" areas. By showing the current condition of wilderness character and how it varies across the entire wilderness, the intent of the map is to help staff maintain high quality areas while raising the quality of wilderness character in other areas.
- *Comparing the condition of wilderness character between wildernesses* - the map may facilitate inappropriate comparison of wilderness character among different wildernesses, as this approach is being repeated for other wilderness areas. The maps will show the current status or trend of wilderness character in different colors, and it will be easy for users to compare the quantity of a given color among different wildernesses. Comparing these maps among different wildernesses, however, is neither valid nor appropriate because each map is built with data from the unique context of a particular wilderness.
- *Assuming that the resulting maps accurately and precisely describe wilderness character* - the variety of map products can be misconstrued as an accurate and precise description of wilderness character. These maps are instead only an estimate of selected aspects of wilderness character for which spatial data were available for this particular wilderness. Map products are therefore a representation of wilderness character. In addition, these maps do not portray in any way the symbolic, intangible, spiritual, or experiential values of wilderness character. In short, while these maps are useful for the purposes described in this report, they do not describe the complexity, richness, or depth of wilderness character.
- *Comparing wilderness character map products over time may be difficult* – the map is a product of the spatial datasets that are available the time the map is created. Future datasets may be more effective in representing impacts to wilderness character but the resulting map products may not then be comparable to the current map. In addition, the rationale for assigning degradation values to measures may change over time. The rationale used in making decisions for the current map is based on the working group's experience and understanding of a specific impact. This experience and understanding will change over time, especially because of staff turnover, potentially affecting the rationale used in making these decisions.

A team approach was used to develop the wilderness character map for the Olympic Wilderness, tapping the experience and knowledge of the staff that work at the park. Together, this team has approximately 92 person-years of on-the-ground experience in the Olympic Wilderness. The team conducted two face-to-face meetings and had several phone and email conversations in developing the map products described in this report. All decisions about developing the map were made by team consensus.

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

- Overview of developing the wilderness character map – describes the conceptual foundation for how the map was developed.
- Methods – describes the measures used to represent the degradation of wilderness character, along with 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, and final concerns about the overall process.

OVERVIEW OF WILDERNESS CHARACTER MAP DEVELOPMENT

Our objective is to develop a GIS-based approach to spatially depict the quality of wilderness character in the Olympic Wilderness[1]. The interagency strategy for monitoring wilderness character, as described in *Keeping it Wild* (Landres et al. 2008), is used as the basis for developing this approach. This document identifies four qualities of wilderness character that apply uniquely to every wilderness: natural, untrammeled, undeveloped, and opportunities for solitude or a primitive and unconfined type of recreation, as well as a set of indicators[2] and measures[3] to evaluate their condition. In addition to these four qualities, a fifth quality is used, called other features of value, based on the last clause of Section 2(c) 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)

Spatial datasets, which are obtained from a variety of sources, are processed into measures, i.e. raw data is converted into a standardized project-specific format, and assigned and weighted under an appropriate indicator. The indicators for each quality are combined together to produce a map for the condition of that quality, and the five maps, one for each quality, are in turn combined to create an overall map of the current condition of wilderness character in OLYM (Figure 2).

A total of 80 datasets[4] are used for delineating wilderness character in OLYM and comprise local, regional, and national spatial data at varying scales, accuracy, and completeness (as is often the case with geospatial datasets). This variation may reduce the integrity of the map products, however, initial dataset quality is identified and recorded, and as improved data become available these can replace older data. This procedure builds in flexibility and adaptability to differences for data quality and availability.

The datasets from the various sources are processed, converted to raster grids[5], and standardized[6] into measures. These represent features, conditions, and actions that degrade the quality of wilderness character. Maps of the OLYM wilderness begin from a baseline condition of optimal wilderness character and measures record where each quality has been degraded. For example, the exotic species measure records (under the plant and animal species and communities indicator) where the natural quality has been degraded. Each measure is formatted to depict the spatial extent of degradation on a standardized scale. Creating a standardized range of values for all measures allows them to be evaluated together on a common relative scale (Carver et al. 2008). For example, the soundscape and air quality maps are each depicted using different units of measure (decibel vs. parts per billion), and so cannot be directly compared without

[1] The analysis was run for the entire park, and the non-wilderness areas where clipped out of the final results.
[2] Indicators are distinct and important elements within each quality of wilderness character, which 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.
[4] This total is smaller than the sum of the data sources in Figure 2 because some datasets are used to map wilderness character for more than one quality.
[5] Raster data type consists of rows and columns of cells, with each cell storing a single value.
[6] Standardization of measures is achieved using a linear rescaling of the input values (slicing) onto a 0-255 scale on an equal interval basis

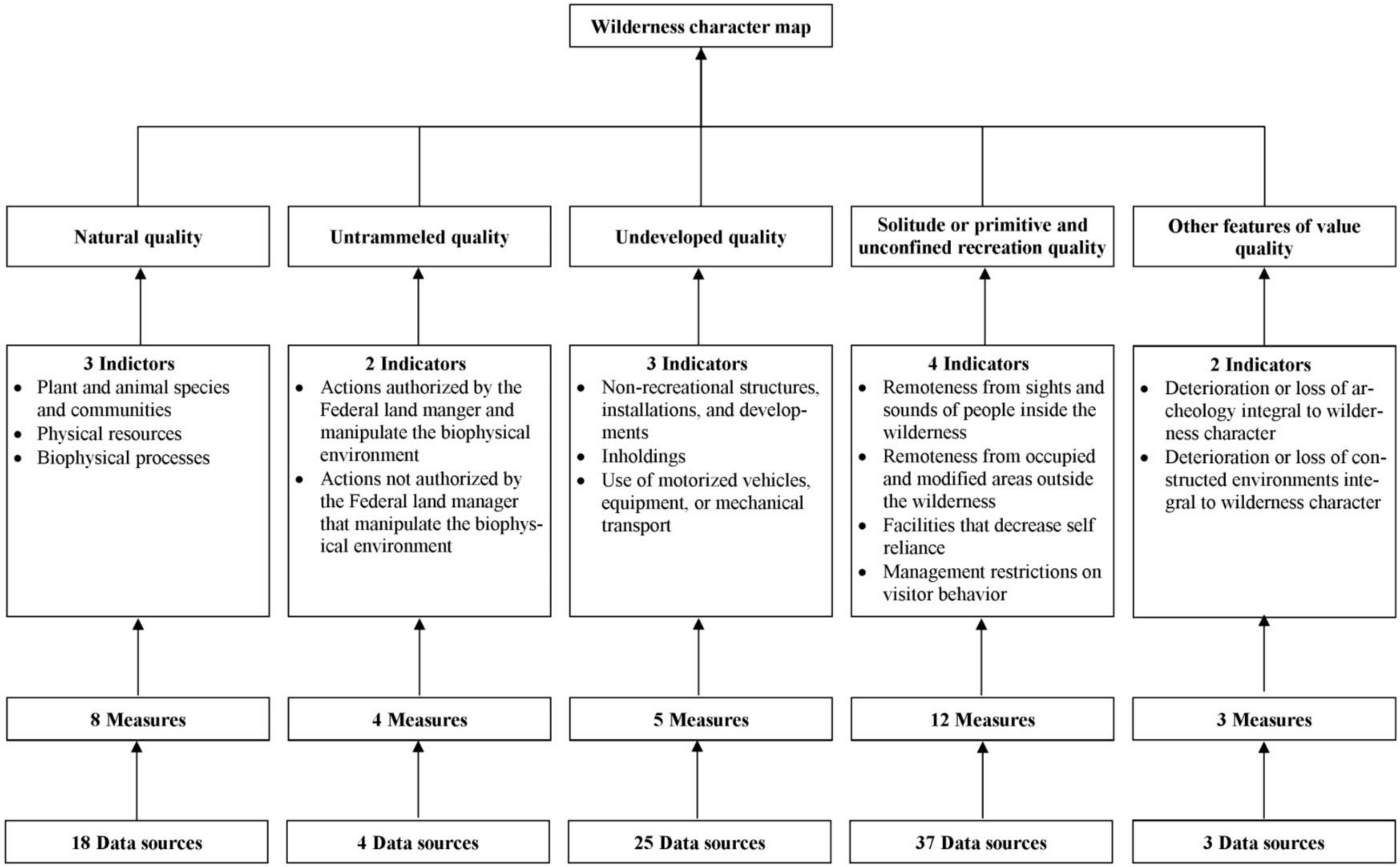

Figure 2. Flow chart for developing the wilderness character map.

standardization. Higher values of standardized measures represent “degraded” conditions and lower values represent “optimal” conditions (or in as good a condition as can be expected). Lastly, the standardized values of certain measures were adjusted based on OLYM staff input in order to acknowledge additional factors influencing the particular measure – these exceptions are described in the methods section.

The resolution of measures are set at 30 m, albeit some datasets such as air quality and soundscape have a significantly lower native resolution. Although using a 30 x 30 m pixel size may be deemed too coarse for many features in OLYM (e.g. trails, campsites), the sheer size of the OLYM wilderness means that choosing a lower resolution would make these features impossible to see when viewing the wilderness character maps in their entirety.

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

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

A number of cautions are presented for each measure in the methods section, which are necessary for creating and interpreting the wilderness character maps. These cautions describe and qualify the decisions made when formatting the datasets into measures and explain the calibration of the parameters for the travel time and viewshed models.

METHODS

The five qualities of wilderness character are mapped using a combination of available datasets and the latest GIS-based techniques. The maps are produced for all lands within the Olympic National Park boundary with additional buffer zones extending beyond the park boundaries to 15 and 30 km respectively for running the travel time and viewshed models. These buffer zones are necessary to account for edge effects[7] from visible human features and points of access immediately outside the park. The data sources, notes on processing, and associated cautions are described for all the measures that inform the five wilderness qualities. Notes for relevant technical GIS terms and processes are included as footnotes.

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

A number of basic processing tasks are performed for datasets in ArcGIS before they can be used as measures to create the wilderness character map. Values are assigned to the vector[8] datasets to represent their spatial impact in OLYM. These vectors are then converted to grids at 30 m resolution, whereby their extent is represented by the above values and the rest of the park, not represented by any vector datasets, is reclassed as 0. Some of the vector datasets may have a range of values depending on the data they represent. For example, the measure “trails” has a value of 1 for way trails, a value of 2 for primitive trails and a value of 3 for foot trails, secondary trails, all-purpose trails and nature trails (to represent their respective impact on the solitude and primitive and unconfined recreation quality), and the rest of the park is classed as 0. The raster datasets retain their native resolution and are clipped at the park boundary. All the grids are stretched to a standardized range of values and these measures are then projected in ArcGIS using the NAD 1983 UTM Zone 10N coordinate system. Unless stated otherwise, all point data, such as camp areas, were assumed to affect only the location of where those points occur.

Each measure is “weighted” (or assigned a percentage) out of a total of 100 for each indicator to reflect its importance in relation to other measures. For example, under the management restrictions indicator, only a small percentage of wilderness visitors will use pack animals (horses, mules, llamas, etc.). Therefore, the pack animal restrictions measure is assigned a weight that is lower than the other two restrictions that may to review the map outputs, modifying the weighting scheme as needed, and then rerunning and reviewing the maps until results are satisfactory. Weights were also provided for “missing” measures should they become available in the future. These weights, and their impact to existing measures weights, are indicated in

[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).
[8] Vector data type uses points and lines to represent features. Polygons are represented by boundaries.

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 or deteriorated areas of wilderness character as brown.

Natural Quality

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

<u>Indicators and measures</u>
Measures were selected for each of the three indicators recommended in *Keeping it Wild* (Landres et al. 2008). The following indicators, with their measures and relevance to the natural quality, were used:

Indicator: Plant and animal species and communities

- Exotic species – this is a direct measure of the degradation of the natural quality because the presence of these species is not natural to OLYM. Exotic species often displace native species, damage native habitats, and or introduce diseases that would otherwise not occur resulting in change to the natural environment.
- Loss of habitat from trampling – this is a direct measure of the degradation of the natural quality because presence of human caused bare ground contributes to loss of native plants, compacted soil, erosion, exposed roots and introduction of non-native plants resulting in a change to the natural environment. Presence of human caused trampling in tidal areas contributes to loss of key intertidal species resulting in degradation to the natural environment.
- Loss of range for iconic species – this is a direct measure of the degradation of the natural quality because loss of these native iconic species indicates changes in the natural system.
- Vacant habitat of extirpated species – this is a direct measure of the degradation of the natural quality because loss of these species affects the balance of the natural system.

Indicator: Physical resources

- Air quality – this is a direct measure of the degradation of the natural quality because polluted air has damaging effects on plants and animals thriving in the natural environment.
- Water quality – this is a direct measure of the degradation of the natural quality because polluted water has damaging effects on plants and animals thriving in the natural environment.

Indicator: Biophysical processes

- Glacial retreat – this is a direct measure of the degradation of the natural quality because loss of glaciers contributes to loss of water sources.

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

- Boundary connectivity – this is a direct measure of the degradation of the natural quality because of fragmentation or loss of connectivity between the wilderness and its surrounding habitat.

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 environment they exist in. These data sources are both vector and raster data and exhibit high variation in scale, mostly high levels of accuracy, and differing levels of completeness (Table 1). The following additional measures were considered but not included in the spatial map at this time due to inadequate data or because they were considered too site-specific or there were issues with seasonality: loss of prairie, intertidal acidification, mining sites, flow regime, snow pack, and fire regime.

Table 1. Natural quality datasets.

Measures	Source	Type	Scale	Accuracy	Completeness
Exotic species	Fish: OLYM (1) exotic_strm, (2) lakes	Polyline and Polygon	1:24,000	High	Medium
	Goats: OLYM MAa02_Polys_2011	Polygon	25m	High	Medium
	Pests: USDA Aerial Survey Detection Data 2006 – 2010	Polygon	1:100,000	High	Medium
	Plants: (1) EPMT_wilderness_pts (2) OLYM_survey_GeyserValley	Point	10m	High	Medium
Loss of habitat from human trampling	Intertidal trampling: OLYM intertidal_trampling	Polygon	10m	High	Med-high
	Human-caused bare ground: OLYM camp areas	Point	10m	High	Med-high
Loss of range for iconic species	Elk: OLYM elkdecline	Polygon	100m	High	High
	Marmot: OLYM marmots and marmots_polys	Point and polygon	25m	High	High
	Anadromous fish: DATAGAP		N/A	N/A	N/A
	Spotted owls: OLYM sp_ba_owl3	Raster	25m	High	High
Vacant habitat of extirpated species	Fisher: OLYM fisher_use	Raster	25m	High	High
	Wolves: OLYM wolf_habitat	Raster	25m	High	High
Air quality (contaminants)	University of Washington and Air Resources Division, NPS	Raster	12km	Medium	High
Water quality (high lakes survey)	OLYM Park_303d	Polygon	1:24,000	High	Low
Glacial retreat	OLYM glacier_loss	Polygon	1:24,000	High	High
Boundary connectivity	OLYM OLYMsheds	Polygon	1:24,000	High	Low

Exotic species – fish

- Sources: Exotic streams polyline dataset created by Roger Hoffman, OLYM GIS specialist, and OLYM lakes polygon dataset.
- Processing: Queried OLYM lakes dataset for presence of exotic fish. Locations of rivers and lakes with exotic fish are given a value of 1.
- Cautions: Without surveying all the rivers in OLYM, it is difficult to know exactly which rivers have exotics in them.

