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Mapping Wilderness Character in the Boundary Waters Canoe Area Wilderness

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Abstract

A GIS-based approach was used to depict how threats to wilderness character vary in extent and magnitude across the Boundary Waters Canoe Area Wilderness. Based on the interagency strategy to monitor wilderness character, *Keeping It Wild: An Interagency Strategy for Monitoring Wilderness Character Across the National Wilderness Preservation System* (Landres et al. 2008a), 53 locally relevant measures were identified by the project core team to capture impacts to the five qualities of wilderness character. These measures were depicted using a variety of spatial datasets, which were normalized using a common relative scale such that disparate metrics could be analyzed together. Each measure was "weighted" by the project core team to reflect its relative impact to wilderness character. Maps generated for each of the weighted measures were then added accumulatively to create a combined map delineating the overall spatial pattern and variation of threats to wilderness character across the Boundary Waters Canoe Area Wilderness. This combined map depicts a wilderness that has not been substantially impacted by threats, with the highest quality wilderness character primarily found away from entry points and travel routes, especially in areas with fewer and smaller lakes; in contrast, the lowest quality wilderness character was highly correlated with lakes that allow motorized use, especially those that are wilderness entry points. The map products presented in this report provide managers with a tool to better understand the extent and magnitude of threats to wilderness character, holistically evaluate tradeoffs associated with decisions and actions in wilderness, and ultimately improve wilderness stewardship.

Keywords: Wilderness Act, wilderness, wilderness character, mapping wilderness character, Boundary Waters Canoe Area Wilderness, Superior National Forest

Cover—River in the Boundary Waters Canoe Area Wilderness (photo by Ann Schwaller).

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Executive Summary

The recent development of an interagency strategy to monitor wilderness character, *Keeping It Wild: An Interagency Strategy for Monitoring Wilderness Character Across the National Wilderness Preservation System* (Landres et al. 2008a), allows on-the-ground managers and decisionmakers to assess whether stewardship actions for an individual wilderness are fulfilling the legislative mandate to "preserve wilderness character." By using credible data that are consistently collected, one can assess how wilderness character changes over time and evaluate how stewardship actions affect wilderness character. As most of these data depict spatial or geographic features in wilderness, a Geographic Information System (GIS)-based approach was developed to depict threats to wilderness character in the Boundary Waters Canoe Area Wilderness (BWCAW).

A set of measures was identified by the project core team to capture impacts to the five qualities of wilderness character (untrammeled, natural, undeveloped, solitude or primitive and unconfined recreation, and other features of value). These measures were depicted using a variety of spatial datasets, which were normalized using a common relative scale such that disparate metrics could be analyzed together. Each measure was "weighted" by the project core team to reflect its relative impact to wilderness character. Maps generated for each of the weighted measures were then added together to produce a composite map of threats to wilderness character. The map products presented in this report delineate the spatial pattern and variation of threats to wilderness character across the BWCAW.

These maps will be used by Superior National Forest staff to inform and support forest plan revisions, Wilderness Stewardship Performance planning, and management decisionmaking. The maps, and this approach, do not represent a determination of significant effects, nor do they endorse specific management decisions or trigger management action. Instead, this project provides managers with a tool to better understand the extent and magnitude of threats to wilderness character across the BWCAW, holistically evaluate tradeoffs associated with decisions and actions in wilderness, and ultimately improve wilderness stewardship.

Foreword

Beginning in 2013, the Superior National Forest partnered with the Aldo Leopold Wilderness Research Institute to develop a map of threats to wilderness character in the BWCAW. The primary goal of this project was to spatially depict how threats to wilderness character vary in magnitude and extent across the wilderness. This project was also intended to improve our understanding of the current condition of wilderness character, contribute to planning efforts by facilitating the evaluation of broad-scale impacts to wilderness character, and create a baseline from which changing threats to wilderness character can be monitored over time. As the first National Forest to map threats to wilderness character for use in future planning efforts, the Superior National Forest has been nationally recognized for our commitment to outstanding wilderness stewardship and received the 2014 Aldo Leopold Award for Overall Wilderness Stewardship Program.

More than 50 people across various disciplines and organizations contributed their expertise, knowledge, and feedback to making this project a success. Internal collaboration spanned a variety of resource fields, including: air, archaeology, botany, ecology, fire/fuels, fisheries, geology, hydrology, law enforcement, recreation, silviculture, soils, wilderness, and wildlife. External consultation included representatives from Federal and State agencies, universities, and non-profit organizations. The highly collaborative nature of this project ensured a comprehensive approach to understanding and spatially representing threats to wilderness character in the BWCAW.

The map products presented in this report provide managers with a valuable tool for understanding how threats to wilderness character vary across the wilderness. While these maps are not an absolute or incontrovertible determination of the condition of wilderness character, they are estimates of selected impacts and limited by the quality and availability of spatial datasets. They represent our best approximation of the threats to wilderness character in the BWCAW. Overall, we consider the map products presented in this technical report to be a vital resource for wilderness managers that will help us understand the myriad effects of actions taken in and adjacent to wilderness, to make thoughtful and informed stewardship and planning decisions, and to improve our effectiveness in preserving wilderness character.

Richard Periman
Acting Forest Supervisor, Superior National Forest

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Acronyms and Abbreviations

ALR—Anthropogenic Light Ratio
BWCAW—Boundary Waters Canoe Area Wilderness
CASTNET—Clean Air Status and Trends Network
CMAQ—Community Multiscale Air Quality
dBA—A-Weighted Decibels
DEM—Digital Elevation Model
DHS—Department of Homeland Security
DSM—Digital Surface Model
EPA—Environmental Protection Agency
FSM—Forest Service Manual
GIS—Geographic Information System
HP—Horsepower
MBS—Minnesota Biological Survey
Minnesota DNR—Minnesota Department of Natural Resources
MODIS—Moderate Resolution Imaging Spectroradiometer
NNIS—Non-Native Invasive Species
NPS—National Park Service
NWPS—National Wilderness Preservation System
OHV—Off-Highway Vehicles
PRISM—Parameter-Elevation Regressions on Independent Slopes Model
RAWS—Remote Automated Weather Stations
SNF—Superior National Forest
SNOTEL—Snowpack Telemetry
TIFF—Tagged Image File Format
USGS—U.S. Geological Survey
USDA—U.S. Department of Agriculture

Introduction

The Wilderness Act of 1964 established the National Wilderness Preservation System (NWPS) "for the protection of these areas, [and] the preservation of their wilderness character" (Wilderness Act of 1964, Section 2[a]). In congressional testimony clarifying the intent of wilderness designation, Howard Zahniser (1962) said, "The purpose of the Wilderness Act is to preserve the wilderness character of the areas to be included in the wilderness system, not to establish any particular use"; legal scholars (McCloskey 1999; Rohlf and Honnold 1988) subsequently confirmed that preserving wilderness character is the Act's primary legal mandate. Furthermore, the policies of all four wilderness managing agencies state that they are to preserve wilderness character in all areas designated as wilderness.

The condition of wilderness character varies across a wilderness based on the intensity and distribution of human influences that degrade it (Forest Service Manual [FSM] 2320.6) (USDA Forest Service 2007). Just as variation in other landscape features can be depicted spatially, so too can the condition of wilderness character. Maps depicting spatial variation in wilderness attributes have been produced at a variety of scales: globally (Sanderson and others 2002), continentally (Carver 2010), nationally (Aplet and others 2000), and locally (Carver and others 2008). Adding to this body of work, a recent study for Death Valley National Park (Carver and others 2013; Tricker and others 2012) provided a spatially explicit description of how impacts to wilderness character vary across the Death Valley Wilderness. This approach has been strongly supported by the National Park Service (NPS), and further studies have been conducted for wildernesses within Olympic, Denali, Sequoia and Kings Canyon, Saguaro, and Gates of the Arctic national parks. The Boundary Waters Canoe Area Wilderness (BWCAW) is the first Forest Service administered wilderness for which this approach has been used to develop a map of threats to wilderness character.

The Boundary Waters Canoe Area Wilderness

The BWCAW was one of the original wildernesses designated by the Wilderness Act. First recognized for its unique recreational opportunities in 1926 when it was designated as a primitive area by the Secretary of Agriculture, it was named the Superior Roadless Primitive Area in 1938. Efforts to preserve public recreational opportunities in the area began soon after its establishment. The Izaak Walton League of America established an endowment in 1943 to raise funds for the purchase of private lands in the primitive area, which were then sold to the Forest Service until 1961. Shortly after, the Thye-Blatnik Act of 1948 allowed Federal acquisition of adjacent resorts and other private lands until 1968. An Executive Order issued by President Truman in 1949 also created an air-space reservation of 4,000 feet (the only such reservation held by a wilderness area today). After being renamed as the Boundary Waters Canoe Area in 1958 and designated as wilderness in 1964, additional legislation—the Boundary Waters Canoe Area Wilderness Act of 1978 (Public Law 95-495)—increased the wilderness acreage, terminated logging activity, established the Mining Protection Area, and limited and regulated motorized recreation in the area. Over 17 million federal dollars were spent between 1980 and 1990 to implement the 1978 Boundary Waters Canoe Area Wilderness Act, including funding private land purchases, recreation construction, assistance to resorts, and assistance to communities.

Located in the Superior National Forest (SNF) in northeastern Minnesota, the BWCAW is over 1,098,000 acres in size and extends nearly 150 miles along the international boundary with Canada. Voyageurs National Park, encompassing over 125,000 acres of recommended wilderness, lies directly to the west of the BWCAW, while Canada's Quetico Provincial Park, with over a million acres of land managed as wilderness, lies to the north. Together, these three contiguous areas form a wilderness core of approximately 2.5 million acres in the heart of the North American continent (fig. 1). This core is surrounded by a network of protected lands that include the non-wilderness areas of the SNF, Grand Portage National Monument, and numerous State and provincial parks. Within the SNF, four ranger districts—La Croix, Kawishiwi, Tofte, and Gunflint—administer the BWCAW (fig. 2).

The BWCAW is the only large temperate lake-land wilderness in the NWPS and is renowned for its water-based recreational opportunities. Great glaciers repeatedly scraped and gouged this area over the past 2 million years, leaving behind rugged cliffs and crags, gentle hills, shorelines of exposed bedrock, sandy beaches, and an abundance of rivers and lakes dotted with islands. With several hundred miles of streams and over 1,000 lakes (varying in size from 10 acres to 10,000 acres), approximately 190,000 acres (20 percent) of the surface area of the BWCAW is water. This network of connecting waterbodies provides unique opportunities for long distance travel by watercraft—a rare experience within the continental United States. Around the lakes and rivers, a mix of wetlands, boreal forest, and temperate hardwoods provides habitat for iconic north woods species such as wolves, black bears, bobcats, lynx, moose, beavers, loons, bald eagles, and peregrine falcons.

Humans have been occupying and visiting the area that is now the BWCAW for millennia. Archaeological sites dating back over 10,000 years attest to the long history of human presence in this area. More recent cultural resource sites provide glimpses of the beginning of European contact with Native Americans, the fur-trade and the voyageurs, the period of logging, mining, and settlement, and the work of early managers including the Forest Service and the Civilian Conservation Corps. Visitors today enjoy similar experiences and opportunities to those that came generations before, connecting them to the past as they contribute to the enduring human relationship with the land.

The BWCAW is one of the most popular wilderness areas in the country and receives approximately 150,000 visitors each year. To accommodate the high recreational use, it contains 67 entry point locations with access to over 1,200 miles of canoe routes, 12 hiking trails, and nearly 2,000 designated campsites (each with a latrine and fire grate). Opportunities for canoeing, kayaking, camping, hiking, fishing, and hunting abound in summer and fall, while winter visitors can enjoy ice fishing, skiing, snowshoeing, and dogsledding. The wilderness offers freedom to those who wish to pursue an experience of expansive solitude, personal challenge, and connection with nature.