Exotic species – mountain goats

- Sources: MAa02_Polys_2011 polygon dataset
- Processing: The locations of goats in OLYM are ranked by density. The following values are assigned in relation to the density ranking: Low = 1, Medium = 2, High = 3.
- Cautions: None.

Exotic species – pests

- Sources: USDA Aerial Survey Detection Data. Used 2006 – 2010 datasets to capture full extent of pests in OLYM.
- Processing: Queried datasets for all records of Balsam wooly adelgid. Created a simple metric of severity. For branch infestation, values were assigned to the existing metric: Low = 1, Medium = 2, High = 3. The severity of bole infestation is recorded as number of trees killed per acre. The following ranges were used to assign values: 0 – 0.779 (Low) = 1, 0.779 – 1.579 (Medium) = 2, 1.579 + (High) = 3. Then converted the shapefiles to rasters and combined them using the MAX[10] function.
- Cautions: The survey methods for these datasets are prone to some subjectivity – see aerial survey detection methods for more details.

Exotic species - plants

- Sources: EPMT_wilderness_pts, OLYM_survey_GeyserValley
- Processing: Queried EPMT database for presence of exotics. Locations for all exotic plants occurring in OLYM are given a value of 1.
- Cautions: Most exotic plant species are known to occur outside the wilderness boundary. These areas are controlled to prevent exotic species from penetrating into the wilderness. Other than a number of former homesteads, there are few known locations where exotic species thrive within the wilderness. The park has not conducted a comprehensive parkwide survey to locate all areas containing exotic plants.

Exotic species layers added together and sliced to 0-255

Loss of habitat from human trampling – intertidal trampling

- Sources: OLYM polygon dataset
- Processing: Locations of intertidal trampling occurring in OLYM are given a value of 1.
- Cautions: None.

[10] Uses multiple input rasters to determine the maximum on a cell-by-cell basis (ESRI Inc. 2008)

Loss of habitat from trampling – human-caused bare ground

- Sources: OLYM Campareas point dataset
- Processing: Used 'SQ_FT_TL' attribute, which records amount of bare ground per camp site in square feet.
- Cautions: There are many social trails that haven't been captured - these should be considered a DATAGAP.

Loss of habitat from trampling layers added together and sliced to 0-255

Loss of range for iconic species – Roosevelt elk

- Sources: OLYM elk decline
- Processing: Locations of elk decline occurring in OLYM are given a value of 1.
- Cautions: None.

Loss of range for iconic species – Olympic marmot

- Sources: OLYM marmots and marmots_polys
- Processing: Joined marmots and marmots_polys datasets together using "Unit_Num' field. Queried all complete surveys for abandoned sites. Locations of abandoned sites in OLYM were given a value of 1.
- Cautions: None.

Loss of range for iconic species – anadromous fish

- Sources: DATAGAP - finding and assembling all available data on the historic ranges of salmonids and current barriers to salmonids for the park was beyond the scope of this project. This information could be used to show the reduction in range for salmon stocks if it were available. Such an analysis would provide a valuable input to the natural quality.
- Processing: None.
- Cautions: None.

Loss of range for iconic species – Northern spotted owls

- Sources: OLYM sp_ba_owl3 raster dataset. This grid represents lost habitat in low country from competing with barred owls on a scale of 1-5
- Processing: Inverted grid.
- Cautions: This dataset is a model of habitat occupancy and could be improved with better distribution data.

Loss of range for iconic species layers added together and sliced to 0-255

Vacant habitat of extirpated species – fisher

- Sources: OLYM fisher_use raster dataset. This grid has a range of values from 0 (no restoration) – 14 (complete restoration).
- Processing: Inverted the grid and removed NoData values. Because the status of fisher reintroduction ranges from excellent to satisfactory, it was decided not to stretch the values to 0-255. Instead, all standardized values higher than 54 were reclassed back to 54.

- Cautions: Park staff expects this data to change with more information, as this project is still in process.

Vacant habitat for extirpated species – wolves

- Sources: OLYM wolves habitat raster dataset
- Processing: Locations of extirpated wolves in OLYM were given a value of 1.
- Cautions: None.

Vacant habitat species layers added together and sliced to 0-255

Air quality - Ozone

- Sources: Data obtained from the University of Washington was converted into a grid at 12km resolution by Mike Barna at NPS Air Resources Program.
- Processing: Re: project raster to NAD 1983 UTM Zone 10N coordinate system.
- Cautions: The air quality data is at a very low resolution (Figure 3). Also, the amounts of ozone are very low for the Olympic Peninsula. Stretching the values can be misleading as the range of values is very slight. Lastly, a DATAGAP exists for wet deposited nitrate and ammonium.

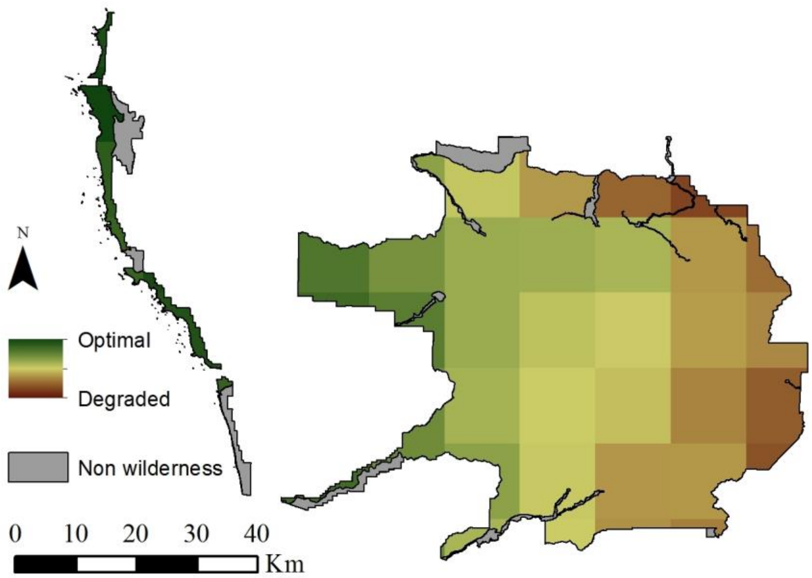

Figure 3. Ozone in OLYM. Green depicts optimal quality and brown depicts degraded quality.

Water quality – high lake survey

- Sources: OLYM park_303d polygon dataset
- Processing: Locations with impaired waters (according to the Environmental Protection Agency (EPA) Clean Water Act 303(d) list of impaired waters) in OLYM are given a value of 1.
- Cautions: This dataset has low completeness. The data from the EPA is not comprehensive. Park staff would need to survey and monitor all the high country lakes in the park to make this dataset complete.

Glacial retreat

- Sources: OLYM glacier loss polygon dataset. Depicts glacier loss from 1987 to 2009.
- Processing: Locations of glacier loss occurring in OLYM are given a value of 1.
- Cautions: Not all glacial retreat can be attributed to anthropogenic causes.

Boundary connectivity

- Sources: OLYM watersheds polygon dataset. The flow of nutrients is disrupted in drainages with dammed rivers.
- Processing: Queried out drainages which have dams on rivers. The locations of these drainages are given a value of one. This measure is divided by 4 to account for 3 missing datasets – see Cautions.
- Cautions: This measure is missing three additional inputs that would be important factors, but would be time-consuming data to collect. The following are inputs that could be used in the future to complete this measure: 1. Percentage of clear cuts within each watershed; 2. Number of roads and stream crossing within each watershed; and 3. Total number of miles of roads per watershed.

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	Exotic species	30	Important because exotic species degrade habitat quality
	Loss of habitat from trampling	10	Minor issue due to the scale of the land and impacts resulting from this measure on the natural environment
	Loss of range for iconic species	30	Important to track natural conditions and suitable habitat for iconic species
	Vacant habitat of extirpated species	30	Important to track the balance of the natural environment when changes occur such as reintroductions of extirpated species or vacant niches that have not been filled due to loss of native species
Physical resources	Water quality	90	Impacts on plant and animal species and can affect the balance of the natural environment
	Air quality	10	Minor impact in OLYM
Biophysical resources	Glacial retreat	50	Equal weighting because both measures are important measurements of the loss and or degradation to natural resources
	Boundary connectivity	50	
		300	

Maps

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

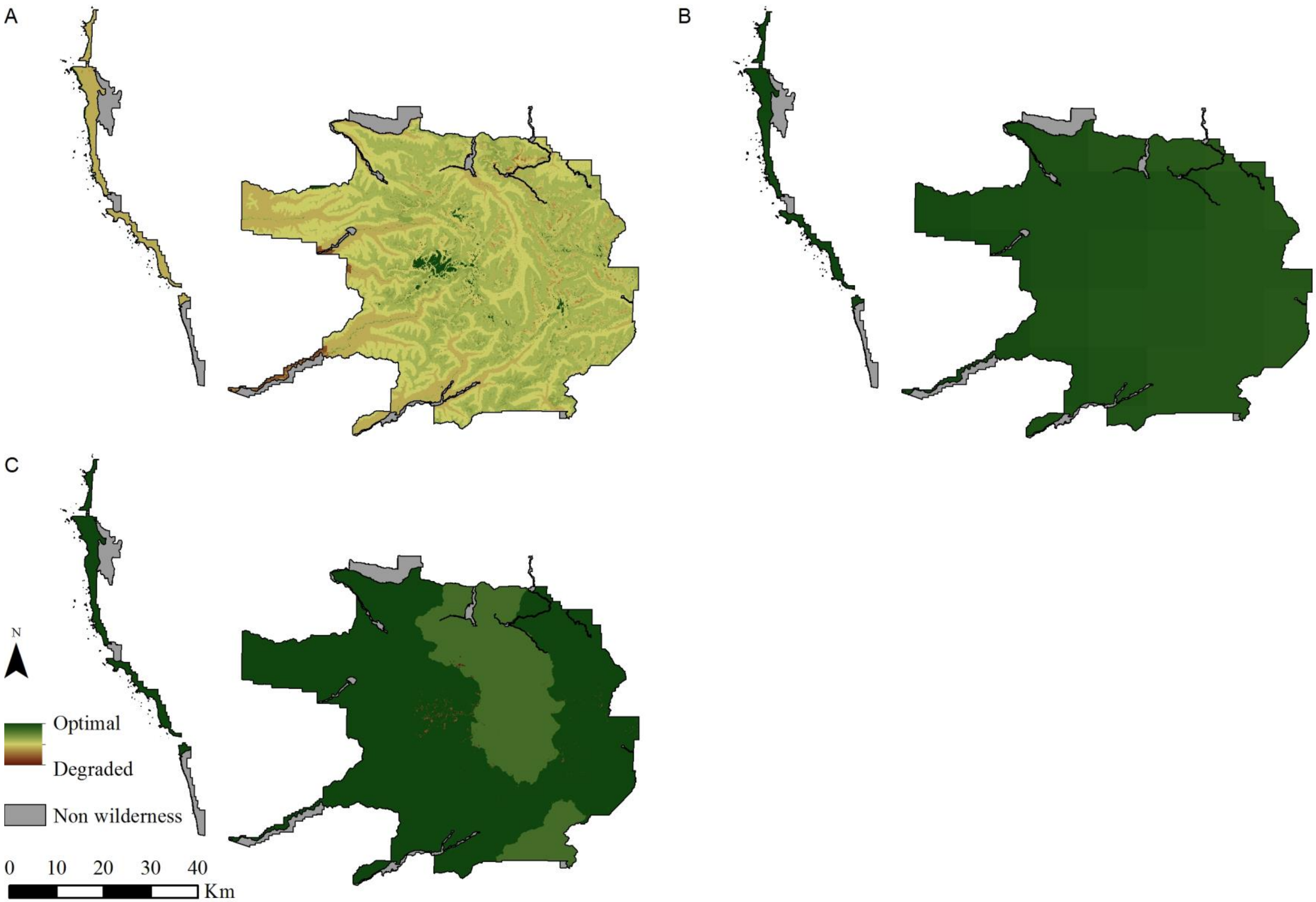

Figure 4. Indicator maps for (A) plant and animal species and communities, (B) physical resources, and (C) biophysical processes. Green depicts optimal quality and brown depicts degraded quality.

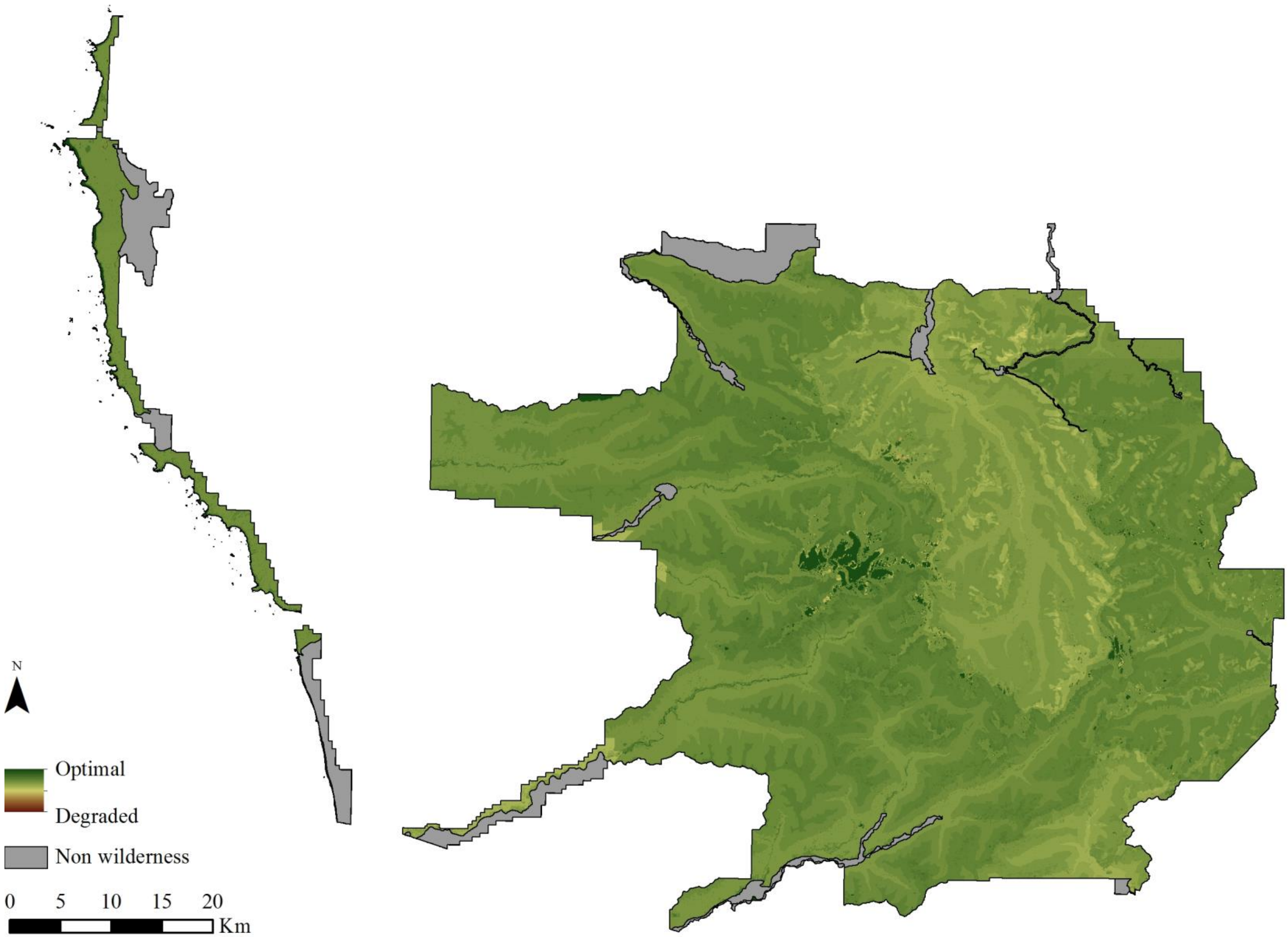

Figure 5. Natural quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.

Untrammeled Quality

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

There are important temporal questions to consider when developing a map of this quality. When possible OLYM staff decided that the baseline for including management actions would go back 5 years from the present time, 2012. When this was not possible, the most recent complete dataset were used. For example, the park needed to go as far back as 10 years to obtain complete data for much of the camping and trails information. This captures the spatial dimension of actions that occurred in the past, however, the protocol in *Keeping It Wild* only counts actions during the year in which they occur. Other parks may choose to follow this protocol or devise a more appropriate method for counting management actions.

<u>Indicators and measures</u>
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

- Exotic species removals – this is a direct measure of the degradation of the untrammeled quality because removing exotic species is a deliberate manipulation of the park's flora and fauna.
- Mechanical fuels treatments, prescribed fires – removing potential fuel loads and intentional burning is a deliberate manipulation of the landscape degrading the untrammeled quality.
- Fire suppression zones – fire suppression is a deliberate manipulation to the natural process, degrading the untrammeled quality.
- Animal collaring/ marking/ implanting/ hazing – the act of capturing and collaring/marking/implanting animals impacts the untrammeled quality.
- Wildlife transportation, reintroduction – the methods and act of transplanting fish and reintroducing mammals into the ecosystem degrades the untrammeled quality.
- Rehabilitation (terrestrial) – manipulating the landscape degrades the untrammeled quality.

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

- Illegal taking (forest products and wildlife) – intentional taking of park resources degrades the untrammeled quality.

Data sources, processing and cautions

The untrammeled quality map is composed of four measures (Table 3). Four additional measures: fire suppression zones and poaching incidents, animal collaring/marking/implanting/hazing, wildlife transportation and reintroduction, and other agencies fisheries were identified but not included due to a lack of relevant data or data sensitivity.

Table 3. Untrammeled quality datasets.

Measures	Source	Type	Scale	Accuracy	Completeness
Exotic species removals	Fish: DATAGAP	N/A	N/A	N/A	N/A
	Plants: EPMT_wilderness_pts	Point	10m	High	High
Mechanical fuels treatments, prescribed fires	Mechanical_tools	Point	1:100,000	Medium	High
Fire suppression zones	DATAGAP	N/A	N/A	N/A	N/A
Animal collaring/marking/implanting/hazing	DATAGAP	N/A	N/A	N/A	N/A
Wildlife transportation, reintroduction	Fish: DATAGAP	N/A	N/A	N/A	N/A
	Mammals: DATAGAP	N/A	N/A	N/A	N/A
Rehab (Terrestrial)	Reveg_areas	Polygon	10m	High	High
Illegal taking (forest products and wildlife)	Poaching_incidents_	Point	100m	Low	Low

Exotic species removal – fish

- Sources: No significant removals during period.
- Processing: None.
- Cautions: None.

Exotic species removals – plants

- Sources: EPMT_wilderness_pts point dataset.
- Processing: Queried dataset for all removals. Locations of exotic plant removals occurring in OLYM are given a value of 1.
- Cautions: None.

Mechanical fuels treatments, prescribed fires

- Sources: OLYM Mechanical_tools point dataset.
- Processing: Queried dataset for all instances of trammels. The locations of mechanical fuel treatments occurring in OLYM are given a value of 1.
- Cautions: None.

Fire suppression zones

- Sources: DATAGAP - there is very little data for this measure and any fires suppressed in the last five years did not have much effect on the natural cycles.
- Processing: None.
- Cautions: None.

Animal collaring/marking/implanting/hazing

- Sources: DATAGAP due to data sensitivity.
- Processing: None.
- Cautions: None.

Wildlife transportation, reintroduction - fish

- Sources: No significant transplants during this period.
- Processing: None.
- Cautions: None.

Wildlife transportation, reintroduction – mammals

- Sources: No significant transplants during this period.
- Processing: None.
- Cautions: None.

Rehabilitation (terrestrial)

- Sources: OLYM Reveg_areas polygon dataset.
- Processing: Locations of revegetation occurring in OLYM are given a value of 1.
- Cautions: None.

Illegal taking (forest products and wildlife)

- Sources: OLYM poaching_incidents point dataset.
- Processing: Locations of all poaching incidents occurring in OLYM are given a value of 1.
- Cautions: Dataset has both low accuracy and completeness.

<u>Weighting</u>

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 first set of weights equals 100 for those measures with data currently available. A second set is provided in brackets for all measures, those with and without data. In the future, should the datagaps be filled with improved or newly available data, these previously excluded measures can be added to a rerun of the wilderness character map.

Table 4. Indicators and measures for the untrammeled quality with weights and rationale. The first set of weights equals 100 for those measures with data currently available. A second set is provided in brackets for all measures, those with and without data.

Indicators	Measures	Weight	Rationale
Authorized actions	Exotic species removals	50 (20)	Important to understand impacts of removing exotic species
	Mechanical fuels treatments, prescribed fires	25 (10)	Few small areas
	Fire suppression zones	DATAGAP (20)	Important to understand impacts of fire suppression
	Animal collaring/ marking/ implanting/ hazing	DATAGAP (20)	Small footprint, but many species affected
	Wildlife transportation, reintroduction	DATAGAP (20)	Few and infrequent sites, but important to understand the impacts associated with these actions
	Rehabilitation (terrestrial)	25 (10)	Few, scattered sites
Unauthorized actions	Illegal taking (forest products and wildlife)	100	Somewhat frequent occurrence with potential for long lasting impacts
		200	

Maps

The weighted measures for each indicator are added together using a raster calculator to create maps for authorized and unauthorized actions (Figure 6). After these indicator maps are created, the raster calculator is used to add the two indicator maps together to create the untrammeled quality map (Figure 5). Please note that although the maps appear completely green, very small areas of trammeling do exist but are difficult to see at this low scale.

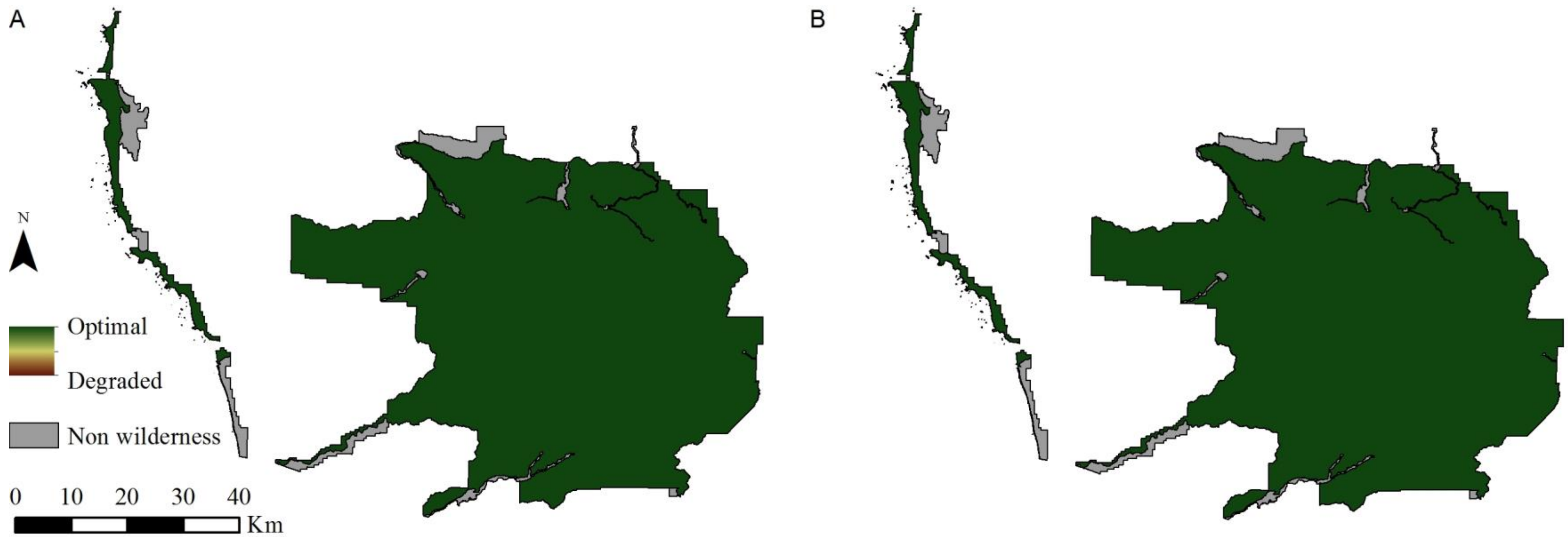

Figure 6. Indicator maps for (A) authorized actions and (B) unauthorized actions. Green depicts optimal quality and brown depicts degraded quality.

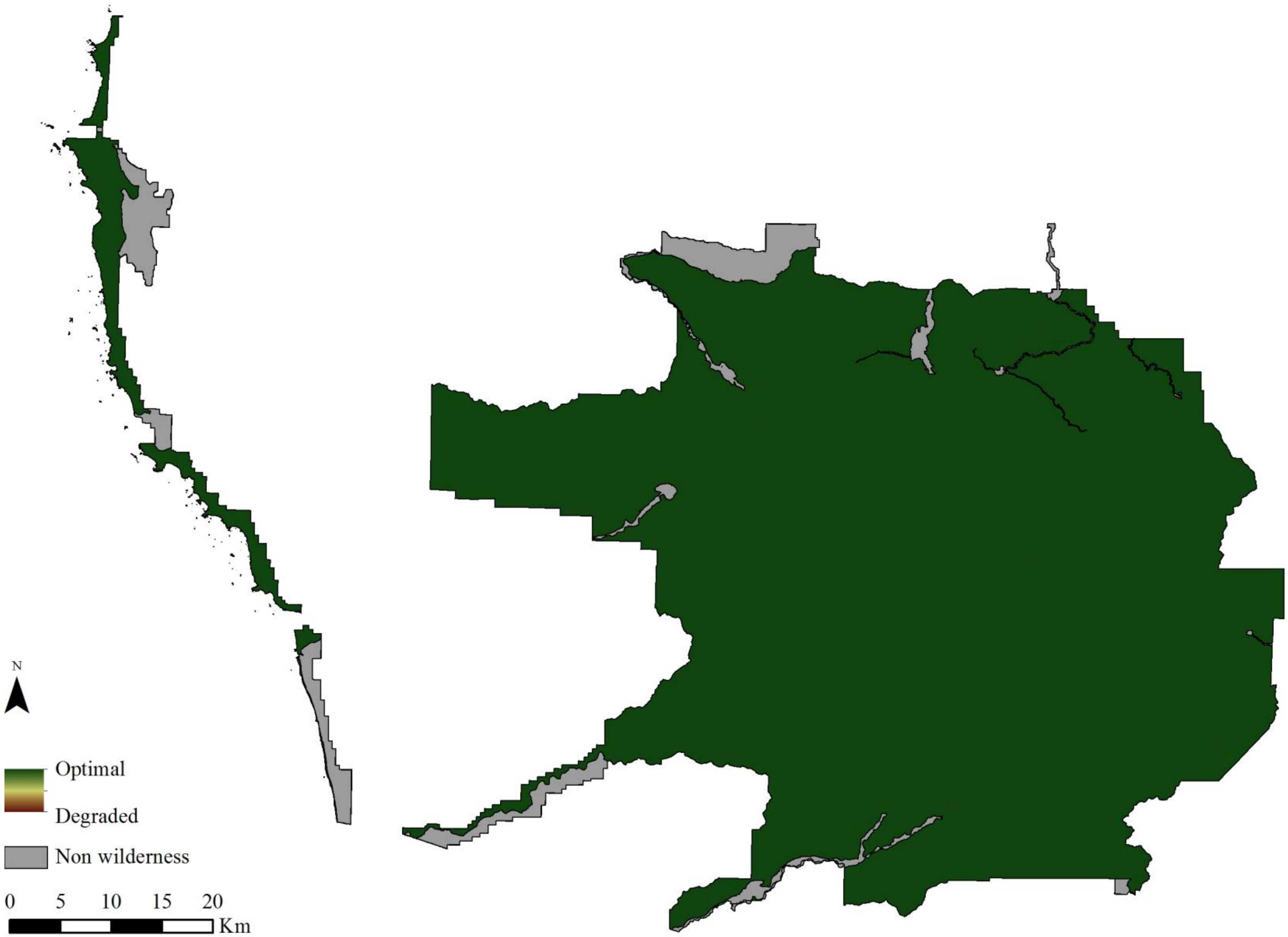

Figure 7. Untrammeled quality of wilderness character. Green depicts optimal quality brown depicts degraded quality.

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

- Roads and borrow pits in potential wilderness – roads and borrow pits are a sign of modern human occupation, the presence of these structures degrades the undeveloped quality.
- Non-recreational structures and installations – old roads, temporary and permanent structures and scientific installations in wilderness are a sign of modern human occupation which degrades the undeveloped quality.

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

- Inholdings (state) – state lands have the potential to be developed by non-NPS interests which would degrade the undeveloped quality.

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

- ORV trespass – unauthorized motorized vehicle trespass and use of motorized vehicles degrades the undeveloped quality. These uses are often unknown activities that the park has little control over.
- Administrative uses – administrative use of motorized vehicles, motorized equipment and mechanical transport (including aircraft) degrades the undeveloped quality. These are actions permitted by the park - the park makes decisions about allowing or not allowing these types of uses.

Data sources, processing and cautions

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

Table 5. Undeveloped quality datasets.