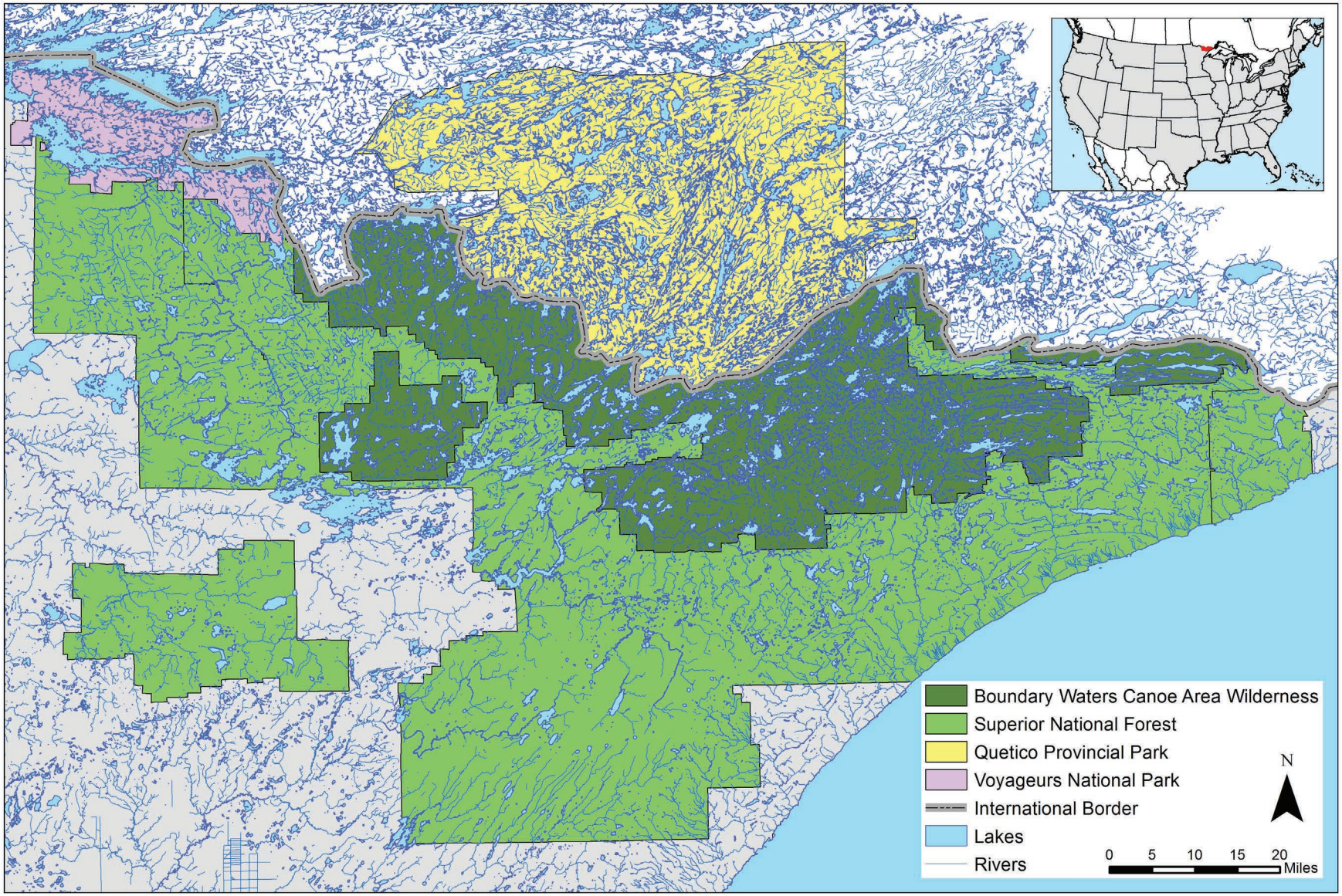

Figure 1—The BWCAW and surrounding protected areas.

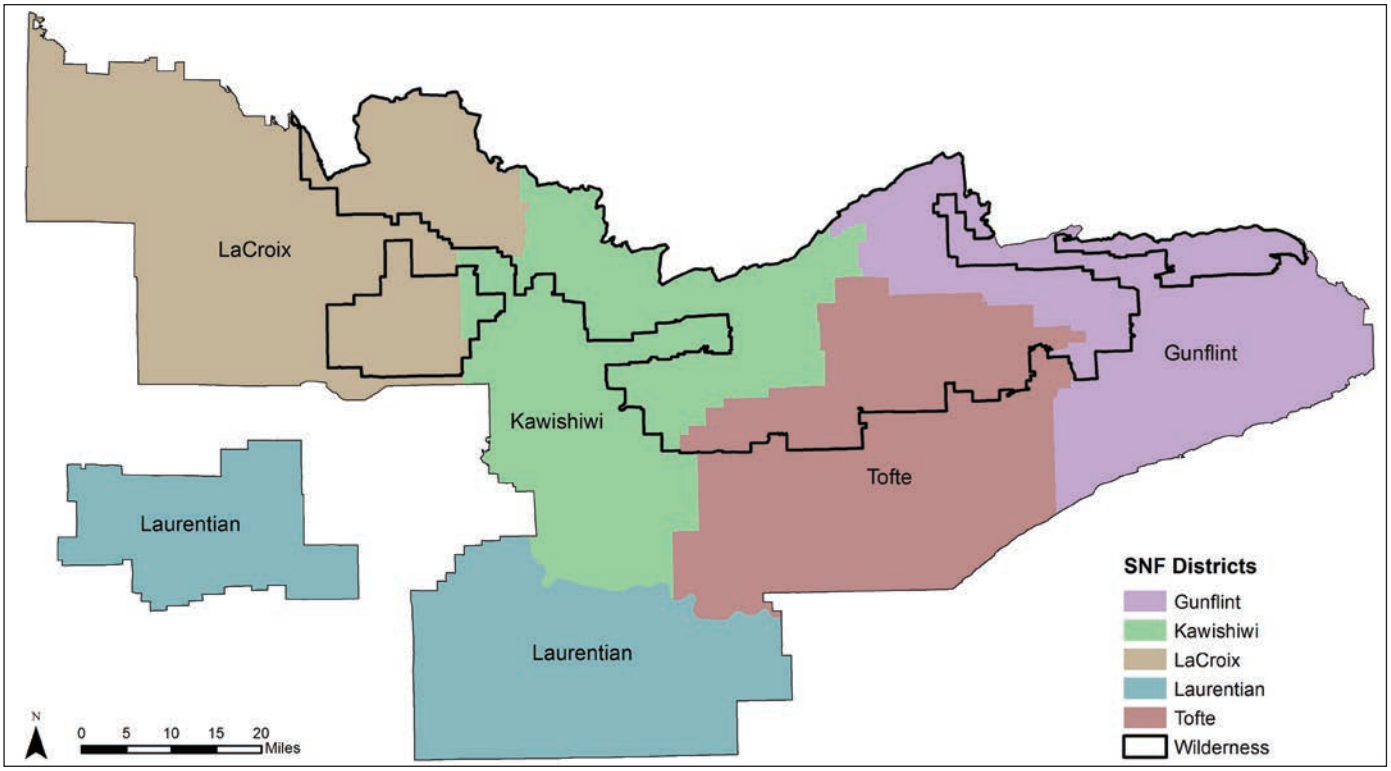

Figure 2—Ranger districts of the SNF and BWCAW.

Purpose of This Mapping Project

The purpose of this project was to develop an approach that spatially depicts threats to wilderness character in the BWCAW and how they vary across the wilderness. This mapping effort:

- Shows the current extent and magnitude of threats to wilderness character and how they vary across the BWCAW;
- Provides a measurement baseline from which future monitoring can show how threats to wilderness character change spatially over time;
- Allows the SNF to analyze the potential impacts of different management actions on wilderness character;
- Identifies areas within the wilderness where resource managers should make an effort to control or mitigate impacts, including monitoring conditions, establishing thresholds, or taking direct action;
- Identifies specific activities or impacts outside the wilderness that may pose a substantial risk of degrading wilderness character inside wilderness;
- Improves internal staff communication about wilderness and wilderness character and improves external communication between the forest and the public on related issues; and
- Identifies and fills data gaps by collecting information from local staff and digitizing new spatial data.

In addition to the immediate benefits described above, this project improved and consolidated existing spatial datasets and generated new datasets. These datasets, and the maps produced by this project, lay the groundwork for future wilderness character mapping efforts in the BWCAW. When and if the SNF is able to conduct future iterations of the map of threats to wilderness character, the maps in this report can serve as the baseline for assessing how threats to wilderness character change spatially over time.

Concerns and Cautions

There are a number of potential concerns about producing maps of threats to wilderness character. Despite these concerns, managers have recognized these maps as the best available tool for spatially representing impacts to wilderness character. Following are some major cautions to consider about this overall effort.

- *Creating sacrifice zones*—The map may facilitate the inappropriate creation of "sacrifice zones" or internal buffers 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. Forest Service wilderness policy explicitly prohibits this by stating: "Do not maintain internal buffer zones that degrade wilderness values" (FSM 2320.3) (USDA Forest Service 2007). By showing the current extent and magnitude of threats to wilderness character and how they vary across the entire wilderness, the intent of the map is to help staff maintain high quality areas while improving lower quality areas.

- *Comparing wilderness character among wildernesses*—Since this approach has been used for other wilderness areas, the map may facilitate inappropriate comparisons of wilderness character among different wildernesses. These maps show the current extent and magnitude of threats to wilderness character in different colors (representing pixel values), and it would be easy for users to compare the quantity of a given color from one wilderness to another. 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 map completely describes wilderness character*—The map may be misconstrued as an accurate and precise description of wilderness character. The map is instead only an estimate of selected threats to wilderness character for which spatial data were available for this particular wilderness. As an approximate representation of threats to wilderness character, the map should not be considered an absolute and complete description. In addition, the map does not portray the threats to the symbolic, intangible, spiritual, or experiential values of wilderness character. In short, while this map is useful for the purposes outlined above, it does not describe the complexity, richness, or depth of wilderness character.

- *Updating datasets in the future such that maps are not directly comparable*—As datasets are updated over time, future iterations of the map may not be comparable

with the original map. Each map is a product of both the best available spatial data and the locally defined methods for processing those data. As with all long-term monitoring efforts, changes in the type and quality of data or in the data processing techniques can make comparisons between original and subsequent data invalid. Therefore, proposals to use new or altered data, or to change data processing methods, need to be assessed carefully to ensure the comparability of map products over time.

Report Outline

A team approach was used to develop the map of threats to wilderness character in the BWCAW, tapping the experience and knowledge of SNF staff (see page ii for a full list of staff involved). Together, the project core team and other SNF staff have more than 400 person-years of on-the-ground experience in and with the BWCAW. The project core team, and other SNF staff as required, conducted many face-to-face meetings and had numerous phone and email conversations while developing the map products described in this report. All decisions about developing the map were made by project core team consensus.

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

- *Overview of the Process for Developing the Map of Threats to Wilderness Character* describes the conceptual foundation for how the map was developed.
- *Methods* describes the measures that were used to represent the degradation of wilderness character, along with the data sources, data processing methods, data and measure cautions, and the rationale for measure weighting.
- *Map of Threats to Wilderness Character* discusses some of the patterns revealed in the map, approaches to improving map development in the future, and final concerns about the overall process.

Overview of the Process for Mapping the Threats to Wilderness Character

This wilderness character mapping project used a Geographic Information System (GIS) to spatially describe and assess impacts to wilderness character in the BWCAW. With this approach, it is essential to understand the variety of activities and influences that "threaten" wilderness character, as well as the role of wilderness managers in mitigating or responding to such threats. In the BWCAW, there has been, and continues to be, a substantial amount of human influence—ranging from a long history of human use and resource extraction, to current high visitation levels, to reasonably foreseeable future impacts from climate change. Although the BWCAW is far from being considered a "pristine" or "pure" wilderness, managers are nevertheless tasked with protecting and preserving its wilderness character from further degradation. As stated in Forest Service policy: "Each designated wilderness is affected by a variety of human influences that vary in intensity. …The goal of wilderness management is to identify these influences, define their causes, remedy them, and close the gap…between the attainable level of purity and the level that exists on each wilderness" (FSM 2320.6) (USDA Forest Service 2007). Only by understanding the myriad human influences that affect—or "threaten"—wilderness character can managers meet wilderness stewardship goals.

For this report, "threats" to wilderness character are defined as a combination of

- Historical activities that continue to degrade wilderness character (e.g., historical logging activity, departure from natural fire regimes);
- Current actions or influences that degrade wilderness character (e.g., non-native invasive species, administrative motorized/mechanized use); and
- Impending issues that are likely to degrade wilderness character into the future (e.g., change in winter temperature, night sky obfuscation).

By identifying and depicting threats to wilderness character, the maps produced in this report provide managers with a tool to better understand the extent and magnitude of impacts to wilderness character in the BWCAW and thereby improve wilderness stewardship.

This project adheres to the interagency strategy for monitoring wilderness character, as described in *Keeping It Wild: An Interagency Strategy for Monitoring Wilderness Character Across the National Wilderness Preservation System* (Landres and others 2008a)[1]. The *Keeping it Wild* monitoring strategy was formally endorsed in 2009 by the Interagency Wilderness Policy Council (which is composed of the highest policy-level personnel responsible for wilderness in each of the four wilderness managing agencies).

[1] An updated interagency wilderness character monitoring strategy, described in *Keeping it Wild 2: An Updated Interagency Strategy to Monitor Trends in Wilderness Character Across the National Wilderness Preservation System* (Landres and others 2015), was released in October 2015 prior to the publication of this report. While this project was based on the original *Keeping it Wild*, early and final drafts of *Keeping it Wild 2* were used for additional clarification and guidance in writing the report.