Measures	Source	Type	Scale	Accuracy	Completeness
Roads and borrow pits in potential wilderness(1)	OLYM dp_road2	Polyline	1:6,000	High	High
Non-recreational structures	Administrative: OLYM (1) buildings2011utm_pt, (2) repeaters, (3) wolfcrk_peds, (4) wolfcrk_vaults	Point	10m	High	Med - high
	Scientific: OLYM (1) LTEM_WX, (2) UNAVCO, (3) veg_plots, (4) elk_exclosures, (5) high_lakes, (6) tagged goat range, (7) tagged elk range	Point and polygon	10m-100m	High	Med - high
	Infrastructure: OLYM (1) landscapes, (2) other_disturbed, (3) towers3d	Polygon	10m	High	Med - high
	Abandoned roads (old quarry & logging roads): OLYM joe_creek	Polygon	10m	High	Med - high
State inholdings	OLYM state	Polygon	1m	High	High
ORV trespass	OLYM (1) illegal_mechanical_use, (2) illegal_mechanical_use_points	Point and polyline	1000m	Medium	Medium
Admin use	OLYM (1) mechanical_tools, (2) helicopter_flight_paths, (3) elk_flights_all, (4) goat_flights_2011, (5) fisher_all, (6) SAR_2007	Point and polyline	10m	High	Medium

Roads and borrow pits in potential wilderness

- Sources: OLYM dp_road2 polyline datasets
- Processing: Locations of roads and borrow pits occurring in OLYM are given a value of 1.
- Cautions: None.

Non-recreational structures – administrative

- Sources: OLYM buildings2011utm_pt, repeaters (radio towers), wolfcrk_peds and wolfcrk_vaults (electrical pedestals and vaults along the Wolf Creek trail), point datasets.
- Processing: Locations of administrative structures occurring in OLYM are given a value of 1. Layers added together and sliced
- Cautions: None.

Non-recreational structures – scientific

- Sources: OLYM LTEM_WX (permanent weather stations), UNAVCO (continuously operating GPS stations) and veg_plots point datasets; and elk_exclosures, high_lakes (those with scientific instruments installed), tagged elk range, and tagged goat range polygon datasets.
- Processing: Locations of scientific structures occurring in OLYM are given a value of 1. Layers added together and sliced
- Cautions: None.

Non-recreational structures – Infrastructure

- Sources: OLYM landscapes and other_disturbed polygon datasets and towers3d point dataset.
- Processing: Locations of infrastructure occurring in OLYM are given a value of 1. Layers added together and sliced
- Cautions: None.

Non-recreational structures – abandoned roads

- Sources: OLYM joe_creek polygon dataset
- Processing: Locations of abandoned roads in OLYM are given a value of 1.
- Cautions: None.

Non-recreational structures together and sliced to 0-255

Inholdings

- Sources: OLYM state polygon dataset
- Processing: Locations of state inholdings in OLYM are given a value of 1.
- Cautions: None.

ORV trespass

- Sources: OLYM illegal_mechanical_use polyline and illegal_mechanical_use_points points dataset
- Processing: Locations of illegal mechanical use in OLYM are given a value of 1. Layers added together and sliced
- Cautions: None.

Administrative uses

- Sources: OLYM mechanical_tools point dataset; and helicopter_flight_paths, elk_flights_all, goat_flights_2011, fisher_all, and SAR_2007 polyline dataset.
- Processing: Locations of administrative use in OLYM are given a value of 1. For wildlife surveys, the processed rasters were added together using weights (helicopter surveys 80%/fixed wing surveys 20%) to emphasize the greater noise impacts of the helicopter surveys. Layers added together and sliced.
- Cautions: SAR dataset is largely incomplete (only uses the SAR_2007 data).

<u>Weighting</u>

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 6). The “weighted” measures under each indicator total 100.

Table 6. Indicators and measures for the undeveloped quality with weights and rationale.

Indicator	Measures	Weight	Rationale
Non-recreational structures, installations, and developments	Roads and borrow pits in potential wilderness	30	Few, but important to track for future reference
	Non-recreational structures	70	Many individual small footprints scattered throughout the wilderness
Inholdings	State inholdings	100	Potential for development with impacts on the surrounding land
Use of motor vehicles, motorized equipment, or mechanical transport	ORV trespass	20	Infrequent occurrence, but with lasting impacts
	Administrative use	80	Important actions to track for understanding the impacts on the ecosystem, the natural soundscape, the visitor experience and future management of designated wilderness areas
		300	

Maps

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

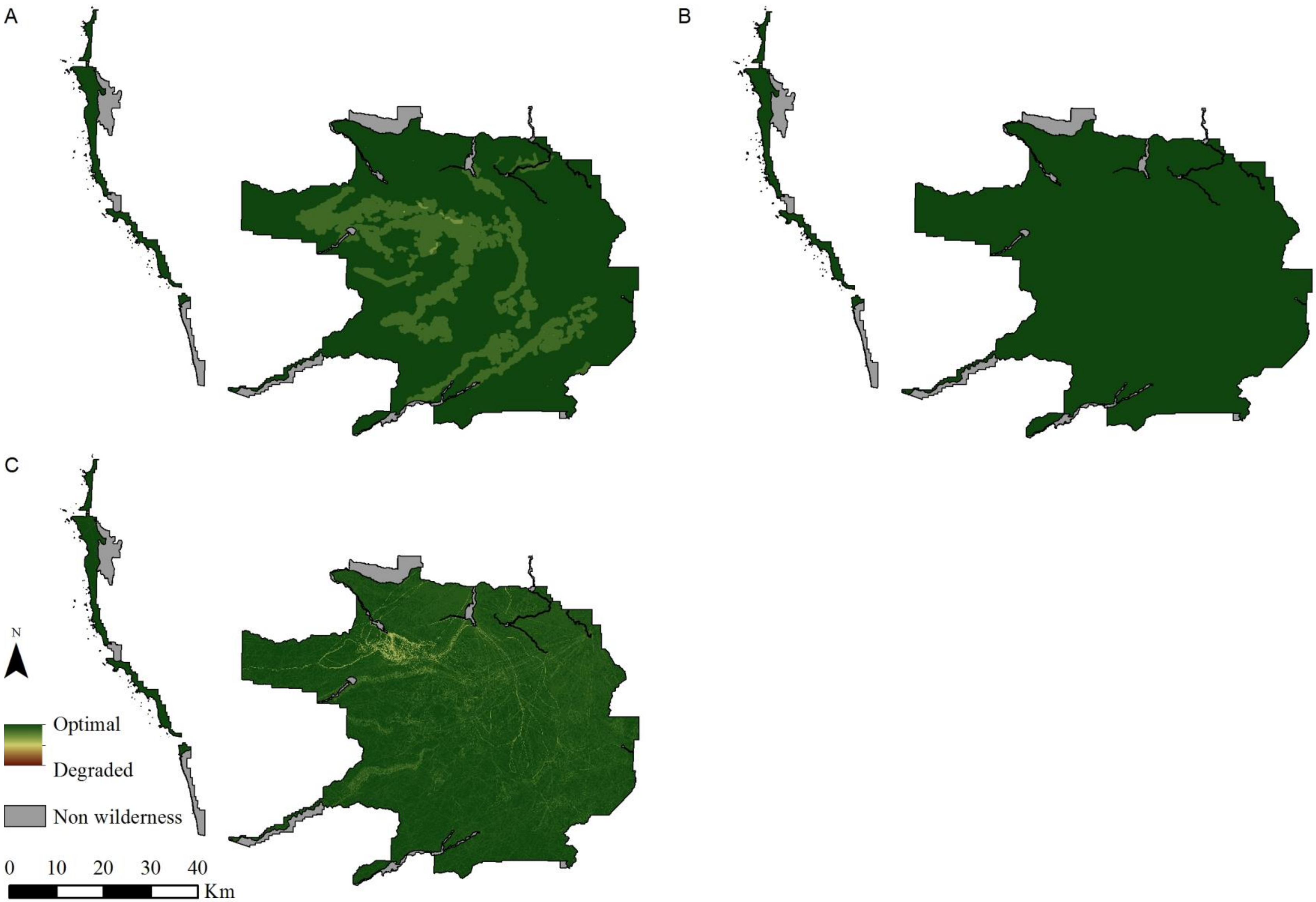

Figure 8. Indicator maps for (A) non-recreational structures, installations, and developments; (B) inholdings; and (C) use of motor vehicles, motorized equipment, or mechanical transport. Green depicts optimal quality and brown depicts degraded quality.

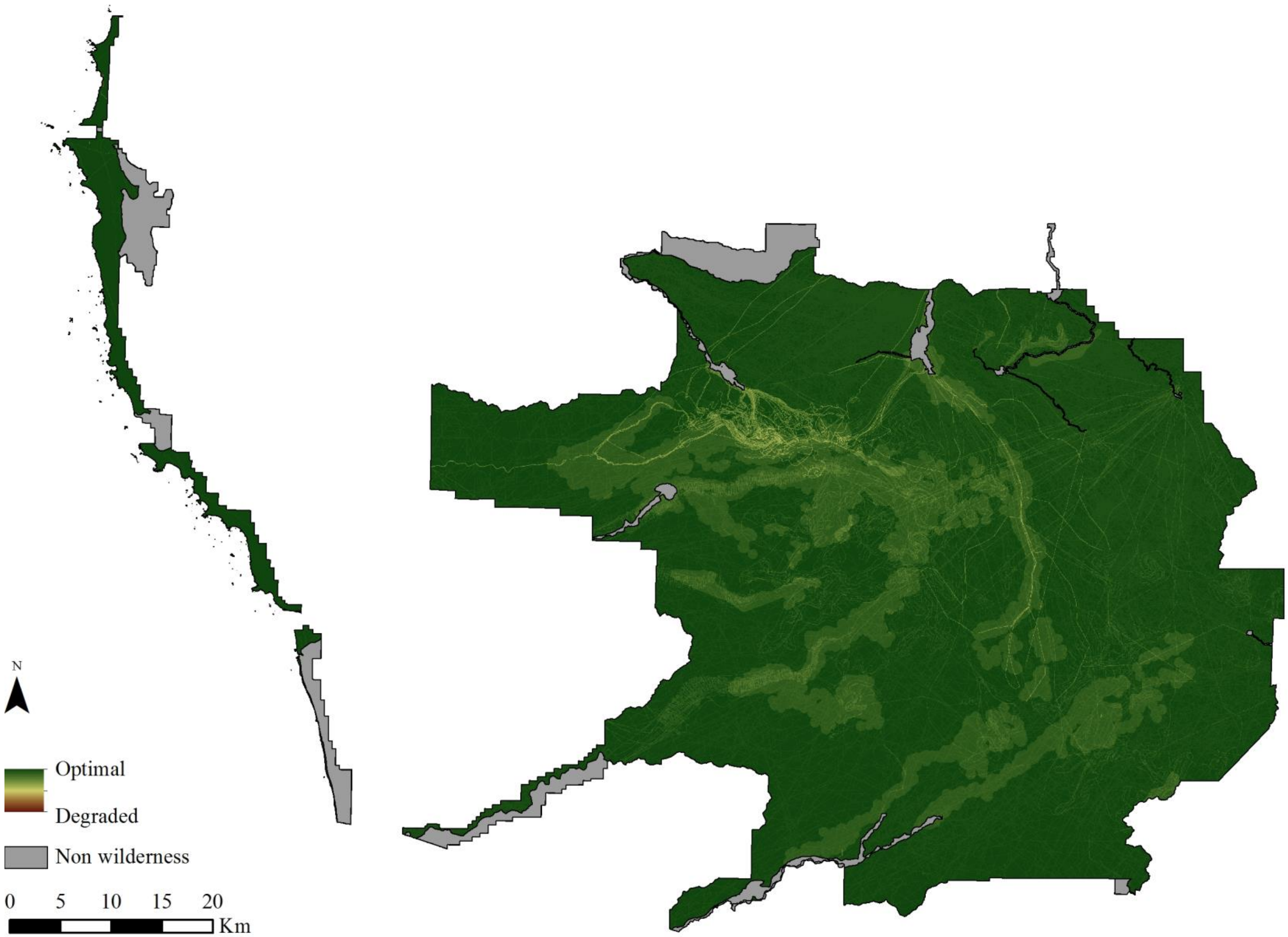

Figure 9. Undeveloped quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.

Solitude or Primitive and Unconfined Quality

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

Indicators and measures

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

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

- Travel time model – calculates the time it takes a person of average fitness to travel across the landscape from various access points (paved roads), taking into account cost surfaces[11] (elevation and land cover) and barrier features (steep ground and water).
- Viewshed model – calculates the line-of-sight impacts (using distance decay) of modern human features both inside and outside the wilderness.
- Trail encounters – a measure of human presence influencing the feeling of remoteness which degrades the opportunity for solitude.
- Year round visitor overnight use patterns – same measure as day use (trail encounters) - however, overnight use patterns were weighted more because overnight users have higher expectations of solitude in wilderness.
- Human waste (designated camp areas without privies) – a measure of human presence degrading the opportunity for solitude and primitive and unconfined recreation.

Indicator: Remoteness from occupied and modified areas outside the wilderness

- Soundscape – measurement of human presence outside the wilderness degrading the opportunity for solitude.
- Nightsky – not enough data - but if data is found this would be a measure of the visual loss of astronomical features - this loss degrades opportunities for remoteness, solitude, and primitive recreation.
- Air quality (particulates impacting visibility) – this would be a measure of air particulates contributing to a loss of visual distant features of the landscape - impacts to visibility degrades the opportunity for solitude and primitive recreation.

Indicator: Facilities that decrease self-reliant recreation

- Trails – developed and maintained trails concentrate visitor use degrading the opportunity for solitude.
- Camp areas – the presence of designated camp areas concentrates visitor use degrading the opportunity for solitude.

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

- Wireless coverage – this is non-NPS commercial use facility that was included because of the proximity of this park to the greater Seattle area - hikers using cell phones in the wilderness degrades the opportunity for solitude and decreases self-reliance.

Indicator: Management restrictions on visitor behavior

- Access restrictions (group size, quota areas) – agency restrictions that inhibit free choice and limit group size degrades the opportunity for unconfined recreation.
- Use restrictions (designated camp sites/areas, food storage requirements, campfire restrictions, blue bags, fishing and shellfish restrictions) – agency restrictions that modify visitor behavior degrades the opportunity for unconfined recreation.
- Pack animal restrictions – agency restrictions that dictate what type of pack animals are allowed and where they can go degrades the opportunity for primitive and unconfined recreation.

<u>Travel time and viewshed modeling</u>

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

<u>Travel time</u>

Travel time is modeled in OLYM based on a GIS implementation of Naismith's Rule[12], with Langmuir's correction[13]. Terrain and land cover information are used to delineate the relative time necessary to walk into a roadless area from the nearest point of legal motorized access taking into account the effects of distance, relative slope, ground cover, and barrier features such as very steep ground. The travel time (or "remoteness") model, developed by Carver and Fritz (1999), assumes a person can walk at a speed of 5 km/hr over flat terrain and adds a time penalty of 30 minutes for every 300 m of ascent and 10 minutes for every 300 m of descent for slopes greater than 12 degrees. When descending slopes between 5 and 12 degrees, a time bonus of 10 minutes is subtracted for every 300 m of descent. Slopes between 0 and 5 degrees are assumed to be flat. Ancillary data layers are used to modify walking speeds according to ground cover (e.g., Naismith's 5 km per hour on the map can be reduced to 1 km per hour or less when walking

[12] Naismith's Rule is a simple formula that helps to plan a hiking expedition by calculating how long it will take to walk the route, including ascents. Devised by Scottish mountaineer, William Naismith, the basic rule states: "Allow…an hour for every three miles on the map, with an additional hour for every 2,000 feet of ascent" (1892: 136).

[13] Langmuir's correction acknowledges the need to descend slowly in steep terrain as it is necessary to take shorter steps, or reduce slope angle and extend path length by zig-zagging.

through dense vegetation). They also include barrier features that force a detour as "null" values[14].

- *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 10 m Digital Elevation Model (DEM), resampled to 30 m, provides terrain elevation data, the combined OLYM species and USGS National GAP Land Cover data provide land cover data, and a number of road datasets from OLYM, US Forest Service, and Washington Department of Natural Resources are used to create the road classes. Additionally, OLYM dirt road, trail and river 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:
    1. *Source grid:* This is the road network that provides vehicular access to the park.
    2. *Cost surface:* Impedance values are assigned to the various land cover classes when traveling off trail in OLYM (impedance are factors that inhibit travel). The majority of forested areas and shrubland are estimated at 1 km/hr. Meadows, heather and areas with permanent snow are estimated at 3 km/hr. Any developed areas are assigned speeds of 5 km/hr (for a full list of land cover impendence values that represent off-trail travel, see Appendix A). Additional features not found in the land cover data are used to amend the base cost surface for a more accurate depiction of the cost surface. Trails are overlaid onto the cost surface at 5km/hr, due to their low resistance to movement. Rivers are generally a time consuming obstacle in OYLM and are programmed to take 15 minutes to cross.
    3. *Barriers to movement:* These include the Dosewallips River (excluding two known fording areas), all lakes and any areas where slope angles exceed 40 degrees.

  The standardized travel time measure has been inverted to reflect high degradation of solitude values near access points, and lower degradation further away from these features (Figure 10).
- *Cautions*: Naismiths's Rule and the model used to implement it here assumes the person "travelling the landscape" is a fit and healthy individual and does not make allowances for load carried, weather conditions, or navigational skills. The model does, however, take barrier features and conditions underfoot into account. Steep slopes are considered impassable on foot and are included as barrier features by coding these as NoData (null values) in the model inputs. This forces the model to seek a solution that involves walking around the obstacle. The model also uses a cost or friction surface that controls walking speed according to the land cover or conditions underfoot. A slow speed of 1 km/hr (0.278 m/s) is assumed for most land cover types in the park, but some areas are

[14] 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.

easier to travel in, falling within a range of 3 – 5 km/hr (1.112 - 1.389 m/s). The angle at which terrain is crossed (i.e., the horizontal and vertical relative moving angles[15]) is used to determine the relative slope and height lost/gained. These values are input into the model using a simple lookup table as shown in Table 7. The paved road network, both within and outside the OLYM boundary, is used as the access points from which to calculate remoteness of non-road areas. The road network outside OLYM is included in the analysis to avoid any possible edge effects in the travel time calculation.

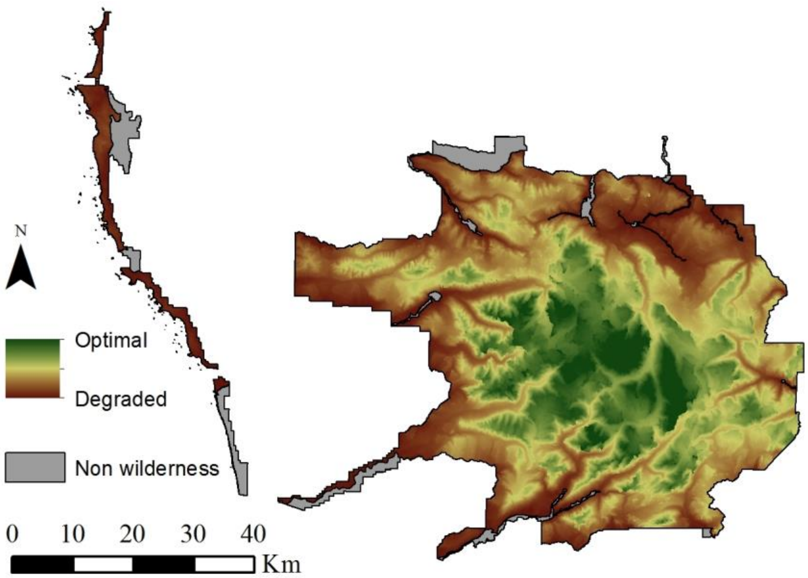

Figure 10. Travel time model. This map depicts the fastest route it would take a person to walk to every pixel in OLYM from the source grid (paved road network). Brown indicates the pixels that are within quicker reach and therefore we assume that these pixels represent a lower opportunity for solitude, and green represents pixels that will take longer to reach and therefore represent greater opportunity for solitude. (Map is displayed using standard deviations.)

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

Table 7. Naismith's Rule expressed in the vertical relative moving angle (VRMA) field.

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

Viewshed

The visual impacts of modern anthropogenic features in the OLYM wilderness are modeled using a custom-built software tool. The presence of these artificial features, which may be located within or adjacent to the wilderness, are assumed to detract from a sense of solitude. Previous work on the effects of human features on perceptions of wilderness, carried out at national and global scales, has tended to focus on simple distance measures (Lesslie 1993, Carver 1996, Sanderson et al. 2002). More recent work has used measures of visibility of anthropogenic features in 3D landscapes, using digital terrain models (Fritz et al. 2000, Carver and Wrightham 2003). This is feasible at the landscape scale utilizing viewshed algorithms and land cover datasets to calculate the area from which a given feature can be seen[16].

- *Sources*: Visibility analysis and viewshed calculations rely on the ability to calculate "line-of-sight" from one point on a landscape to another. It has been shown that the accuracy of viewsheds produced in GIS is strongly dependent on the accuracy of the terrain model used and the inclusion of intervening features or "terrain clutter" in the analysis (Fisher 1993). While previous studies have made use of a digital surface model (DSM) for obtaining "terrain clutter" (Carver et al. 2008), the extent of OLYM and relative lack of features allows feature information to be collated and formatted manually (Table 8). A resolution of 30 m for feature inputs was considered adequate for this analysis. Viewshed distance and height information were determined for each feature by the working group. The resampled USGS 10 m DEM was used to provide terrain elevation data.

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

Table 8. Human features impacting viewshed.

Feature type	Data source	Viewshed distance	Height	Accuracy	Completeness
Radio repeaters, SNOTEL towers/weather stations, GPS stations	Repeaters, LTEM_WX, UNAVCO	5 km	Variable	High	Med – high
Kloochman Rock radio repeater & helipad	Repeaters	5 km	Variable	High	Med – high
Small structures (privies, wood sheds, Pyramid Peak lookout, RS tent platforms)	Buildings2011utm_pt	5 km	2 m	High	Med – high
Medium structures (backcountry cabins, shelters, yurt at Glacier Mdws Dodger Point Lookout)	Buildings2011utm_pt	5 km	3 m	High	Med – high
Snowdome (unique location and size)	Buildings2011utm_pt	5 km	3 m	High	Med – high
Coastal targets and monuments	Buildings2011utm_pt	5 km	5 m	High	Med – high
Hurricane Ridge ski lift operations structures & installations	Towers3d	5 km	7 m	High	Med – high
Trails (using veg type)	Trail_master	5 km	1 m	High	Med – high
Camping tents clusters (areas with average of 10 tents)	Campareas_all2	5 km	2 m	High	Med – high
Towers outside the park (cell towers w/lights, Nippon smokestack in Port Angeles)	Towers, pen_microwave	15 km	Variable	High	Med – high
Roads, road cuts, & Lake Cushman causeway	Roads	15 km	5 m	High	Med - high
HWY 101	Washington Dept of Natural Resources	15 km	5 m	High	High
Large structures/Inholdings - houses at Lake Crescent, houses Lake Ozette, Lake Cushman	Landscapes	15 km	8 m	High	Med - high
EV Chalet (unique location and size)	Buildings2011utm_pt	15 km	7 m	High	Med - high
Hurricane Hill parking lot/trailhead	Other_disturbed	15 km	3 m	High	Med - high
Deer Park campground and parking lots	Other_disturbed	15 km	3 m	High	Med - high
Glines Dam disturbed area - concrete spillways, parking area, boat launch, reveg, interp area	Other_disturbed	15 km	3 m	High	Med - high
Minor developments/clustered buildings (Sol Duc Lodge & Elwha maintenance area)	Landscapes	15 km	8 m	High	Med - high

Ships on the coast	Heads-up digitized	15 km	10 m	High	High
Cushman Reservoir disturbed landscape (unnatural manmade features on the landscape)	Cushman	30 km	4 m	High	High
Hurricane Ridge Lodge/Visitor Center	Buildings2011utm_pt	30 km	8 m	High	Med - high
Hurricane Ridge parking lot	Other_disturbed	30 km	3 m	High	Med – high
Obstruction Point parking lot/trailhead	Other_disturbed	30 km	3 m	High	Med – high
Land management areas outside the park	Olym_fast_dist_attributio n_outsidepark	30 km	Variable	High	High
Major developments/town sites (PA, Brinnon, La Push)	Uga, city	30 km	8 m	Medium	Med - high

- *Processing*: Viewshed analyses such as these are extremely costly in terms of computer processing time. Detailed analyses can take weeks, months, or even years to process depending on the number of anthropogenic features in the database. Recent work by Washtell (2007), however, has shown that it is possible to both dramatically decrease these processing times and improve their overall accuracy through judicious use of a voxel-based landscape model[17] and a highly optimized ray-casting algorithm. The algorithm, which is similar to those used in real-time rendering applications and in some computer games, was designed to perform hundreds of traditional point viewshed operations per second. By incorporating this into a custom-built software tool that has been designed to work directly with GIS data, it is possible to estimate the visibility between every pair of cells in a high-resolution landscape model utilizing only moderate computing resources. This "viewshed transform" approach represents a maturation of traditional cumulative viewshed techniques (Carver et al. 2008) and is used to:
    1. calculate the viewshed for every single feature;
    2. incorporate estimates of the proportional area of each visible feature; and
    3. run separate viewshed calculations for each of the different categories of features listed in Table 8, which can then be combined together to create the viewshed map.

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.

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

1. The cell resolution was limited to 30 m for all features;

[17] A voxel is a volumetric pixel.

2. A “pessimistic” re-sampling was done to generate the 30 m feature inputs guaranteeing that features smaller than this area were included[18] and that the viewsheds produced an accurate representation of the visual impacts of these features;
3. The landscape was split into a number of overlapping tiles such that they could be simultaneously analyzed by a cluster of desktop computers;
4. The viewshed analysis was run for 5 km, 15 km and 30 km maximum viewshed distances.

The three batched outputs are combined together using the MINIMUM function in ArcGIS to provide an overall viewshed grid for OYLM. The normalized viewshed measure needs to be inverted to reflect high degradation of solitude values near human features and lower degradation further away from these features (Figure 11).

- *Cautions*: Categorizing the anthropogenic features in OYLM 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 forested 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 Hurricane Ridge Visitor Centre) are assigned a maximum viewshed distance of 30 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 analyzing viewshed results.

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

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

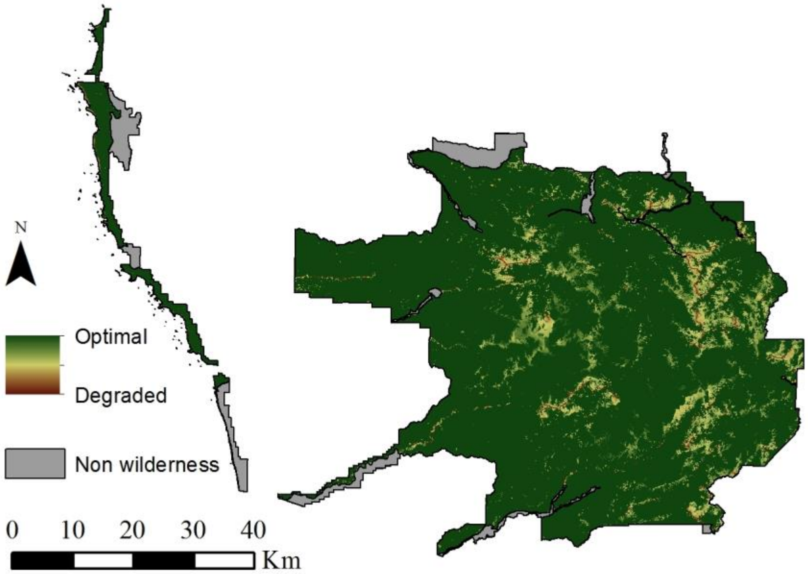

Figure 11. Viewshed impacts in OLYM. Green depicts optimal quality viewshed and brown depicts degraded quality viewshed.

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 9), which encompass a range of different scales, variability in accuracy and completeness, and both vector and raster data. Two additional measures: visibility and night sky were identified but not included due to a lack of relevant data.

Table 9. Solitude and primitive and unconfined quality datasets.

Measures	Source	Type	Scale	Accuracy	Completeness
Travel time	OLYM species, USGS National GAP Land Cover, road datasets from OLYM, US Forest Service, and Washington Department of Natural Resources, OLYM dirt road, trail and river datasets		Various	Medium	High
Viewshed	See Table 8	N/A	N/A	N/A	N/A
Trail encounters	OLYM trail_master	Polyline	10m	Low	Low
Year round visitor overnight use patterns	OLYM campareas_all2	Point	10m	High	High
Human waste (designated camp areas without privies)	OLYM human_waste	Point	10m	High	High
Soundscape	NPS Natural Sounds Program: L90 flat-weighted grid	Raster	500m	High	High
Night sky	DATAGAP	N/A	N/A	N/A	N/A
Air quality –visibility	DATAGAP	N/A	N/A	N/A	N/A
Trails	OLYM trail_master	Polyline	10m	High	High
Camp areas	OLYM campareas_all2	Point	10m	High	High
Wireless coverage	WA_wireless_clip	Polygon	1:10,000	Medium	High
Access restrictions	OLYM Superintendent's Compendium	Polygon	1:100,000	High	High
Use restrictions	OLYM Superintendent's Compendium	Polygon	1:100,000	High	High
Pack animal restrictions	OLYM Superintendent's Compendium	Polyline and polygon	1:100,000	High	High

Trail encounters

- Sources: OLYM trail_master polyline dataset.
- Processing: The average of all hikers encountered as per ranger inventory count is used to assign values to each section of trail occurring in the OLYM. These averages indicate the likelihood of encountering another hiker.
- Cautions: This dataset has low completeness - the majority of the data was collected during the summer months.

Year round visitor overnight use patterns

- Sources: OLYM campareas_all2 point dataset.
- Processing: Clipped out all campsites that lie within the forest. Then used the 'Total_of_I' values (total of individuals using the campsite over 5 years) to determine the likelihood of encountering people camping.
- Cautions: None.

Human waste (designated camp areas without privies)

- Sources: OLYM human_waste point dataset

- Processing: The total number of human waste recorded around campsites in OLYM without privies is used to represent this measure.
- Cautions: None.

Soundscape

- Sources: Raster dataset provided by the NPS Natural Sounds Program. A L90 increase over natural noise grid depicting anthropogenic noise (which captures existing noise minus natural noise) is used (Figure 12).
- Processing: Re: project raster to NAD 1983 UTM Zone 10N coordinate system.
- Cautions: The soundscape output is currently limited to 500 m resolution. However, 30 m resolution grids will be available in the near future.