Therefore, by adhering to the interagency strategy, this project is consistent with Forest Service and interagency policies, terminology[2], and monitoring protocols for wilderness character.

The Five Qualities of Wilderness Character

Keeping It Wild provides a tangible definition of wilderness character and identifies four qualities of wilderness character that apply uniquely to every wilderness: untrammeled, natural, undeveloped, and solitude or primitive and unconfined recreation. These qualities apply to all designated wilderness areas because they are based on the legal definition of wilderness from the Wilderness Act (1964, Section 2[c]). In addition to these four qualities, a fifth quality—other features of value—was also used for this project based on the last clause of Section 2[c] in the Wilderness Act: a wilderness "may also contain ecological, geological, or other features of scientific, educational, scenic or historical value" (Landres and others 2012, 2015).

Actions managers choose to take—or not take—in wilderness have the potential to degrade or improve these qualities and affect wilderness character. Challengingly, actions taken to protect or improve one quality of wilderness character may often result in the degradation of another quality (Landres and others 2008a, 2015). For example, although maintaining latrines at campsites protects water quality and benefits the natural quality, the latrines are also facilities that decrease opportunities for primitive recreation and installations that diminish the undeveloped quality. These types of tradeoffs are inherent to many aspects of wilderness stewardship, and understanding how a single action may have different effects on the qualities of wilderness character is essential for evaluating management decisions and actions in wilderness.

In addition to the actions, or inaction, of managers, wilderness character may also be affected by factors outside the jurisdiction of the Forest Service. For example, air pollution, night sky light pollution, and climate change are not under the direct control of wilderness managers but can still have substantial effects on the qualities of wilderness character. The inclusion of these types of external impacts in the interagency wilderness character monitoring strategy (and, consequently, in this mapping project) does not constitute an application of wilderness laws, policies, and restrictions to non-wilderness areas (i.e., the creation of a "buffer" around wilderness); instead, it is an acknowledgment that broad-scale social and ecological changes may affect wilderness character (Landres and others 2008a, 2015). As stated in Forest Service policy, "Because wilderness does not exist in a vacuum, consider activities on both sides of wilderness boundaries during planning" (FSM 2320.3) (USDA Forest Service 2007).

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[2] Terminology used in this report to describe threats to wilderness character—including "degraded," "negative impact," "significant," etc.—reflects common vocabulary used in laws, policies, and interagency wilderness character monitoring documents. These terms do not imply an analysis of impacts or determination of significant effects, such as required by the National Environmental Policy Act or other agency decisionmaking processes.

Certain activities may be legally allowed in wilderness and yet also threaten wilderness character. Although the Wilderness Act prohibits "nonconforming" uses (such as motorized use, mechanical transport, or the installation of permanent developments), specific exceptions have been permitted through special provisions in the Wilderness Act itself and in subsequent wilderness legislation (such as the Boundary Waters Canoe Area Wilderness Act of 1978). The Wilderness Act (1964, Section 4[c]) states that nonconforming uses or activities may be permitted only "as necessary to meet minimum requirements for the administration of the area for the purpose of this Act (including measures required in emergencies involving the health and safety of persons within the area)." Additional special provisions may also be legislated for a specific wilderness to allow, or require, nonconforming activities by managers or visitors. Even in situations where such uses are both legal and justifiable, however, nonconforming activities still degrade wilderness character (Landres and others 2005, 2008a, 2015). This is supported by Forest Service wilderness policy, which states, "In wildernesses where the establishing legislation permits resource uses and activities that are nonconforming exceptions to the definition of wilderness as described in the Wilderness Act, manage those nonconforming uses and activities in such a manner as to minimize their effect on the wilderness resource" (FSM 2320.3) (USDA Forest Service 2007). Over time, the cumulative effects of these legal yet nonconforming uses may cause a substantial impact to wilderness character, which emphasizes the need to carefully weigh future decisions related to such activities.

The Mapping Framework

The five qualities of wilderness character form the foundation of the interagency monitoring strategy and are the first level of the hierarchical monitoring framework. As described in *Keeping it Wild*, this framework divides wilderness character into successively finer components: the qualities of wilderness character are divided into a standard set of indicators[3], which are monitored in turn through a set of locally relevant measures[4]. For this project, measures were selected by the project core team to represent threats to wilderness character in the BWCAW. Individual measures were mapped using spatial datasets and weighted to reflect their respective influences on wilderness character. Maps of the measures were then added accumulatively using these weights to create maps of the indicators and qualities, as well as an overall map of threats to wilderness character in the BWCAW (fig. 3).

For this mapping project, measures were explicitly selected to represent features, conditions, and actions that threaten wilderness character in the BWCAW. For example, the authorized developments measure depicts where the undeveloped quality has been degraded by the presence of permanent installations. While some actions, conditions, or features in wilderness may have a positive influence on wilderness character (such as the preservation of an endangered keystone species), such "value added" features are

[3] Indicators are distinct and important elements within each quality of wilderness character. They have measurable attributes that can be the focus of wilderness character monitoring efforts.
[4] Measures are specific and tangible aspects of an indicator that can be measured to gain insight into the status of the indicator and to assess trends over time.

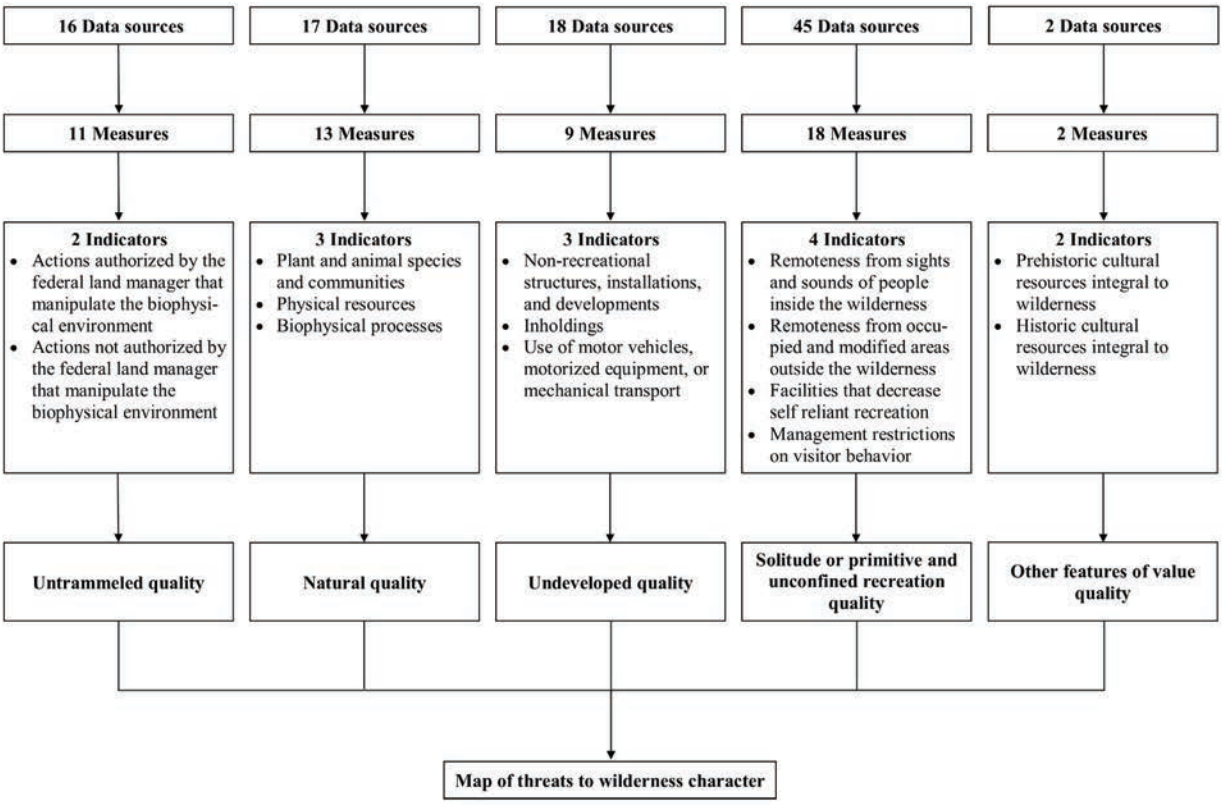

Figure 3—Flow chart of the framework used for mapping threats to wilderness character.

not encompassed by the selected measures. Similarly, when actions or features have a mix of both positive and negative effects (such as management regulations that confine visitors in order to protect natural resources), the selected measures only quantify the negative impacts. The BWCAW project core team decided to adopt this "negative mapping" approach because it allows for the full magnitude of threats to be depicted. In contrast, simultaneously displaying positive and negative impacts on a single map would result in these opposing influences being mutually offset or cancelled out, thereby obscuring the true extent of their individual effects on wilderness character. Therefore, the map products presented in this report only depict threats to wilderness character and do not capture management activities that benefit or improve wilderness character.

At first glance, it could appear inappropriate or meaningless to combine measures into a single overall map since each measure captures a unique and distinct impact to wilderness character. For example, it may seem counterintuitive to combine the areal extent of invasive plants with the probability of encounters with other visitors. However, since all measures quantify threats to wilderness character, combining measures is both appropriate and important for understanding and recording the magnitude of their cumulative effects. Additional information on the rationale and methods for accumulatively combining disparate measures to produce an overall map of threats to wilderness character are described by Carver and others (2013). While data and maps for individual measures are relevant for local management purposes, the intent of this mapping project is also to understand and report on the big picture—to represent the

cumulative spatial pattern and variation of threats to wilderness character. This big picture is a powerful and effective tool for communicating wilderness issues within the agency and with external audiences (Landres and others 2008b).

Mapping threats to wilderness character differs from wilderness character monitoring in a key way. While monitoring efforts focus on assessing change in wilderness character over time by producing a single overall trend direction (i.e., improving/upward, stable, or degrading/downward), this mapping project examined the current (baseline) extent and magnitude of threats to wilderness character and how those cumulative threats vary across the wilderness. The overall map of threats to wilderness character was therefore generated directly from the weighted measures, and it did not undergo a standardization process at each level of the hierarchical framework (as is the case when deriving trends for wilderness character monitoring). This approach allowed the magnitude of threats to be depicted so that qualities with few or lightly weighted measures (i.e., fewer or milder threats) had a proportionally smaller influence on the overall map of threats to wilderness character than qualities with many or heavily weighted measures (i.e., more or greater threats).

The maps produced through this project depict the BWCAW's current degree of departure or degradation from an "optimal condition" of wilderness character. This optimal condition reflects an ideal manifestation of wilderness character as expressed in the Wilderness Act—in other words, a state in which there are no threats to wilderness character. Each measure is depicted across the wilderness on a scale from its "optimal condition" (i.e., no threat) to its most "degraded condition" (i.e., highest current threat level). When the measures are combined accumulatively, therefore, the overall map of threats to wilderness character is similarly depicted on a scale from its optimal condition (i.e., no threats to wilderness character) to its most degraded condition (i.e., highest cumulative threat level from all measures). The optimal conditions depicted in the map products do not represent the condition of wilderness character in the BWCAW in 1964 or in 1978, and therefore cannot be used to determine if threats to wilderness character have increased or decreased since the time of designation.

Methods

Selecting measures under each indicator of the five qualities was an iterative and collaborative decisionmaking process. Possible measures were first identified by the project core team and then evaluated for both their relevance to the indicator and the availability and quality of the required data. SNF staff assessed data quality for each dataset using two metrics: accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is across the wilderness). In general, only measures that were relevant, and that had readily available data of sufficient quality, were included. For certain measures this involved developing new datasets based on institutional knowledge (i.e., drawing known locations of impacts onto paper maps, which were then digitized by Teresa Hanson, SNF GIS Analyst). In some cases, potential measures had insufficient or non-existent data but were acknowledged by SNF staff for their significance to their respective indicators; these "data gap" measures are noted below under each applicable quality. As data improve or become available, the data gap measures should be reevaluated for inclusion in future iterations of the map of threats to wilderness character.

Weighting Measures

Once all measures were selected, each was evaluated independently to determine the magnitude of its effect on wilderness character. Some measures have a greater impact to wilderness character than others; for example, the shoreline erosion measure has a relatively smaller impact (because it only occurs at one location), whereas the departure from natural fire regimes measure has a relatively greater impact (because fire suppression is widespread and causes blowdowns, tree species changes, and fuel buildup). To accurately portray the variable magnitudes of the measures' effects, each measure was assigned a "weight" —a value from 1 (low impact) to 10 (high impact)—by the project core team. The project core team then reviewed the map outputs and modified the weighting scheme to reflect their knowledge of the condition of wilderness character on the ground. While this interactive process runs the risk of allowing staff to "game the system" to produce a desired outcome, staff experience has been shown to be highly accurate in judging resource conditions (Cook et al. 2009). The project core team used caution and consensus-driven oversight to ensure accuracy in the maps produced.