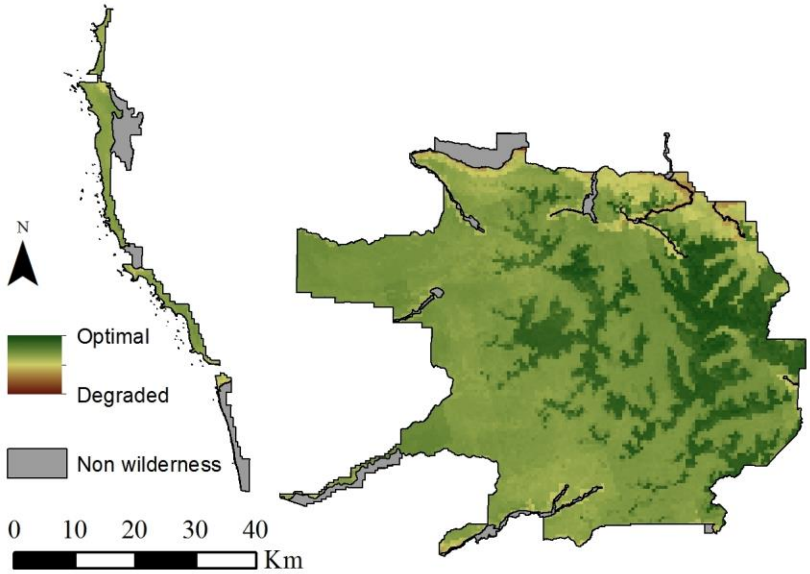

Figure 12. OLYM soundscape map.

Night sky

- Sources: This data does not currently exist for OLYM.
- Processing: None.
- Cautions: None.

Air quality

- Sources: This data does not currently exist for OLYM.
- Processing: None.
- Cautions: None.

Trails

- Sources: OLYM trail_master polyline dataset
- Processing: The locations of trails occurring in OLYM are given values based on their classification. Way trails = 1; primitive trails = 2; and foot trails, secondary trails, all-purpose trails and nature trails = 3.

- Cautions: None.

Camp areas

- Sources: OLYM campareas_all2 point dataset.
- Processing: The locations of campsites occurring in OLYM are given values based on an OLYM created self-reliance matrix. The following classes explain the scoring system for different types of campsites: 0 = the most primitive campsite and thus requires the greatest degree of self-reliance - there is no defined campsite and no facilities; 1 to 3 = an obvious campsite with a "measureable area" and nothing else; 4 to 8 = in addition to a campsite with a "measureable area" there is typically one other facility or structure in addition to a sign or signs; e.g. there may be a toilet facility or a bear wire or a shelter, but usually only one or maybe two of these types of structures; 9 or greater = campsites that have the whole suite of facilities, namely signs, toilet, food storage, and possibly a shelter as well. Thus the degree of self-reliance required is greatly reduced.
- Cautions: None.

Wireless coverage

- Sources: WA_wireless_clip polygon dataset
- Processing: Locations with cell service in OLYM are given a value of 1.
- Cautions: None.

Access restrictions

- Sources: OLYM created polygon datasets using the Superintendent's Compendium.
- Processing: Locations with the following restrictions in OLYM are given a value of 1: areas subject to group size limits, quota areas (how many people can camp in an area per night), no camping within a quarter mile of the following areas unless in a designated campsite: Hoh Lake, Elk Lake in the Hoh district, Glacier Meadows Ranger Station, Lake Crescent, Olympic Hot Springs, Grand Lake, Moose Lake, Gladys Lake, Lake Constance, Upper Lena Lake, Flapjack Lakes/Gladys Divide. Royal Lake, CB Flats, and Hoh Lake to Bogachiel Peak; no camping (unless in a designated campsite) in the Queets corridor downstream from the trailhead to the park boundary and all areas on the coastal strip south of the Hoh Indian Reservation; no camping within 1 mile of a trailhead (unless in a designated campsite).
- Cautions: None.

Use restrictions

- Sources: OLYM created polygon datasets using the Superintendent's Compendium.
- Processing: Locations in OLYM with the following use restrictions are given a value of 1: food storage requirements, campfire restrictions, blue bag requirements, and no-sledding zones.
- Cautions: Fishing restrictions were excluded from this measure as the number of zones and complexity of regulations make it difficult to develop a value system to represent these restrictions spatially.

Pack animal restrictions

- Sources: OLYM created polygon datasets using the Superintendent's Compendium.

- Processing: Locations with pack animal restrictions occurring in OLYM are given a value of 1.
- Cautions: Pack animal restrictions are weighted lower than access and use restrictions because they will only affect a small number of wilderness visitors.

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 10). The "weighted" measures under each indicator total 100. Although data for visibility and night sky 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 10.

Table 10. Indicators and measures for the solitude and primitive and unconfined recreation quality with weights and rationale. The first set of weights equals 100 for those measures with data currently available. A second set is provided in brackets for all measures, those with and without data.

Indicator	Measure	Weight	Rationale
Remoteness from sights and sounds of people inside the wilderness	Travel time	20	Access into and remoteness of the wilderness are important resources to assess for management
	Viewshed	20	Important resource to assess, because certain views or features can either enhance or degrade the opportunity for solitude
	Trail encounters	20	Equally important to assess
	Year round visitor overnight use patterns	30	Most important issue when thinking about effects of sights and sounds inside the wilderness
	Human waste (designated camp areas without privies)	10	Few scattered areas throughout the park
Remoteness from occupied and modified areas outside the wilderness	Soundscape	100 (50)	Important resource identified in the 2008 General Management Plan (GMP) as a park value, to inventory, protect, and preserve
	Night sky	DATAGAP (30)	Important resource identified in the GMP as a park value, to inventory, protect, and preserve
	Air quality - visibilty	DATAGAP (20)	Important resource issue identified in the GMP, OLYM is a Class 1 air quality area under the Clean Air Act – this designation allows very little additional deterioration of air quality
Facilities that decrease self-reliant recreation	Trails	45	Very noticeable on the landscape – decreases self-reliance
	Camp areas	45	Very noticeable on the landscape – decreases self-reliance
	Wireless coverage	10	Less noticeable - the least influential on self-reliance
Management restrictions on visitor behavior	Access restrictions	40	Impacts visitor use
	Use restrictions	40	Impacts visitor use
	Pack animal restrictions	20	Does not impact as many visitors - only impacts a specific type of visitor use
		400	

Maps

The weighted measures for each indicator are added together using a raster calculator to create separate maps for remoteness from sights and sounds of people inside the wilderness, remoteness from occupied and modified areas outside the wilderness, facilities that decrease self-reliant recreation, and management restrictions on visitor behavior (Figure 13). 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 14). Finally, the raster calculator is used to add the four indicator maps together to create the solitude or primitive and unconfined quality map (Figure 15).

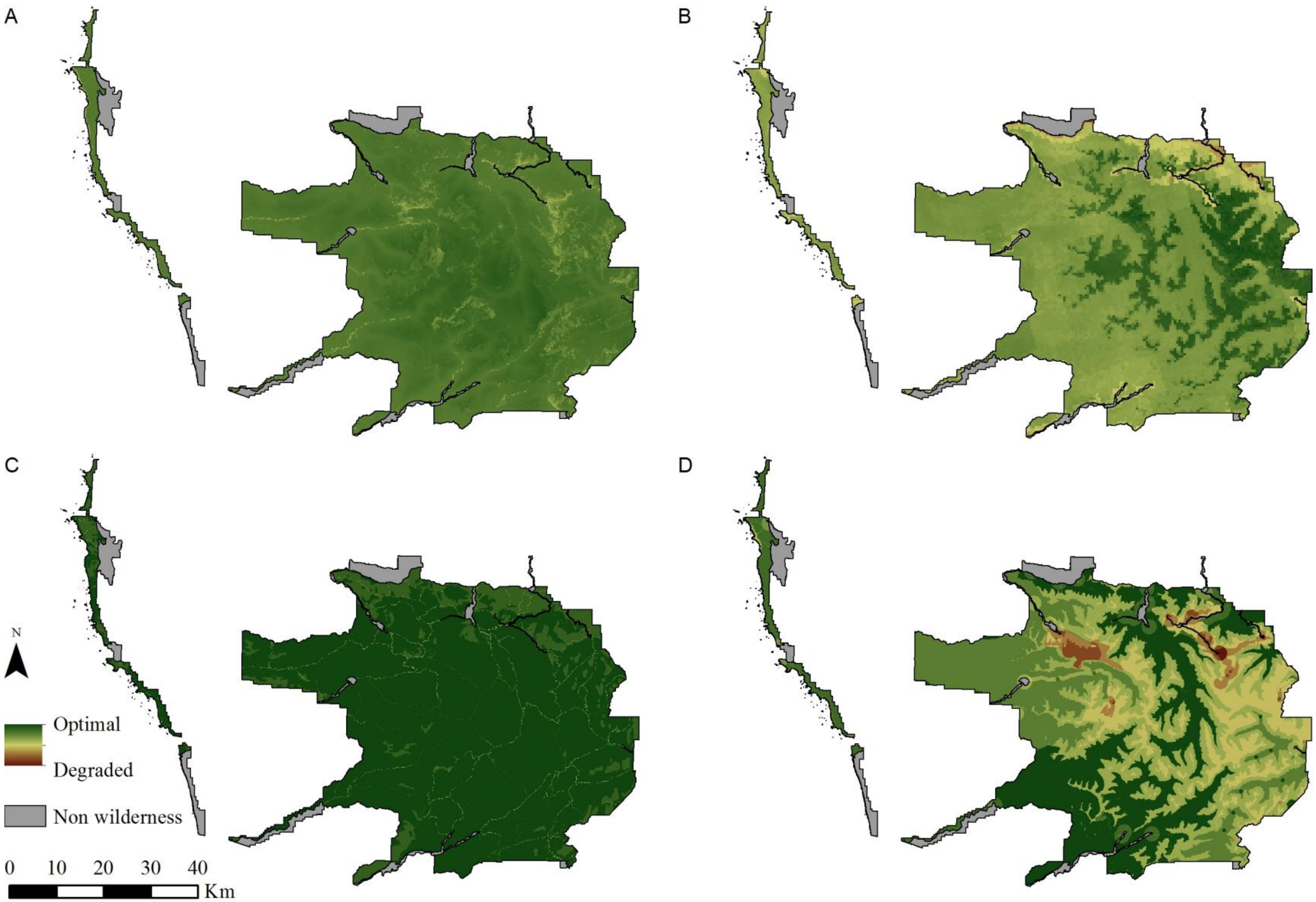

Figure 13. Indicator maps for (A) remoteness from sights and sounds of people inside the wilderness, (B) remoteness from occupied and modified areas outside the wilderness, (C) facilities that decrease self-reliant recreation, and (D) management restrictions on visitor behavior. Green depicts optimal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

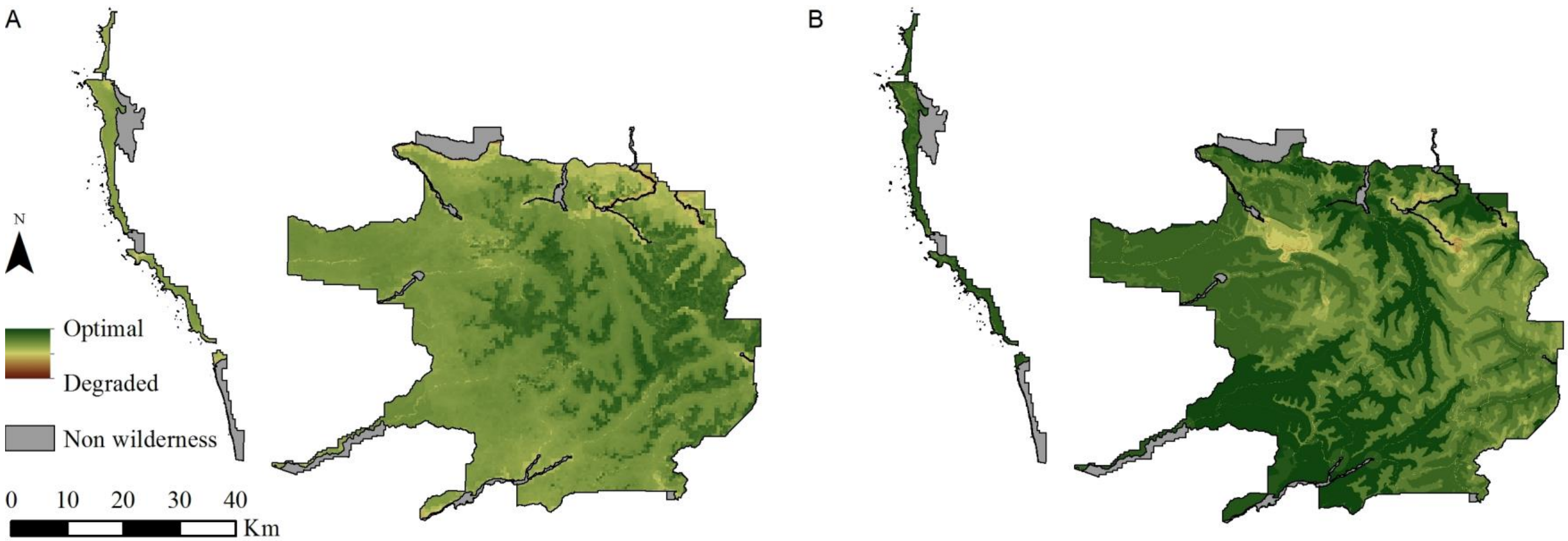

Figure 14. Combined indicator maps for (A) opportunities for solitude inside wilderness, and (B) opportunities for primitive and unconfined recreation inside wilderness. Green depicts optimal quality and brown depicts degraded quality.