Specific rationales for weights assigned to each measure can be found in tables 2, 4, 6, 9, and 11 under their respective qualities. The following questions were used to help determine weights for all measures:

- Is the measure specific to a particular area (lower weight) or spread throughout the wilderness (higher weight)?
- Does the measure represent a major management issue, e.g., suppressed fires (higher weight), or is it something relatively benign, e.g., boundary markers (lower weight).
- Does the measure depict an emerging threat that requires intensive management, e.g., the spread of non-native invasive species (higher weight), or does it depict

an issue that has largely been solved and is no longer of high concern to management, e.g., sulfur deposition (lower weight)?

- Is the measure relevant to a particular time of year or season (lower weight), or is it an issue year-round (higher weight)?
- Are the data representing the measure accurate and complete (higher weight) or are they of poorer quality (lower weight)?
- Are the data qualitative (lower weight) or quantitative (higher weight)?

Data Sources and Processing Techniques

Measures were mapped by applying GIS-based techniques to their respective datasets. A total of 87 datasets were used for measuring and delineating threats to wilderness character in the BWCAW. These datasets were obtained from a variety of sources and comprised local, regional, and national spatial data at varying scales, accuracy, and completeness. This variation placed limitations on how the map products were developed and necessitated the use of adaptable data processing methods, as described below. Metadata were developed for each data layer used in this mapping project and include documentation of processing flows, quality/completeness, editing, development, and cautionary notes. All data and metadata were organized and stored on a network drive to ensure accessibility and facilitate use in future analyses. Datasets included

- Commonly used data layers that are stored in the SNF's Spatial Reference Library (a centrally located geospatial repository that is accessible to SNF staff);
- Existing data layers associated with previous or ongoing SNF projects;
- Existing datasets that were edited, combined, or refined as a prerequisite for use in this project; and
- Original datasets that were developed from local sources (including records, reports, and expert knowledge) and converted into a geospatial format.

A number of basic processing tasks were performed using ArcGIS[5] for datasets before they were used as measures to create the map of threats to wilderness character. All datasets were projected in ArcGIS using the NAD 1983 UTM Zone 15N coordinate system. For vector[6] datasets, a value was assigned to each feature by the project core team to represent its spatial impact in the BWCAW. Some of the vector datasets had features with a range of values because of the data they represent; for example, under the authorized developments measure, small markers and plaques were ranked with a value of 1, larger dams and docks with a value of 2, and functional structures with a value of 3. The vector datasets were then converted to raster grids[7] whereby locations of the features or their associated effects were represented by the assigned values; unaffected areas of the wilderness (i.e., where no degradation occurs) were set to a value of 0.

[5] GIS software developed by Environmental Systems Research Institute.
[6] Vector data type uses points, lines, and polygons to represent features.
[7] Raster data type consists of rows and columns of cells, with each cell storing a single value.

The values for all raster grid layers were normalized[8] by stretching them to a standardized range of values (0–255). This normalized range of values allows datasets, and therefore measures, to be evaluated together on a common relative scale (Carver and others 2008). For example, the campsite noise inside wilderness and nitrogen deposition measures use different units (decibels vs. parts per billion) and cannot be directly compared without normalization. Lower values of normalized measures were used to represent optimal conditions (i.e., no threat) and higher values to represent degraded conditions (i.e., high threat level).

In the following sections, the measures and datasets used are described for each of the five qualities of wilderness character. Measures are organized by their weight within each quality, with higher weighted measures listed first. For each measure included in this analysis, the specific data sources, processing, and cautions are also described. All datasets and measures used the units of the original data source(s); throughout this report, metric units (e.g., kilometers) and imperial units (e.g., miles) are used interchangeably. The maps represent a grid of values (approximately 5 million pixels at a 30-meter resolution) and use a blue-red color ramp and the "minimum-maximum" stretch method[9] to enhance the color contrast; areas of optimal condition (no threat) are shown in blue, while areas of degraded condition (high threat level) are shown in red.

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

[9] The stretch method defines the type of histogram stretching that was applied to raster datasets to enhance their appearance. The minimum-maximum stretch applies a linear stretch on the output minimum and output maximum pixel values, which were used as endpoints for the histogram (ESRI 2015).

Untrammeled Quality

The untrammeled quality focuses on the degree to which wilderness is unhindered and free from modern human control or manipulation. The untrammeled quality is degraded by actions that intentionally manipulate or control ecological systems (in contrast to the natural quality, which is degraded by the *effects* of modern civilization) (Landres and others 2008a, 2015).

To spatially depict the baseline of threats to untrammeled quality in the BWCAW, the project core team decided to provide a cumulative summary of all trammeling actions from 1978 (the year of the Boundary Waters Canoe Area Wilderness Act) to 2014. While some measures had data available for the entire 37-year period, other measures did not; in these cases, the most recent complete datasets were used instead.

Indicators and Measures

Keeping it Wild delineates two indicators under the untrammeled quality. The measures selected for the BWCAW are described below for each of these indicators. No data gap measures were identified for this quality.

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

- Suppressed fires—Locations where naturally ignited fires were suppressed. Wildfires are natural ecosystem processes and their suppression interferes with the biophysical environment. Fire suppression occurs either across the areal extent of a fire or along a particular front. The SNF has been suppressing naturally ignited fires since its establishment in 1909. From 1994 to 2013 there were 14 large wildfires in the BWCAW that received a suppression response.
- Fish stocking—Lakes where fish stocking has occurred. The intentional introduction of native or non-native species is a manipulation of the wilderness and its community of life. Since the 1930s, the Minnesota DNR has been stocking fish in the area that is now the wilderness. While species that were stocked before 1978 and have survived to the present day are now considered to be indigenous, the act of bringing native *or* non-native animals into the wilderness is still a trammeling action. From 1988 to 2013, 72 lakes were stocked with fish; species stocked included lake trout, brook trout, rainbow trout, and walleye.
- Prescribed fires—Areas burned by prescribed fires. Prescribed burns are used to deliberately manipulate vegetation communities and influence fire regimes. In the BWCAW, prescribed burns are intended to help offset decades of fire suppression. From 2000 to 2013, 21 prescribed fires were ignited in the wilderness.
- Fish surveys—Lakes where fish surveys have been conducted. Surveys of fish and wildlife interfere with animal communities and cause significant stress or mortality for the individuals captured. Surveying lakes for fish can involve setting nets with buoys, angling, seining, and/or electrofishing. The Minnesota DNR has been conducting fish surveys in what is now the wilderness since the 1930s; from 1978 to 2013, the DNR surveyed 396 lakes.

- Non-native plant treatments—Locations where non-native invasive plants were treated manually and chemically. The intentional treatment or removal of plants, especially in significant numbers, purposefully alters vegetation communities. Most non-native terrestrial plants in the wilderness are restricted to disturbed areas such as trails, portages, campsites, and burned areas. From 2009 to 2013, non-native invasive plants were treated at 1,781 locations in the BWCAW; the majority of these locations were treated by hand-pulling or cutting plants.
- Dam water level manipulation—Active dams affecting water levels. Dams allow humans to manipulate wilderness hydrology by controlling water flow, which can affect flow regimes, channel shape, sediment transportation, water temperature and chemistry, and shoreline erosion. Out of 31 dams in the BWCAW, only a limited number are still functioning and impounding water. Of these, only two—the Fall Lake and Prairie Portage dams—are still active and causing fluctuations in water levels.
- Animal manipulation—Locations of beaver and wolf captures by authorized agencies. Trapping wildlife causes significant stress to individual animals and interferes with the community of life in wilderness. Two species are trapped by authorized agencies in the BWCAW: the Minnesota DNR traps and removes beavers, and the USGS captures wolves. Beaver removal was conducted on Big Rice, Little Rice, La Pond, Duck, Muskeg, Hula, and Wood lakes from 2006 to 2012 to improve waterfowl habitat. From 2005 to 2014, 183 wolves were captured (and some collared) for research purposes, mainly on the east side of the Kawishiwi District and the west side of the Tofte District.
- Soil disturbance—Locations where significant authorized soil disturbance has taken place since 1964. Soil disturbance involves the movement or removal of earth and rocks, and it alters the natural environment. In the BWCAW, the primary causes of significant soil disturbance are actions associated with the construction, maintenance, and restoration of authorized visitor facilities; examples of these types of activities include bridge or boardwalk installation, retaining wall construction, shoreline stabilization, and other actions taken to prevent resource damage on portages and campsites. Exploratory drilling also occurred from 1964 to 1978 and produced seven drill holes on the eastern side of the wilderness.
- Fish spawn collection—Lakes where fish spawn have been collected. The collection and removal of fish and wildlife—including spawn—causes stress to trapped and handled individuals and is a direct manipulation of the biophysical environment. Spawn collection is conducted by the Minnesota DNR and involves corralling fish using weirs, handling fish to extract their eggs, and removing spawn from the wilderness. Lake trout spawn have been tested and/or taken from Gillis Lake (from 1980 to 2008) and Mountain Lake (from 2002 to present).

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

- Vandalism of natural resources—Known locations where visitors intentionally manipulated or vandalized natural resources. Visitor actions to deliberately harm or destroy vegetation and other natural resources are a manipulation of

the wilderness environment. In the BWCAW, violations are regularly recorded for visitors who have intentionally cut live vegetation, widened campsites, damaged living trees (e.g., by peeling, carving, or hacking at the bark), or otherwise manipulated the biophysical environment. The vast majority of these types of violations occur at designated campsites (which constitute less than 40 acres of the wilderness); while these areas suffer from repeated vandalism, the remainder of the wilderness is virtually unscathed. From 2009 to 2013, 822 violation notices were written for 224 locations in the wilderness.

- Poaching—Lakes where illegal hunting, trapping, or fishing violations have been recorded by law enforcement. Poaching impacts wildlife and manipulates the community of life in wilderness. While capturing and/or removing animals for any purpose is generally considered a trammeling action, legal hunting, trapping, and fishing were not included under this quality because of their positive associations with primitive recreation and subsistence use in the wilderness. Citations for hunting, trapping, or fishing without the appropriate permit or license are relatively infrequent in the wilderness due to the difficulties of patrolling such a large and heavily used area. Violation notices for illegal poaching were written for 71 locations from 2009 to 2013.

Data Sources, Processing, and Cautions

The datasets used to create the untrammeled quality map are all vector data, of fine scale, and generally of moderate to high accuracy and completeness (table 1). The data sources, data processing information, and cautions are listed below for each measure.

Table 1—Untrammeled quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is across the wilderness) were evaluated for each measure by SNF staff familiar with these data.

Measure	Source	Type	Scale	Accuracy	Completeness
Suppressed fires	(1) FireSuppression_LN; (2) FireSuppression_PL	Polyline and Polygon	1:24,000	High	High
Fish stocking	BWCAW_StockedLakes1988_2013	Polygon	1:24,000	High	Medium
Prescribed fires	PrescribedFiresBWCAW2000_2013	Polygon	1:24,000	High	High
Fish surveys	BWCAW_DNR_SurveyLakes1978_2013	Polygon	1:24,000	High	High
Non-native plant treatments	(1) Planned2014BWCAWweedTreatments; (2) TreatedWeedPointsBWCAW2009_2013	Point	1:12,000	High	High
Dam water level manipulation	BWCAW_NHD_Waterbody	Polygon	1:24,000	High	High
Animal manipulation	(1) BeaverTrappingPoint; (2) WolfCapturePoints	Point	1:24,000	Medium	Medium
Soil disturbance	(1) DisturbedManipulated_PT; (2) DisturbedManipulated_LN; (3) DrilHolesBWCAW	Point and Polyline	1:63,360	Medium	Medium
Fish spawn collection	BWCAW_SpawnTake	Polygon	1:24,000	High	High
Vandalism of natural resources	VandalismFromLEO_Report2009_2013	Point	1:40,000	Low	Low
Poaching	PoachingLakesBWCAW2009_2013	Polygon	1:24,000	Low	Low

Suppressed fires

- *Sources*—(1) Polyline dataset of the SNF fire history geodatabase (Patty Johnson, SNF Prescribed Fire and Fuels Management Officer); (2) polygon dataset of the SNF fire history geodatabase. These datasets were created by relating institutional knowledge of the locations of fire suppression activities (Patty Johnson, SNF Prescribed Fire and Fuels Management Officer) to the SNF fire history geodatabase; SNF staff assessed the original fire polygons from the SNF fire history geodatabase to determine whether fires were suppressed over the entire polygon, over some portion of the polygon, along the entire polygon perimeter, or along some portion of the polygon perimeter. These datasets represent the SNF fire history from 1994 to 2013.
- *Processing*—Locations of suppressed fires were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—The locations of where specific suppression actions are taken on a fire are not regularly recorded, collected, or stored for the SNF. The dataset created for this measure was based on the local knowledge of forest and district staff; therefore, fires that occurred prior to the employment of current personnel (i.e., fires for which spatial information on suppression actions was not available) were not included in this measure. In addition, some of the spatial descriptions from district staff required interpretation by Teresa Hanson, SNF GIS Analyst, and Ann Schwaller, SNF Wilderness Specialist, and therefore may not directly represent the suppression locations. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Fish stocking

- *Sources*—Polygon dataset of lakes stocked with fish, created by relating fish stocking records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov). Within the fish stocking database, stocking records for the BWCAW were only available starting in 1988.
- *Processing*—Locations of stocked lakes were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Prescribed fires

- *Sources*—Polygon datasets of prescribed fires, derived from the SNF fire history geodatabase (Patty Johnson, SNF Prescribed Fire and Fuels Management Officer). This feature class is updated annually with inputs from the SNF district fire reports.
- *Processing*—Locations of prescribed fires were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Fish surveys

- *Sources*—Polygon dataset of lakes surveyed for fish, created by relating fish surveying records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov). Only fish surveying records from 1978 to 2013 were used for this measure.
- *Processing*—Locations of surveyed lakes were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Non-native plant treatments

- *Sources*—Point dataset of treatment locations for non-native plants from 2009 to 2014 (Jack Greenlee, SNF Plant Ecologist).
- *Processing*—Locations of non-native plant treatments were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Dam water level manipulation

- *Sources*—Point dataset of known old dams within the SNF boundary. Dams that actively manipulate water levels were selected from the original dataset (Marty Rye, SNF hydrologist).
- *Processing*—Locations of dams were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Animal manipulation

- *Sources*—(1) Point dataset of beaver removal locations (Dawn Plattner, Minnesota DNR Assistant Wildlife Supervisor); (2) point dataset of wolf captures (Shannon Barber-Meyer and David Mech, USGS Wildlife Biologists). Wolf capture locations were derived by relating a database containing date and location data for wolf capture to written descriptions of trap line loops or routes.
- *Processing*—Locations of beaver removal and wolf trapping were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—The wolf capture points represent approximate locations based on the information in the capture database (generally described to the quarter section—160 acres) and the descriptions of the trap line routes provided by the researchers (e.g. “the traps were placed about halfway along the portages”). Bear dispatch—a trammeling action that manipulates animals—was not included for this measure because data were unavailable. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Soil disturbance

- *Sources*—(1) Point dataset of restoration activities (SNF District Wilderness Staff); (2) polyline dataset of restoration activities (SNF District Wilderness Staff); (3) point dataset of exploratory drilling sites (Jon Van Alstine, SNF Geologist). For restoration activities, SNF District Wilderness Staff were given 1:63,360 scale base maps that they used to indicate line or point features within the BWCAW that have received considerable restoration efforts and/or contain improvements such as boardwalks, retaining walls, shoreline stabilization features, etc.
- *Processing*—All locations were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—Soil disturbance from road building during logging eras was not included for this measure because data were unavailable. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Fish spawn collection

- *Sources*—Polygon dataset of lakes where fish spawn collection occurred, created by relating spawn collection records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov).
- *Processing*—Locations of fish spawn collection were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Vandalism of natural resources

- *Sources*—Point dataset of natural resource vandalism, derived from the law enforcement reported incidents database (Trish Beaudry, SNF Law Enforcement Program Assistant).
- *Processing*—Locations of vandalism were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The NAD83 datum was assumed for the geographic coordinates in the original table. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Poaching

- *Sources*—Polygon dataset of poaching violations, created by relating information from the law enforcement reported incidents database (Trish Beaudry, SNF Law Enforcement Program Assistant) and the Minnesota DNR fishing violations database (Bruce Anderson, Minnesota DNR Assistant Wildlife Manager) to the National Hydrography Dataset (www.nhd.usgs.gov).
- *Processing*—Locations of vandalism were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.

- *Cautions*—The polygon dataset does not convey specific locations of poaching or poaching frequency. The NAD83 datum was assumed for the geographic coordinates in the original table. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Weighting

The assigned weight (on a scale of 1 to 10) and the corresponding rationale for each measure under the untrammeled quality are described in table 2.

Table 2—Measure weights and rationales for the untrammeled quality.

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

Maps

The weighted measures under each indicator were added together using a raster calculator to create two maps: "actions authorized by the Federal land manager that manipulate the biophysical environment" and "actions not authorized by the Federal land manager that manipulate the biophysical environment" (fig. 4). All the measures were then added together using the same process to create the untrammeled quality map (fig. 5).

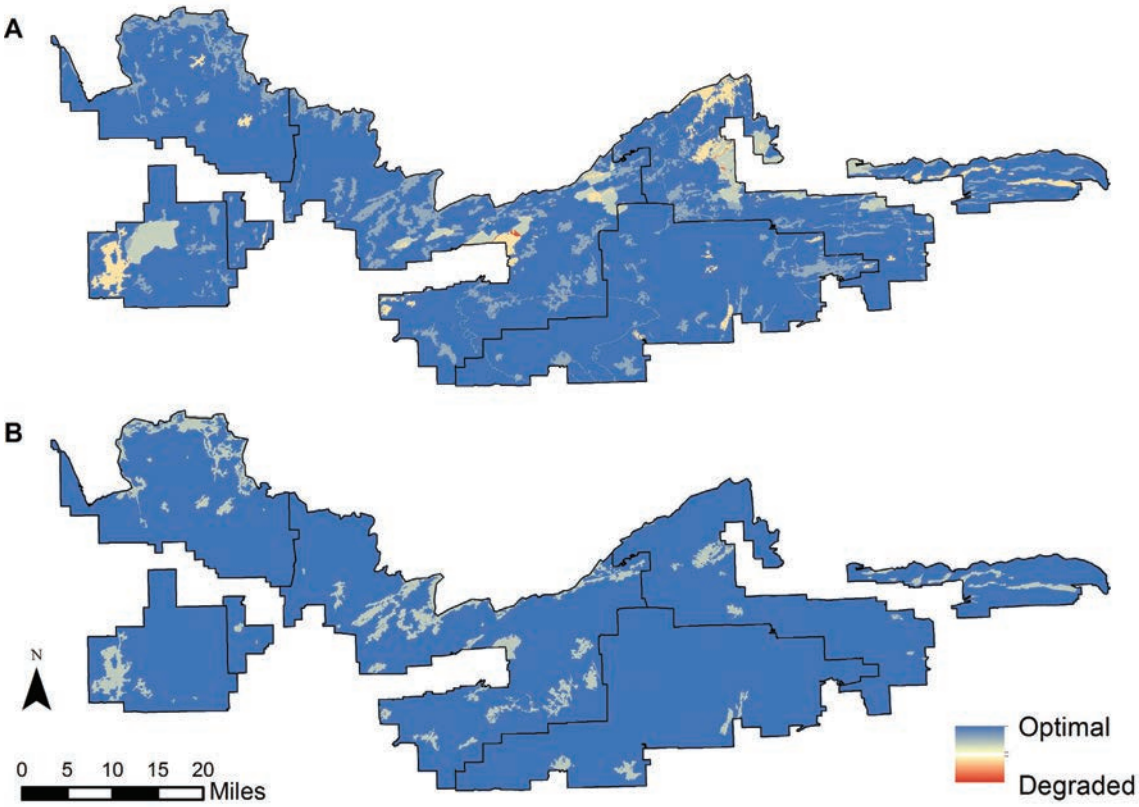

Figure 4—Indicator maps for (A) actions authorized by the Federal land manager that manipulate the biophysical environment and (B) actions not authorized by the Federal land manager that manipulate the biophysical environment. Blue depicts optimal condition and red depicts degraded condition.

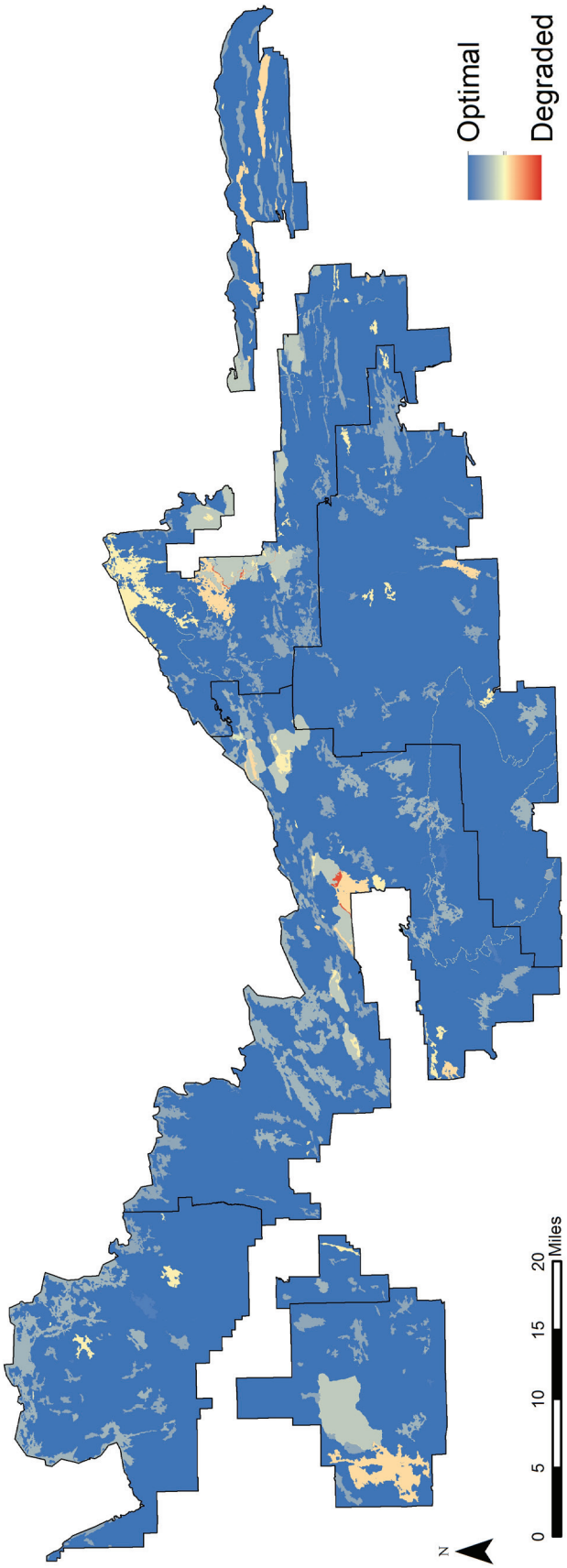

Figure 5—Map of the untrammeled quality of wilderness character. Blue depicts optimal condition and red depicts degraded condition.

Natural Quality

The natural quality centers on the idea that wilderness contains 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 ecological systems inside wilderness (Landres and others 2008a, 2015).

Indicators and Measures

Keeping it Wild delineates three indicators under the natural quality[10]. The measures selected for the BWCAW are described below for each of these indicators.

Indicator: Plant and animal species and communities.

- Non-native invasive species—Known locations of plant and animal non-native invasive species (NNIS). NNIS alter the natural environment and displace native species. Vectors for spread include the many types of recreation and travel, fires and accompanying soil disturbance, and intentional species introductions. Current infestation levels of NNIS are relatively low with most terrestrial species restricted to trails, portages, campsites, and other disturbed or burned areas. NNIS in the BWCAW include the spiny water flea (present in 16 lakes), rusty crayfish (29 lakes), earthworms (94 known sites), and various plants (1,604 known locations of purple loosestrife, leafy spurge, spotted knapweed, Canada thistle, tansy, St. John's wort, orange and yellow hawkweed, milfoil, etc.). Fish species stocked before 1964 that have persisted to the present day (including small mouth bass, rainbow trout, and brook trout) are considered "indigenous" and not included in this measure.
- Historical logging activity—Acres of forest that were historically logged. Historical harvest activities have changed the natural structure of the forest; in comparison to old-growth forests, logged forests are often less biologically diverse and have fewer rare, threatened, and endangered species. While no logging has occurred since 1978, 52,290 acres were logged between 1964 and 1978, and 200,632 or more acres were logged prior to 1964.
- Change in biodiversity—Areas with lower levels of biodiversity, as determined by the Minnesota Biological Survey (MBS). The MBS biodiversity assessments are based on landscape functionality as well as the distribution and ecology of rare plants, rare animals, and native plant communities. In the BWCAW, biodiversity is threatened by trails, portages, campsites, historical timber harvest, high intensity fires, NNIS, and climate change. Only two locations were identified as having decreased or moderate levels of biodiversity: Phoebe Wager Site 129 (encompassing the headwaters of the Kawishiwi River, in the Phoebe River watershed) and

[10] *Keeping it Wild* also describes a fourth indicator under the undeveloped quality: loss of statutorily protected cultural resources. This indicator was not included under the undeveloped quality for this mapping project but instead was encompassed by new indicators under the added other features of value quality.