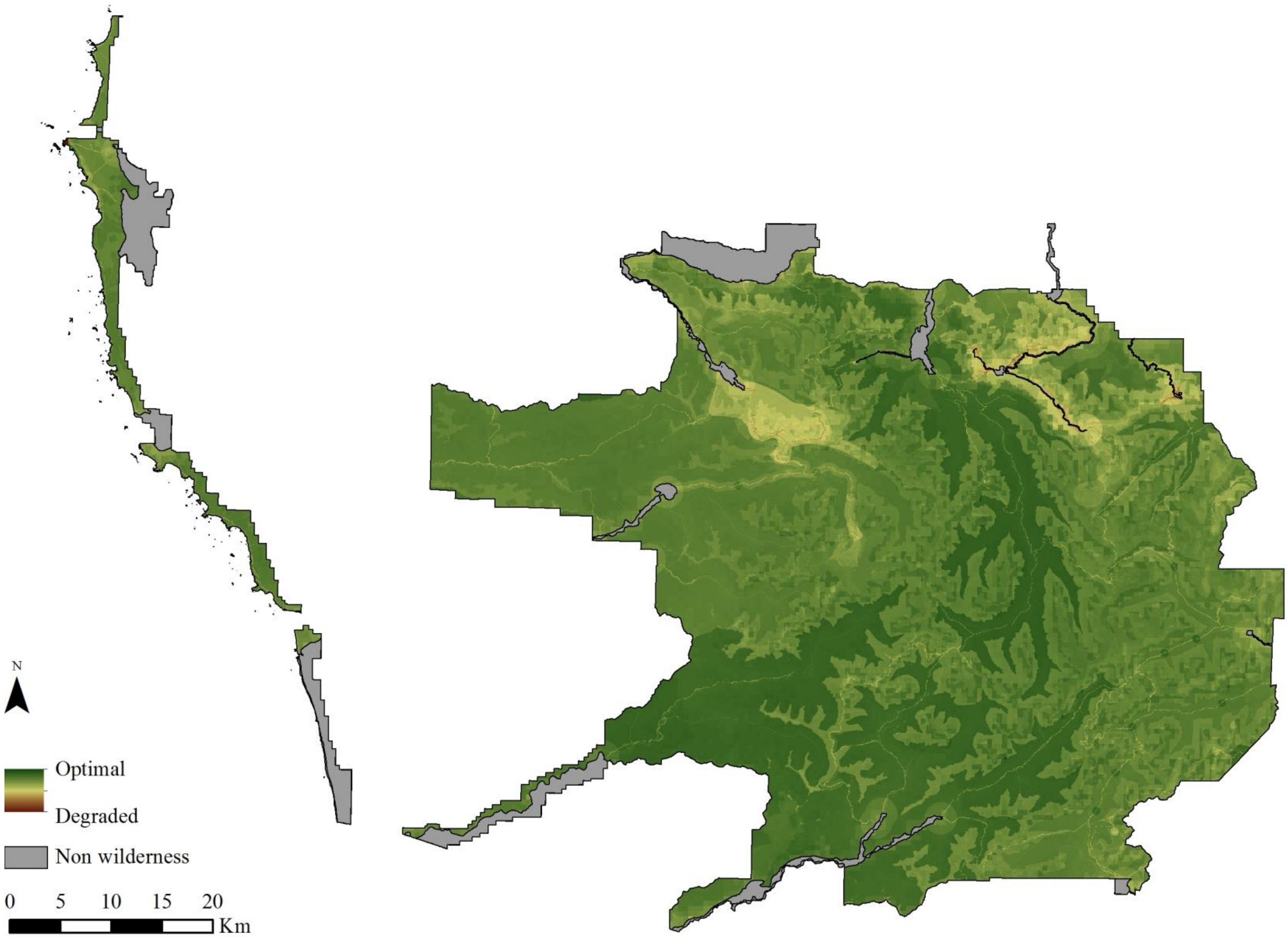

Figure 15. Solitude or primitive and unconfined quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.

Other Features of Value

Unlike the preceding four qualities that apply to every wilderness, this fifth quality is unique to an individual wilderness based on the features that are inside that wilderness. These features typically occur only in specific locations within a wilderness and may 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.

<u>Indicators and measures</u>
Measures were selected for the indicators recommended in Keeping It Wild in the National Park Service. The following indicators, with measures and their relevance to other features of value, were used:

Indicator: Deterioration or loss of archeological resources integral to wilderness character.
- Condition of archeological sites - diminished conditions of archeological sites degrades the other features of value quality.

Indicator: Deterioration or loss of constructed environments integral to wilderness character.
- Condition of classified structures – diminished conditions of classified structures that are unique to OLYM degrades the other features of value quality.
- Condition of cultural landscapes – diminished conditions of cultural landscapes unique to OLYM degrades the other features of value quality.

<u>Data sources, processing and cautions</u>
The other features of value quality datasets are all vector data, of high scale, and high accuracy and completeness (Table 11).

Table 11. Other features of value quality datasets.

Measures	**Source**	**Type**	**Scale**	**Accuracy**	**Completeness**
Condition of archeological sites	OLYM OLYM_ARCH_SITES_CONDITION_POLY	Polygon	1:10,000	High	Medium
Condition of classified structures	OLYM List of classified structures	Polygon	10m	High	High
Condition of cultural landscapes	OLYM Cultural_ landscapes	Polygon	1:10,000	High	High

Condition of archeological sites
- Sources: OLYM ASMIS point dataset buffered to protect sensitive data OLYM_ARCH_SITES_CONDITION_POLY
- Processing: The locations of archeology sites occurring in OLYM are given values based on their condition: Fair = 1, Poor = 2.
- Cautions: This data is highly sensitive.

Condition of classified structures

- Sources: OLYM List of classified structures polygon dataset
- Processing: The locations of classified structures occurring in OLYM are given values based on their condition: Fair = 1, Poor = 2, Destroyed = 3.
- Cautions: None.

Condition of cultural landscapes

- Sources: OLYM Cultural landscapes inventory.
- Processing: The locations of cultural landscapes occurring in OLYM are given values based on their condition: Fair = 1, Poor = 2.
- Cautions: None.

Weighting

The first page of the methods section describes the underlying principle for using a weighting system. A rationale is provided for the weight of each measure (Table 12). The "weighted" measures under each indicator total 100.

Table 12. Indicators and measures for the other features of value quality with weights and rationale.

Indicator	Measure	Weight	Rationale
Archeological resources	Condition	100	Identified in the 2008 General Management Plan (GMP) as an important resource to monitor and preserve
Constructed environment	List of classified structures (LCS)	50	Historic structures are identified in the GMP as an important resource to protect and preserve
	Cultural landscapes inventory (CLI)	50	Important to assess in order to retain a high degree of integrity on cultural landscapes as specified in the GMP
		200	

Maps

The weighted measures for the constructed environment indicator are added together using a raster calculator and maps are created for deterioration or loss of archeological resources integral to wilderness character and deterioration or loss of constructed environments integral to wilderness character (Figure 16). After these indicator maps are created, the raster calculator is used to add the two indicator maps together to create the other features of value quality map (Figure 17).

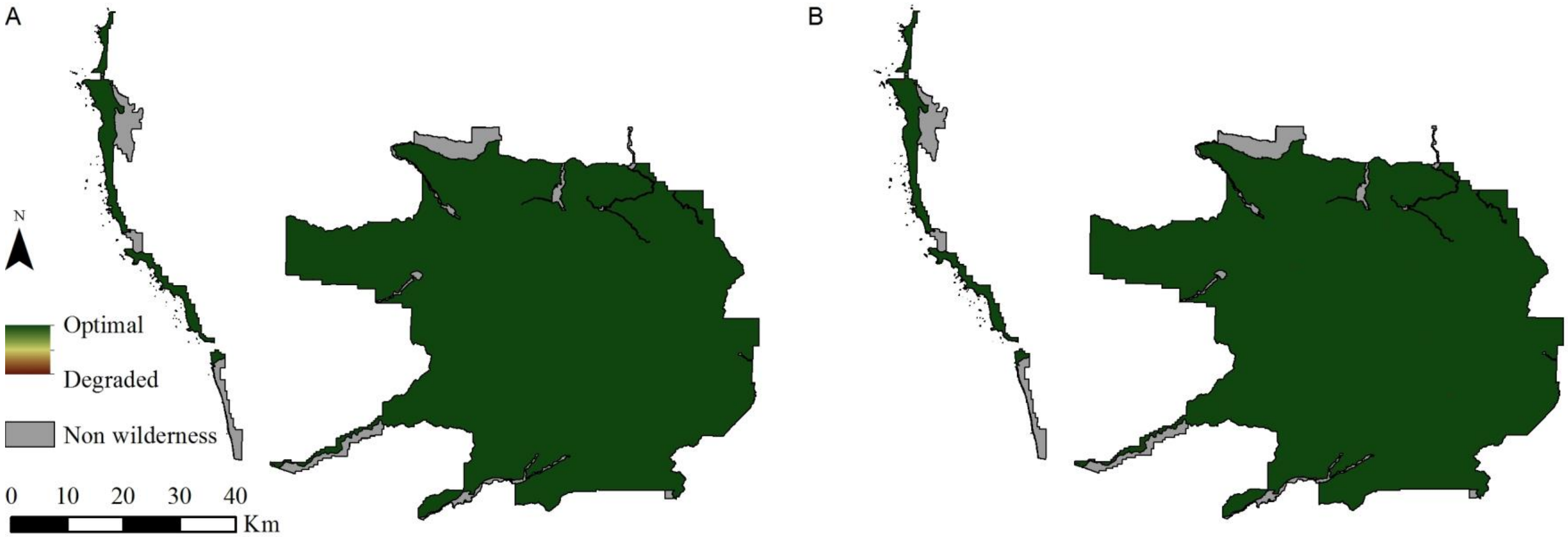

Figure 16. Indicator maps for (A) deterioration or loss of archeology integral to wilderness character, and (B) Deterioration or loss of constructed environments integral to wilderness character. Green depicts optimal quality and brown depicts degraded quality.

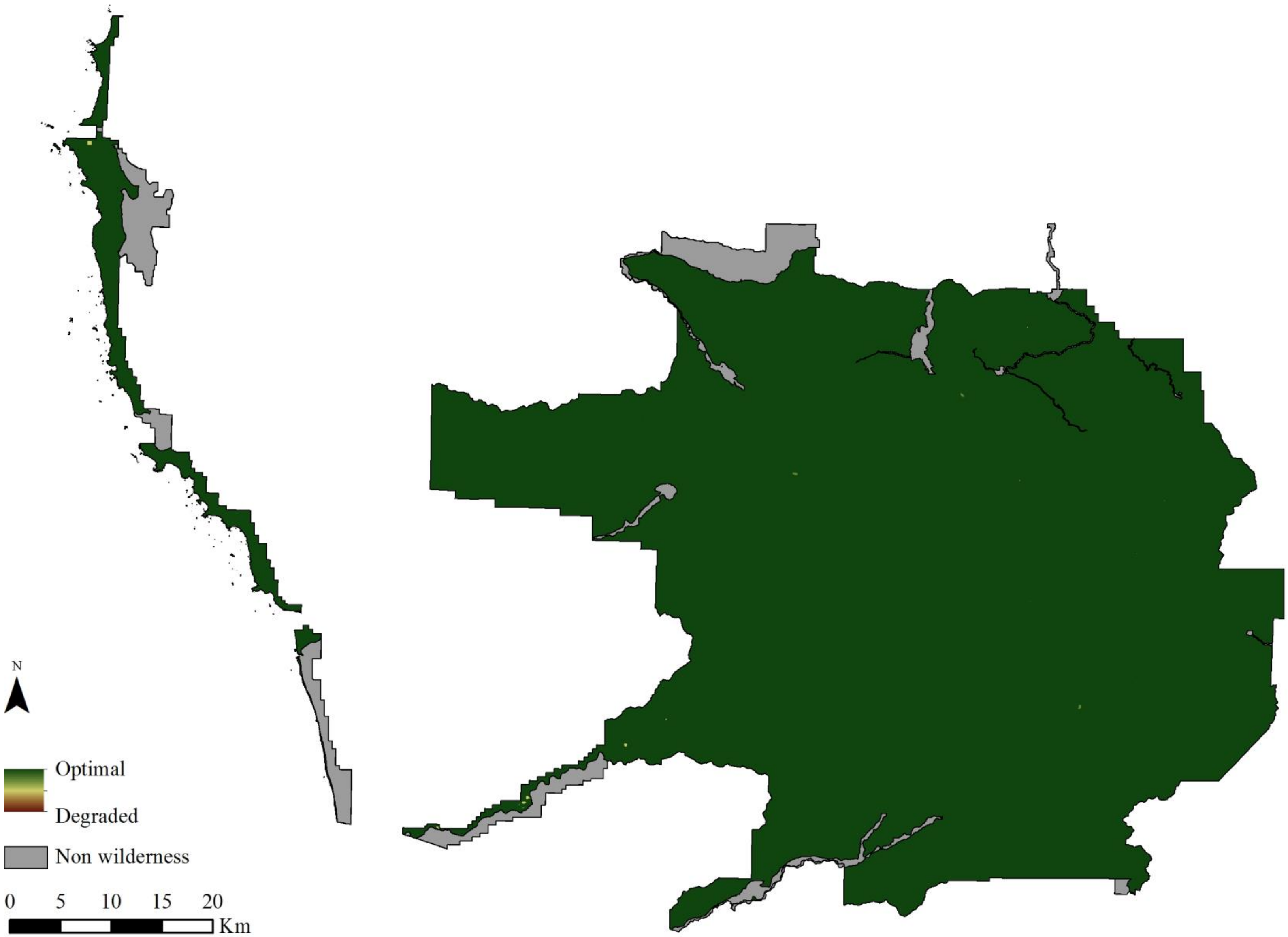

Figure 17. Other features of value quality of wilderness character. Green depicts optimal quality and brown depicts degraded quality.

THE WILDERNESS CHARACTER MAP

The methodology described produces five maps, one for each of the qualities of wilderness character. These maps are then combined to produce a single map of overall wilderness character quality in OLYM. 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. It is then necessary to clip out the non-wilderness areas of OLYM (as the analysis was run for the entire park) when presenting the maps (Figure 18).

Interpreting and discussing these maps requires a clear understanding of the methods used and the many limitations when creating the map products. For example, it is noticeable that the natural and solitude maps are distinctly different in appearance to the untrammeled, undeveloped and other features of value maps. This is because the latter maps only use vector data sources, as opposed to a combination of vector and continuous raster data sources used for the other two maps. Furthermore, it is important to emphasize that the maps represent a grid of values (approximately 4 million pixels). The maps are presented using a color ramp and the “minimum – maximum” stretching technique to best represent these values for display and discussion. In addition, the user should bear in mind that the degraded areas in the overall wilderness character map are generated through the analysis of a multitude of measures: to understand why these areas are degraded one must “drill down” into the individual qualities, indicators, and measures.

An equal interval reclassification[19] 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 OLYM (Figure 19). Small pockets of the highest quality category (91-100%) are found around Mount Olympus and Pelton Peak. The next highest category (81-90%) occurs predominantly in the west of the park, particularly along the Bogachiel River, and between the Queets and Quinault Rivers, and in the coastal strip. The 71-80% is the largest category and covers large swathes of the landscape in the central and eastern parts of the main park section. The bottom four categories contain very small pockets of low quality wilderness character. These are typically found near campsite areas and visitor facilities. Looking at the histogram of the distribution of pixel values (Figure 20), it is clear that the majority of the park has mostly high quality wilderness character with the two dominant categories being 71-80% and 81-90%.