Gunflint Mayhew Site 133 (encompassing portions of the headwaters of the Rainy and Pigeon Rivers, in the Rainy and Lake Superior-North watersheds).

- Extirpated species—The extirpation of caribou across the wilderness. The loss of native species changes the community of life and fundamentally alters natural ecosystems. The extirpation of caribou is used in this measure to represent all extirpations of native species from the BWCAW. Caribou were once common across northern Minnesota, but widespread habitat and food-source loss, as well as increased hunting pressure, resulted in their extirpation in the 1930s. While there have been occasional caribou sightings in the subsequent years, no permanent population has reestablished itself. At this time the State is not considering caribou reintroduction, nor is the SNF considering caribou habitat restoration.
- Habituated bears—Locations that are known to have frequent problems with habituated bears. Bears that are habituated to humans may raid camps or packs for food, or even harass or attack visitors. These behaviors are unnatural, threaten human safety, and may result in lethal bear dispatch. Sixty-four campsites, portages, and trails were identified as being commonly frequented by habituated bears.

Indicator: Physical Resources.

- Recreation-related soil loss—Sites with more than 800 square feet of exposed mineral soil. Exposed soil is more likely to erode or become compacted, which consequently results in decreased soil productivity and loss of vegetation. Soil exposure in the BWCAW is most commonly associated with high levels of recreational use and accompanying maintenance efforts. Out of more than 1,957 total designated campsites, 291 exceed SNF plan standards for the area of disturbed soil.
- Nitrogen deposition—The extent of nitrogen deposition in the wilderness. Nitrogen is a major component of acidic deposition (acid rain) and can cause chemical changes in soil and water that significantly impact nutrient cycling, vegetation growth, and the abundance or survival of aquatic insects and fish. The primary sources of nitrogen pollution are nitrogen oxides (NO_X), generated from the burning of fossil fuels, and ammonia (NH_3), generated from agricultural activities including livestock management and fertilizer application. Nitrogen oxides and ammonia react with water molecules in the atmosphere and return to earth as nitric acid (HNO_3) and ammonium (NH_4). In the BWCAW, nitrogen deposition artificially fertilizes lakes that are naturally nutrient-poor; this fertilization could cause a shift toward non-native species that would otherwise have been unable to survive. While levels of nitrogen deposition in northeastern Minnesota have remained relatively flat for the past 35 years, the spread of agricultural feedlots in southern Minnesota and Iowa threatens to increase nitrogen deposition in the future.
- Sulfur deposition—The extent of sulfur deposition. Like nitrogen, sulfur is a major component of acidic deposition and can negatively impact aquatic and terrestrial plants and animals by chemically altering soils and surface waters. Sulfur can also facilitate the uptake of mercury into the aquatic food chain. The primary source of sulfur pollution is sulfur dioxide (SO_2), which is generated from the burning of

fossil fuels. Sulfur dioxide combines with water molecules in the atmosphere and returns to earth as sulfuric acid (H_2SO_4). Over the last 35 years, sulfur deposition has decreased in northeastern Minnesota (paralleling a similar decrease in sulfur dioxide emissions both regionally and nationally). It is important to continue monitoring sulfur deposition to ensure these gains are maintained.

- Impounded water—Dammed lakes with unnaturally high water levels. Impounding water can affect water temperature and chemistry, flow regime, channel shape, sediment transport, physical habitats, and the species diversity of algae, macroinvertebrates, fish, and riparian vegetation. Dammed lakes with unnaturally high water levels include: Fall, Gabbro, Little Gabbro, Moose, Newfound, and Sucker.
- Shoreline erosion—Shorelines affected by water releases from dammed lakes. Artificial fluctuations in water levels can result in the loss of shoreline soil, leading to subsequent impacts on plant and animal species. Shoreline degradation from artificial water level fluctuation occurs at only one location in the BWCAW, an island within Fall Lake. The changes in the water levels of Fall Lake originate from a dam outside of the wilderness on Garden Lake.

Indicator: Biophysical Processes.

- Departure from natural fire regimes—The degree of departure from the historical fire regime across the wilderness. Fire regime patterns are fundamental ecosystem processes that play a critical role in determining vegetation composition and structure. Departure from the historical fire regime can cause significant changes in plant and animal communities. Humans have altered natural fire regimes over time through fire suppression, fuel management, timber harvest, etc. For this measure, the percent change between historical and current vegetation conditions was used to determine departure from the historical fire regime; the percent change was then classified as representing high, moderate, and low departure. In the BWCAW, the majority of the wilderness shows moderate departure (between 33 percent and 66 percent) from the historical fire regime.
- Change in winter temperature—The change in the average minimum winter temperature across the wilderness over the last century. Winter temperatures determine lake ice extent and duration, growing season timing, and fish and wildlife reproductive phenology, populations, and range shifts; minimum winter temperatures are particularly important because they can limit species survival. Historically, low minimum winter temperatures in northern Minnesota have restricted the suitable habitat of temperate tree species like red maple and have protected the area from non-native plant and animal species that cannot tolerate harsh winters. This may change in the future as northern Minnesota's climate is already warming and is projected to experience dramatic shifts by the end of the century. For this measure, the change in temperature was determined using statistical analyses of all December–February average minimum temperature data from 1901 to 2011. Across the BWCAW, average minimum winter temperatures have increased by approximately 2 to 6 degrees Fahrenheit over the last 110 years.

- Beaver removal—Lakes where beavers have been removed. Beavers are a key wetland species and their removal can have ecosystem level changes including impacts to vegetation, insects and other invertebrates, and fish and wildlife. Only seven lakes in the BWCAW have had beavers removed by the Minnesota Department of Natural Resources (Minnesota DNR).

Data Gap Measures

Additional measures under this quality were identified by SNF staff but were excluded for a variety of reasons. For each data gap measure, the indicator, description, and rationale for their dismissal are listed below.

Timber plantations

- *Indicator*—Plant and animal species and communities.
- *Description*—Many timber units in wilderness were planted with a single tree species after harvest, which led to the cultivation of plantation-like monocultures. These plantations alter vegetation communities, increase homogenization and fragmentation, and directly reduce biodiversity. By transforming large areas of forest from one habitat type to another, plantations may also promote species extinctions. Planting a monoculture after first opening the forest canopy through timber harvesting can increase forest temperature and alter fire patterns and behavior as well.
- *Rationale for dismissal*—Although there are various digital maps for referral (e.g., Heinselman and USGS 2014), as well as some physical SNF maps (e.g., for harvests between 1964 and 1978), data were incomplete. Most maps were not digitized and would have taken considerable time to prepare; they also would have required making too many assumptions and would have led to unacceptable levels of unreliability. The Heinselman maps also lacked information on the type of disturbance (fire vs. timber harvest) and the method of reestablishment (natural succession vs. planting).

Land cover change

- *Indicator*—Plant and animal species and communities.
- *Description*—Timber harvest and other human manipulation in wilderness have caused changes in the natural land cover, which have altered plant communities and patterns of wildlife movement. In the BWCAW, certain boreal plant and animal species are presumed to be losing dominance as a result of land cover change.
- *Rationale for dismissal*—This measure was considered based on the assumption that timber harvest, post-harvest planting, fire suppression, and other manipulation had resulted in decreased jack pine cover in the wilderness. Upon examination, however, it was determined that jack pine cover has actually increased relative to historical data and assumptions. The effect of land cover change on plant communities was therefore less evident than originally believed. In addition, data on changes in wildlife movement patterns as a result of land cover change do not currently exist.

Non-native insects and pathogens

- *Indicator*—Plant and animal species and communities.
- *Description*—Repeated invasions of non-native insects and pathogens have altered the structure and function of forest ecosystems. Short-term disturbances associated with these pests include reduced productivity, tree decline and mortality, disruption of nutrient cycles, and decreased seed production. Longer-term impacts include shifts in tree species composition that alter productivity, nutrient cycling, and biodiversity. Known insect and disease NNIS threats to the boreal forests of the BWCAW include gypsy moth, emerald ash borer, and white pine blister rust. Unsubstantiated reports of viral hemorrhagic septicemia, larch case bearer, and Dutch elm disease have also been recorded for the wilderness.
- *Rationale for dismissal*—While data were available for the wilderness, they were too large scale to be useful. Most maps showed northeastern Minnesota as the general location of infestation, without any further specificity. Some State and county maps had slightly more detail but were still not sufficient for pinpointing infestation locations inside the wilderness.

Water quality

- *Indicator*—Physical resources.
- *Description*—Water quality is of critical importance in the lake-based ecosystems of the BWCAW. Several lakes have had problems with latrine overflow and runoff after heavy rains; in other lakes, loon and fish testing has also revealed unnatural mercury levels. Untreated sewage from latrines can contain more than 120 viruses, including giardia and cryptosporidium, which can cause intestinal illnesses and even death. Lake contamination with mercury—highly potent neurotoxin that impacts the function and development of the central nervous system—can have serious impacts on both people and wildlife.
- *Rationale for dismissal*—Although historical water sampling data are believed to exist, it would have taken considerable time to digitize the data once they were located. Data on mercury concentrations in fish are available for certain sampled lakes but cannot be extrapolated to neighboring non-sampled lakes due to watershed properties controlling mercury cycling. The Minnesota Pollution Control Agency completed representative sampling for latrine runoff in 2014 and 2015, and has plans for continued sampling; these data could potentially be used in future iterations of the map.

Climate change impacts

- *Indicator*—Biophysical processes.
- *Description*—Climate change has already begun to change biophysical processes in the BWCAW. Impacts from climate change include changes to insect and pathogen regimes, precipitation patterns, snow depth, and plant and animal phenology.
- *Rationale for dismissal*—Available data were inappropriate for the scale of the wilderness. Maps for precipitation and snow depth—from RAWS (Remote Automated Weather Stations) data and SNOTEL (Snow Telemetry) data, respectively—were not specific enough for the wilderness. Available plant and animal phenology maps—using MODIS (moderate resolution spectroradiometer) data—could not be used to determine local degradation.

Loss of connectivity

- *Indicator*—Biophysical processes.
- *Description*—Loss of connectivity disrupts ecological process including the movement of wildlife and fire across the landscape. Connectivity in the BWCAW is impacted by dams, timber sale areas, inholdings, separated units (i.e., the Trout Lake and Vento units) and cherry-stem roads (including the Fernberg Road and the Echo, Sawbill, Gunflint, and Arrowhead Trails).
- *Rationale for dismissal*—Data on wildlife movement patterns do not currently exist. Other possible data sources would have required making too many assumptions and were therefore rejected.

Data Sources, Processing, and Cautions

A wide variety of datasets were used to create the natural quality map. These datasets included both vector and raster data, exhibited high variation in scale, had mostly high levels of accuracy, and had differing levels of completeness (table 3). The data sources, data processing information, and cautions are listed below for each measure.

Table 3—Natural quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is across the wilderness) were evaluated for each measure by SNF staff familiar with these data.

Measure	Source	Type	Scale	Accuracy	Completeness
Non-native invasive species	(1) NNIS_AquaticBWCAW.shp; (2) WeedPointsBWCAW2009_2013.shp; (3) BWCAW_WormsPT.shp; (4) BWCAW_WormsLN.shp	Point and Polyline	1:24,000	High	Low to Medium
Historical logging activity	(1) HeinselmanHarvests_Pre1964.shp; (2) Post1964Harvesting.shp	Polygon	1:126,720; 1:24,000	Medium to High	Medium
Change in biodiversity	ModerateBioSignificance.shp	Polygon	1:24,000	High	Medium
Extirpated species	BWCAW_Boundary.shp	Polygon	1:24,000	High	High
Habituated bears	HabituatedBears.shp	Point	1:63,360	Medium	High
Recreation-related soil loss	ExposedSoil.shp	Point	1:63,360	Medium	High
Nitrogen deposition	n_td_mean	Raster	4134m	High	Medium
Sulfur deposition	s_td_mean	Raster	4134m	High	Medium
Impounded water	ImpoundedWater.shp	Polygon	1:24,000	High	High
Shoreline erosion	BWCAW_NHD_Waterbody	Point and Polygon	1:24,000	High	High
Departure from natural fire regimes	VCC_BWCAW	Raster	30m	Medium	High
Change in winter temperature	T1nw0111mnd	Raster	4094m	High	High
Beaver removal	BWCAW_NHD_Waterbody	Polygon	1:24,000	High	High

Non-native invasive species

- *Sources*—(1) Point dataset of survey locations indicating the presence of earthworms (Heather Jenson, SNF Monitoring Crew Leader, and Dan Wovcha, Minnesota DNR Plant Ecologist); (2) point dataset of non-native plant locations

from 2009 to 2013 (Jack Greenlee, SNF Plant Ecologist); (3) polyline dataset of transects with the presence of earthworms (David Chaffin, University of Minnesota Ph.D. Student); (4) polygon dataset of lakes containing spiny water flea and/or rusty crayfish, created by relating aquatic NNIS monitoring data (Jason Butcher, SNF Fisheries Ecologist) to the National Hydrography Dataset (www.nhd.usgs.gov).

- *Processing*—Locations of all NNIS were assigned a value of 1. Layers were converted to individual rasters and added accumulatively. Values were then normalized to 0–255.
- *Cautions:* The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Historical logging activity

- *Sources*—(1) Polygon dataset of stand origin, logging history, and burn areas, digitized from maps annotated by Heinselman and others (2014); (2) polygon dataset of timber sales, digitized from the "BWCA Timber Rehabilitation Report," May 15, 1980 (USDA Forest Service 1980).
- *Processing*—Locations of all timber harvests were assigned a value of 1. Layers were converted to individual rasters and combined together. Overlapping cells were re-classed back to a value of 1, after which values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Change in biodiversity

- *Sources*—Polygon dataset of areas with unnatural ecological changes rated as having moderate biodiversity (Chel Anderson and Lawson Gerdes, Minnesota DNR Plant Ecologists).
- *Processing*—Sites of biodiversity change were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Extirpated species

- *Sources*—Polygon dataset of the BWCAW representing the extirpation of caribou from the entire wilderness (Susan Catton, SNF Wildlife Biologist).
- *Processing*—The entire wilderness was assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—N/A.

Habituated bears

- *Sources*—Point dataset of campsites that are frequented by bears habituated to humans, created by relating institutional knowledge of known problem areas (SNF District Wilderness Staff) to the BWCAW campsite dataset.

- *Processing*—Campsites were buffered by 100 meters and assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Recreation-related soil loss

- *Sources*—Point dataset of campsites that contain more than 800 square feet of exposed mineral soil, created by relating institutional knowledge of known areas (SNF District Wilderness Staff) to the BWCAW campsite dataset.
- *Processing*—Campsites were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Nitrogen deposition

- *Sources*—Raster datasets of nitrogen deposition for the individual years 2007–2012, developed by the Community Multiscale Air Quality (CMAQ) modeling system (Byun and Schere 2006). The datasets were obtained from the Environmental Protection Agency (EPA)-Clean Air Status and Trends Network (CASTNET) ftp server (ftp://ftp.epa.gov/castnet/tdep; download date 10/28/2014).
- *Processing*—The national extent data were clipped to the extent of the BWCAW boundary and a new raster was created to represent the mean of the six input years. The average nitrogen grids were re-projected from Albers to UTM using the bilinear method. Null values along the international border were replaced with a value of 0, and all values were normalized to 0–255.
- *Cautions*—Due to the resolution of these datasets, there are missing values along the international border. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Sulfur deposition

- *Sources*—Raster datasets of sulfur deposition for the individual years 2007–2012, developed by the CMAQ modeling system (Byun and Schere 2006). The datasets were obtained from the EPA-CASTNET ftp server (ftp://ftp.epa.gov/castnet/tdep; download date 10/28/2014).
- *Processing*—The national extent data were clipped to the extent of the BWCAW boundary and a new raster was created to represent the mean of the six input years. The average sulfur grids were re-projected from Albers to UTM using the bilinear method. Null values along the international border were replaced with a value of 0, and all values were normalized to 0–255.
- *Cautions*—Due to the resolution of these datasets, there are missing values along the international border. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Impounded water

- *Sources*—Polygon dataset of lakes that have increased water levels due to the presence of dams, created by relating institutional knowledge of dammed lakes (Marty Rye, SNF hydrologist) to the National Hydrography Dataset (www.nhd.usgs.gov).
- *Processing*—All impounded waters were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Shoreline erosion

- *Sources*—Polygon dataset of lakes affected by dams, created by relating institutional knowledge of dammed lakes (Marty Rye, SNF hydrologist) to the National Hydrography Dataset (www.nhd.usgs.gov).
- *Processing*—The affected island polygon was selected within the dammed lake, converted to a polyline, and assigned a value of 1. The new layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Departure from natural fire regimes

- *Sources*—Raster dataset of vegetation condition class representing the degree of departure from the historical fire regime, developed by LANDFIRE (www.landfire.gov).
- *Processing*—The dataset was re-projected and clipped to the BWCAW boundary. Using the "Description" field, low vegetation departure was assigned a value of 1, moderate vegetation departure was assigned a value of 2, and high vegetation departure was assigned a value of 3. Values were then normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Change in winter temperature

- *Sources*—Raster dataset of the change in average daily minimum winter (December–February) temperatures from 1901 to 2011, developed for the Minnesota Forest Ecosystem Vulnerability Assessment and Synthesis Report (Stephen Handler, Forest Service Northern Research Station Climate Change Specialist; Handler and others 2014). The original data were derived from PRISM (Parameter-elevation Regressions on Independent Slopes Model) (Gibson and others 2002), which models historical measured point data onto a continuous 2.5-mile grid for the entire United States.

- *Processing*—The dataset was re-projected and clipped to the BWCAW boundary. Values were then normalized to 0–255.
- *Cautions*—Distinguishing whether local ecological changes are due to anthropogenic climate change or to natural variation can be difficult, and the threshold at which a change in temperature represents a degradation to wilderness character is unknown. For this measure, therefore, any increase in temperature was interpreted as negatively impacting the natural quality. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Beaver removal

- *Sources*—Polygon dataset of lakes where beavers are trapped, created by relating beaver trapping records (Dawn Plattner, Minnesota DNR Assistant Wildlife Supervisor) to the National Hydrography Dataset (www.nhd.usgs.gov).
- *Processing*—Lakes where beavers are trapped were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Weighting

The assigned weight (on a scale of 1 to 10) and the corresponding rationale for each measure under the natural quality are described in table 4.

Table 4—Measure weights and rationales for the natural quality.

Indicator	Measure	Weight	Rationale
Plant and animal species and communities	Non-native invasive species	6	Medium weight because this measure is of high management concern given the amount of visitation and the number of possible vectors for spread.
	Historical logging activity	3	Low weight because the data from 1964 to 1978 are considered incomplete. Many of the harvest maps from this period were discarded after the BWCAW legislation was enacted.
	Change in biodiversity	2	Low weight because not all areas have been surveyed, and of those that have, only two locations were determined to be less than natural. The weight may change in the future if more areas are surveyed and determined to have low or moderate biodiversity.
	Extirpated species	2	Low weight because it is considered unlikely that caribou will naturally reestablish or be reintroduced in the near future.
	Habituated bears	1	Lowest weight because there are few problem sites relative to the entirety of the BWCAW.

Indicator	Measure	Weight	Rationale
Physical resources	Recreation-related soil loss	6	Medium weight because a significant number of sites are threatened by extensive soil exposure.
	Nitrogen deposition	5	Medium weight because the wilderness is a Class 1 Airshed and nitrogen deposition is above natural levels.
	Sulfur deposition	5	Medium weight because the wilderness is a Class 1 Airshed and sulfur deposition is above natural levels.
	Impounded water	2	Low weight because dammed lakes have caused increased water levels for only a small number of lakes.
	Shoreline erosion	1	Lowest weight because shoreline degradation from water level fluctuation occurs at only one location.
Biophysical processes	Departure from natural fire regimes	8	High weight because the effects of historical and contemporary fire suppression—such as blowdowns, fuel build-up, and changes in the dominant tree species—are significant.
	Change in winter temperature	2	Low weight because it is difficult to anticipate how climate-related impacts may influence management in wilderness. The weight may change in the future as more information becomes available.
	Beaver removal	2	Low weight because beaver removal is limited and is becoming more infrequent.

Maps

The weighted measures under each indicator were added together using a raster calculator to create three maps: "plant and animal species and communities," "physical resources," and "biophysical processes" (fig. 6). All the measures were then added together using the same process to create the natural quality map (fig. 7).

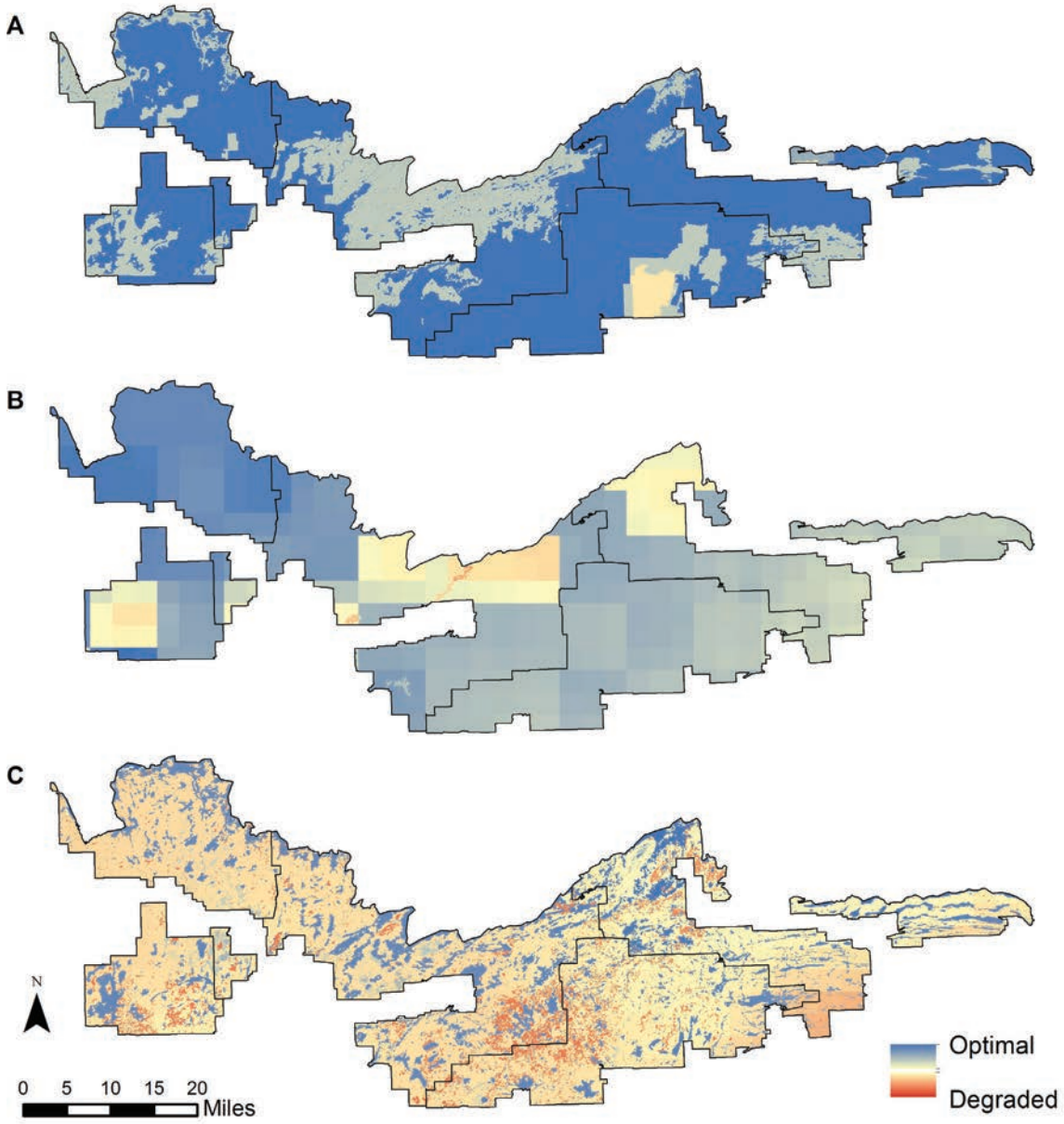

Figure 6—Indicator maps for (A) plant and animal species and communities, (B) physical resources, and (C) biophysical processes. Blue depicts optimal condition and red depicts degraded condition.