[19] This reclassification scheme divides the range of attribute values into equal-sized sub-ranges, allowing the user to specify the number of intervals while ArcMap determines where the breaks should occur (ESRI 2013)

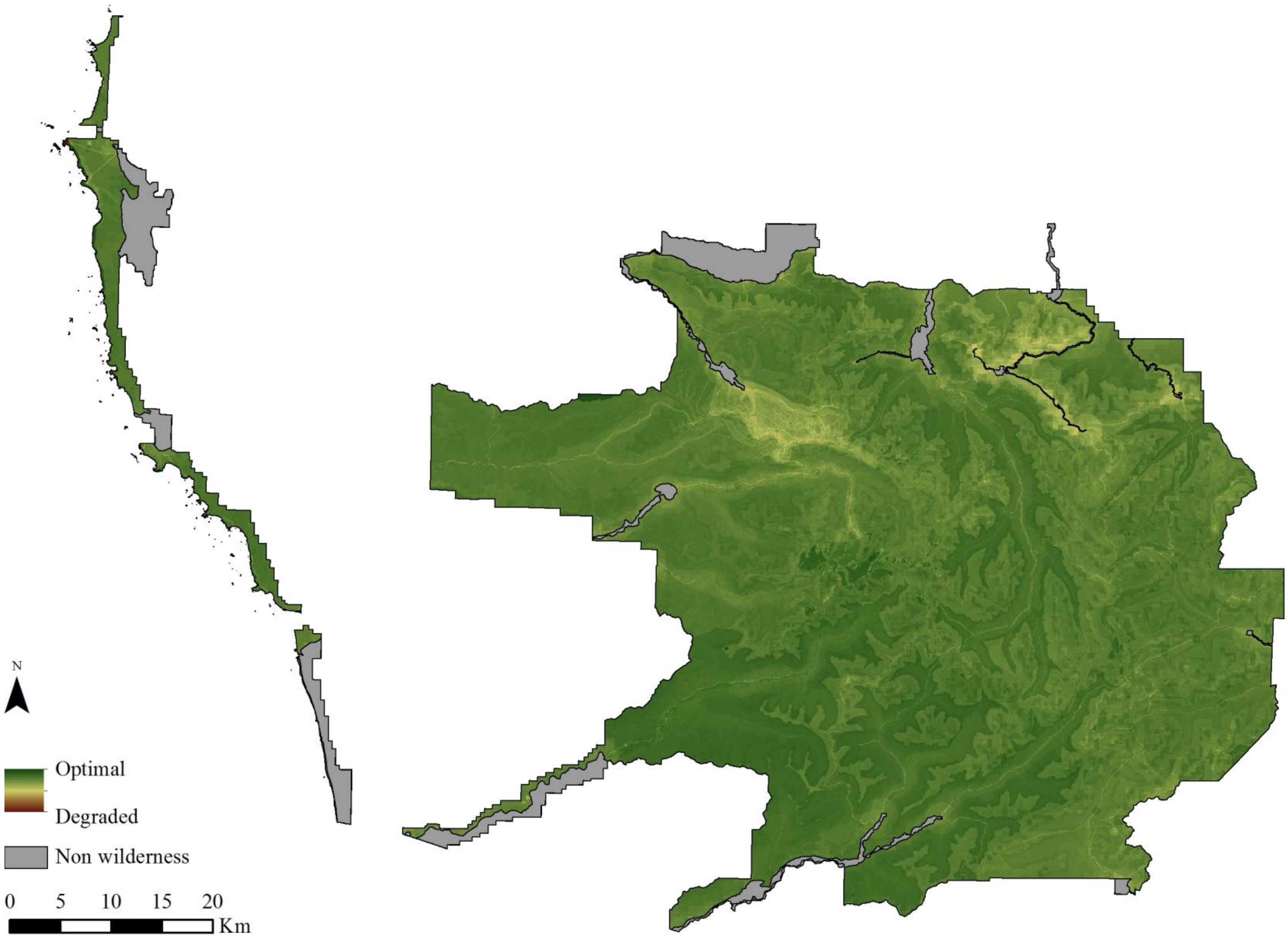

Figure 18. Map of wilderness character in OLYM. Green depicts optimal quality and brown depicts degraded quality.

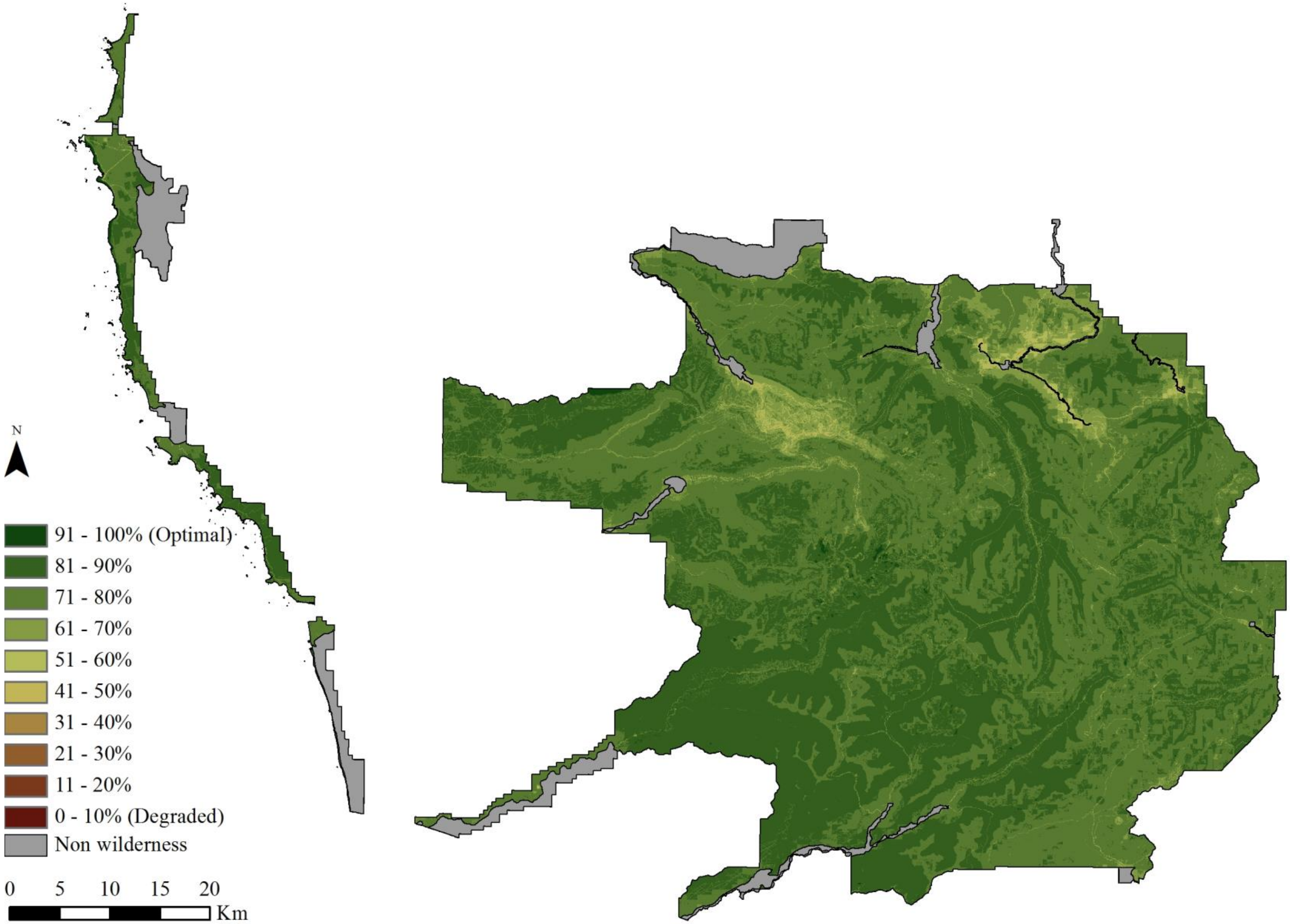

Figure 19. Map of wilderness character in OLYM reclassed into ten equal categories. Green depicts optimal quality and brown depicts degraded quality.

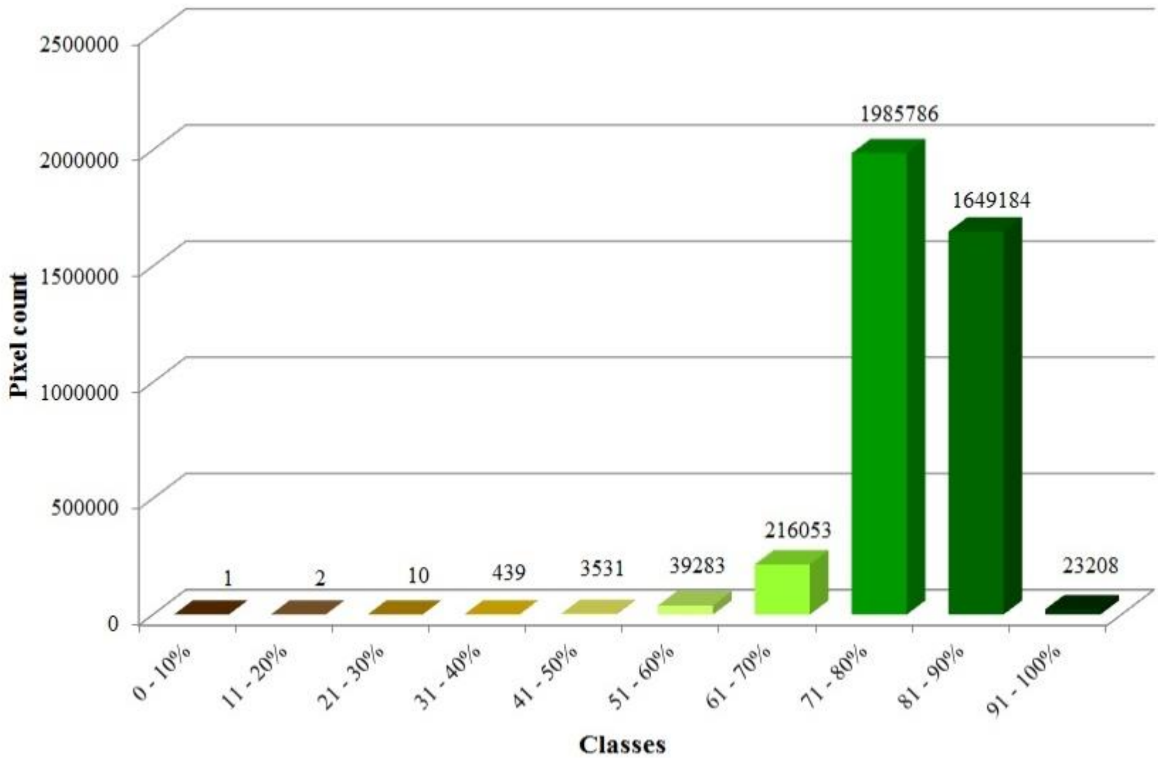

Figure 20. Histogram of the wilderness character map values.

Improvements

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

The issue of data quality also highlights the need for the NPS to manage its spatial database more effectively. Clear communication is required to ensure that contractors providing GIS products for the park submit comprehensive datasets and easy-to-understand metadata. Again, clear communication with scientists conducting research in OYLM can allow for the generation or improvement of spatial datasets that can be used to inform the map products. An example of this communication is the soundscape raster data: discussion with researchers at the NPS Natural Sounds and Night Skies Division facilitated refinements in their model calibration and use of different outputs that are a more accurate of OLYM soundscape.

Park databases can be further improved by creating awareness among park staff to correctly record spatial information gathered in the field. Field staff should be encouraged to learn how to operate GPS units and download data into spatial datasets. Park staff with backcountry experience should be encouraged to meet regularly with GIS technicians to transfer their

knowledge into spatial datasets. Field staff can also be used to ground-truth the accuracy of spatial datasets used in the wilderness character map. In particular, it would be useful to test the output of the travel time and viewshed models against observations in the field.

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

Lastly, there are spatial differences between the park and wilderness GIS boundaries, resulting in a number of slither polygons where these two boundaries overlap. Although this is a relatively minor issue, as these datasets improve the final maps can be rerun to remove these slithers.

Final Concerns about Mapping Wilderness Character

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

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APPENDIX A - Travel impedance for land cover classes

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

OLYM SPECIES - land cover class	Impedance (mph)
Shrub	0.5
Mountain hemlock	0.5
Pacific silver fir	0.5
Sitka spruce	0.5
Conifer mix	0.5
Western red cedar/western hemlock	0.5
Western red cedar	0.5
Alaska yellow cedar	0.5
Douglas fir	1
Western hemlock	1
Subalpine fir	1
Lodgepole pine	1
Hardwood mix	1
Big leaf maple	1
Red alder	1
Less than 25% any species	1
Rock, sparsely vegetated	2
Snow	2
Meadow 1	2
Meadow 2	2
Meadow 3	2
Meadow 4	2
Meadow 5	2
Heather	2
GAP - land cover class	**Impedance (mph)**
North Pacific Broadleaf Landslide Forest and Shrubland	0.5
North Pacific Hypermaritime Sitka Spruce Forest	0.5
North Pacific Hypermaritime Western Red-cedar-Western Hemlock Forest	0.5
North Pacific Maritime Mesic-Wet Douglas-fir-Western Hemlock Forest	1
North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest	1
North Pacific Dry Douglas-fir Forest and Woodland	1
North Pacific Mesic Western Hemlock-Silver Fir Forest	0.5
North Pacific Mountain Hemlock Forest	0.5
North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest	0.5
North Pacific Lowland Mixed Hardwood-Conifer Forest	1
Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland	1
North Pacific Maritime Mesic Subalpine Parkland	1
Northern Rocky Mountain Subalpine Dry Parkland	1
North Pacific Dry and Mesic Alpine Dwarf-Shrubland, Fell-field and Meadow	2
North Pacific Avalanche Chute Shrubland	0.5
North Pacific Montane Shrubland	0.5

North Pacific Hypermaritime Shrub and Herbaceous Headland	0.5
North Pacific Alpine and Subalpine Dry Grassland	2
North Pacific Herbaceous Bald and Bluff	2
North Pacific Maritime Coastal Sand Dune and Strand	1
North Pacific Alpine and Subalpine Bedrock and Scree	0.5
North Pacific Montane Massive Bedrock, Cliff and Talus	0.5
North American Alpine Ice Field	0.5
Rocky Mountain Alpine Bedrock and Scree	0.5
Rocky Mountain Cliff, Canyon and Massive Bedrock	0.5
Temperate Pacific Freshwater Aquatic Bed	0.5
Temperate Pacific Intertidal Mudflat	0.5
Temperate Pacific Tidal Salt and Brackish Marsh	0.5
Temperate Pacific Freshwater Emergent Marsh	0.5
Temperate Pacific Subalpine-Montane Wet Meadow	1
North Pacific Maritime Eelgrass Bed	0.5
North Pacific Bog and Fen	0.5
North Pacific Hardwood-Conifer Swamp	0.5
North Pacific Shrub Swamp	0.5
North Pacific Lowland Riparian Forest and Shrubland	1
North Pacific Montane Riparian Woodland and Shrubland	1
North Pacific Intertidal Freshwater Wetland	0.5
Developed, Open Space (Parks, Golf Courses, Open Space)	3
Developed, Low Intensity	3
Developed, High Intensity	3
Agriculture	3
Pasture/Hay	3
Non-specific Disturbed	2
Recently Mined or Quarried	1
Transitional Vegetation Deciduous Forest	1
Transitional Vegetation Evergreen Forest	0.5
Transitional Vegetation Mixed Forest	0.5
Transitional Vegetation Short Shrub	0.5
Transitional Vegetation Tall Shrub	0.5
Transitional Vegetation Herbaceous - Woody Mix	0.5
Transitional Vegetation Grassland	1
Unconsolidated Shore	0.5