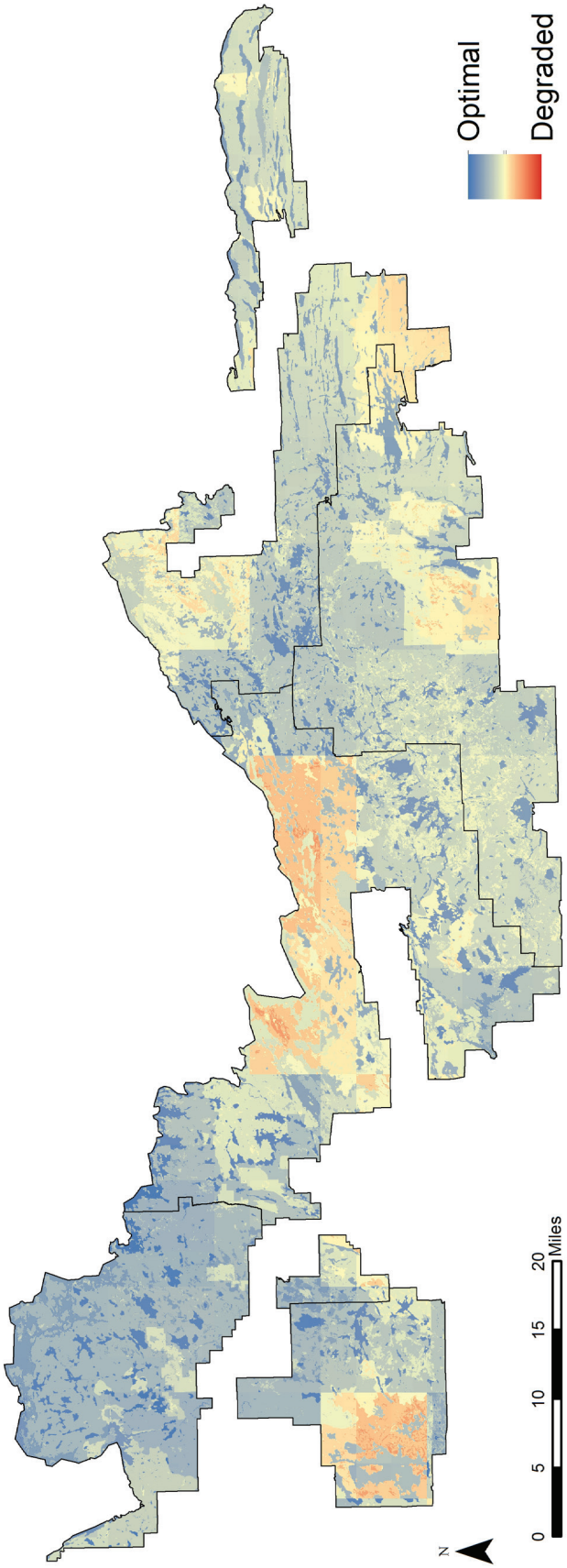

Figure 7—Map of the natural quality of wilderness character. Blue depicts optimal condition and red depicts degraded condition.

Undeveloped Quality

The undeveloped quality centers on the idea that wilderness is without permanent improvements or modern human occupation. This quality is degraded by the presence of structures and installations, as well as the use of motor vehicles, motorized equipment, and mechanical transport, because these increase people's ability to occupy or modify the environment (Landres and others 2008a, 2015).

Indicators and Measures

Keeping it Wild delineates three indicators under the undeveloped quality. The measures selected for the BWCAW are described below for each of these indicators. No data gap measures were identified for this quality.

Indicator: Non-recreational structures, installations, and developments.

- Authorized developments—Locations of authorized non-recreational physical developments. The Wilderness Act defines wilderness as an area without permanent improvements, which include authorized developments. For this measure, developments were ranked based on their areal footprint, size, or noticeability: buildings and structures were depicted as having a large impact, docks and functioning dams as having a moderate impact, and markers or non-functioning dams as having a small impact. Out of 472 authorized non-recreational developments in the wilderness, there are 7 administrative cabins and 2 outhouses, 31 historical dams, 12 docks, 419 border reference markers, and 1 plaque (marking the highest State point).
- Research installations—Locations of authorized research installations. Although research installations are often unnoticeable, they are still developments indicative of modern human modification of the wilderness. In contrast to other management areas of National Forests, in wilderness there is higher scrutiny for approving scientific activities and any associated installations. The BWCAW has relatively few scientific developments: a water gauge in Jack Fish Bay and USGS wolf traps and trap lines.

Indicator: Inholdings.

- Developed inholdings—Locations of physical developments on inholdings inside wilderness. Inholdings are not held to the same regulations as wilderness lands and therefore face a higher threat of development. As private land is considered more likely to be developed than public land owned by the State or county, installations on these inholdings were depicted as having a larger impact. There are 21 developments on wilderness inholdings.
- Infrastructure supporting inholdings—Locations of infrastructure supporting private inholdings. Infrastructure that connects inholdings to the power grid is an obvious sign of modern human habitation in wilderness. In the BWCAW, there are two areas where inholdings are supported with this type of development: Saganaga Lake and Sandpoint Lake. The Saganaga Lake infrastructure includes a road as well as powerlines and supports several privately developed inholdings.

Powerlines adjacent to Sandpoint Lake are located on a State inholding and support private cabins north of the wilderness. While the infrastructure on Saganaga Lake is regularly used and conspicuous, that on Sandpoint Lake is not on travel routes and is substantially unnoticeable.

- Undeveloped inholdings—Areas of undeveloped inholdings in the wilderness. Undeveloped inholdings still pose a risk of development in the future as they are not restricted by Federal laws and policies. These inholdings are generally indistinguishable from wilderness lands and are considered a high priority for acquisition by the Forest Service. For this measure, State and county inholdings were depicted as having a smaller potential impact than private inholdings since they are presumed to be at lower risk for future development. There are approximately 111,230 acres of undeveloped inholdings within the wilderness that are owned by the State (105,926 acres), county (4,863 acres), and private entities (441 acres).

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

- Legal motorized/mechanized use—Areas where motorized use or mechanized travel is legally permitted. Although certain exceptions for motorized equipment and mechanized travel are legally allowed in the BWCAW through special provisions in both the Wilderness Act (1964) and the Boundary Waters Canoe Area Wilderness Act (1978), these uses are generally prohibited in wilderness areas (as described in Section 4[c] of the Wilderness Act of 1964). Motorized use is generally considered to have a greater impact on the undeveloped quality than mechanized transport and is depicted as such for this measure. Trails, portages, and lakes that permit these nonconforming uses are contained within the semi-primitive motorized management area. This area encompasses 6 routes allowing the use of portage wheels, 4 portages allowing rail-car or motorized transport, and 2 trails allowing snowmobiles; it also includes 20 lakes and rivers allowing motorized use, of which 5 have a 10 horsepower (hp) limit, 11 have a 25 hp limit, and 4 have no hp restrictions.

- Administrative motorized/mechanized use—Areas where motorized use or mechanized travel is authorized for administrative agency use. Motorized use and mechanized transport are generally prohibited by the Wilderness Act, but exceptions are allowed when necessary to meet the minimum requirements for administration of the wilderness and when permitted through legislated special provisions. Minimum requirements analyses are conducted by SNF staff for proposed administrative use of motorized equipment or mechanized transport in all non-motorized management areas. The Forest Service, USGS, Border Patrol, and Minnesota DNR regularly use towboats, motorboats, fixed-wing aircraft, float planes, helicopters, and snowmobiles for administrative purposes in the BWCAW. Administrative motorized use by the SNF consists of ski trail grooming with a snowmobile (14.5 miles groomed annually by a partner organization) and fire detection flights (104 miles flown on average each year). Other administrative motorized use includes USGS aerial wolf surveys (55 miles flown from 2012 to 2014), Border Patrol flights (150 miles along the international boundary), and Minnesota DNR activities including fish stocking (72 lakes stocked using

motorized access from 1988 to 2013), fish surveys (80 lakes surveyed using motorized access from 1978 to 2013), spawn collection (2 lakes harvested using motorized access between 1980 and 2013), and aerial moose surveys (294,693 acres surveyed from 2013 to 2014).

- Emergency motorized/mechanized use—Locations where motorized equipment or mechanized transport were used for emergency purposes. While motorized equipment and mechanized transport are permitted in wilderness if necessary to protect human life and safety, they are still considered nonconforming uses. Motorized equipment used during an emergency can include chainsaws, water pumps, generators, helicopters, fixed-wing aircraft, float planes, drones, motorboats, off-highway vehicles (OHVs), and snowmobiles. The SNF consults a pre-emergency authorization matrix and conducts after-action reviews to reduce unnecessary emergency authorizations for nonconforming uses. From 2001 to 2013, motorized use and/or mechanized transport were authorized for law enforcement activities (on 9 lakes and 1 river), search and rescue operations (on 63 lakes, 2 rivers, and 7 trails), wildfire suppression events (84 wildfires), and prescribed burns (9 fires).
- Unauthorized motorized/mechanized use—Locations where unauthorized and illegal motorized use or mechanical transport occurred. Unauthorized nonconforming uses are prohibited by the Wilderness Act. This measure encompasses illegal nonconforming uses that are not permitted by special provisions in the Wilderness Act or subsequent BWCAW legislation. Illegal motorized use or mechanized transport in the BWCAW includes the use of OHVs, snowmobiles, motorboats, tow boats, float planes, ski kites, and canoe sails. From 2009 to 2013, there were 351 violation notices written for unauthorized incidents of nonconforming use.

Data Sources, Processing, and Cautions

The datasets used to create the undeveloped quality map are all vector data, of fine scale, and generally of moderate to high accuracy and completeness (table 5). The data sources, data processing information, and cautions are listed below for each measure.

Table 5—Undeveloped quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is across the wilderness) were evaluated for each measure by SNF staff familiar with these data.

Measure	Source	Type	Scale	Accuracy	Completeness
Authorized developments	AuthorizedPhysicalDevlopment	Point	1:24,000	Low - Medium	Medium - High
Research installations	(1) WolfTrapPortageMidPoint; (2) USGS_GagingStation	Point	1:70,000; 1:24,000	High; Low	High
Developed inholdings	StructureNonFS	Point	1:63,360	High	High
Infrastructure supporting inholdings	InholdingSupportFeature	Polyline	1:20,000	High	High
Undeveloped inholdings	BWCAW_Inholdings	Polygon	1:24,000	High	High
Legal motorized/ mechanized use	(1) SemiPrimitiveMotorRoute; (2) SemiPrimitiveMotorUseLake	Polyline and Polygon	1:24,000	High	High

Measure	Source	Type	Scale	Accuracy	Completeness
Administrative motorized/ mechanized use	(1) FireDetectionRoute_LN; (2) MooseHelicopterSurveyAreas2013_14; (3) WolfSurveyFlight_LN; (4) international_bdny; (5) ski_trail; (6) BWCAW_StockedLakes1988_201; (7) BWCAW_SpawnTake; (8) BWCAW_DNR_MotorSurveyLks1978_2013	Polyline and Polygon	1:40,000	High	High
Emergency motorized/ mechanized use	(1) NonRecMotorUse; (2) NonRecMotorUse_LN	Polyline and Polygon	1:24,000	Medium	High
Unauthorized motorized/ mechanized use	(1) UnauthMotorUseFromLEO_Report; (2) anderson	Point and Polyline	1:40,000	Low	Low

Authorized developments

- *Sources*—Point dataset of authorized developments, derived from SNF INFRA data, International Boundary Commission data, and institutional knowledge (SNF District Wilderness Staff).
- *Processing*—The various types of authorized developments were ranked with the following values by the project core team to depict the differences in their areal footprint, size, or noticeability:
  - 1 = Eagle Mountain plaque, small non-functioning dams, and border reference markers
  - 2 = Larger, still functioning dams and docks
  - 3 = Cabins and outhouses

  The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Research installations

- *Sources*—(1) point dataset of wolf trap line locations (Shannon Berber-Meyer, USGS Wildlife Biologist); (2) point dataset of gauging station.
- *Processing*—All research installation locations were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—Radio collars used to monitor wildlife are considered mobile research installations but were not included in this measure as data were unavailable. Wolf trap line points represent approximate locations based on descriptions of the trap line routes provided by the USGS (e.g., "the traps were placed about halfway along the portages"). The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Developed inholdings

- *Sources*—Point dataset of developed inholdings (SNF District Wilderness Staff).
- *Processing*—The two types of developed inholdings were ranked with the following values by the project core team to depict the differences in their likelihood of future development:
  - 1 = State land
  - 5 = Private land
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Infrastructure supporting inholdings

- *Sources*—Polyline dataset of infrastructure supporting inholdings (SNF District Wilderness Staff).
- *Processing*—The location of the infrastructure was assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Undeveloped inholdings

- *Sources*—Polygon dataset of undeveloped inholdings, derived from information on State-owned fee interests (Minnesota DNR land records system), private inholdings (Liz Schleif, SNF Realty Specialist), and county managed lands (St. Louis County and Cook County databases).
- *Processing*—The two types of developed inholdings were ranked with the following values by the project core team to depict the differences in their likelihood of future development:
  - 1 = State land
  - 5 = Private land
- *Cautions*—Ongoing land exchange projects (through which the Forest Service will acquire State and county lands within the BWCAW) are not included in this measure. Since county managed lands are actually "State tax forfeited lands" and therefore technically owned by the State, there was some overlap in the State and county input feature classes. In populating the "Inholding" column, where the county and State features overlapped, polygons were listed with the county label. Since the State and county features are from different original sources and spatially are not perfectly coincident, there are portions of "State" land adjacent to "State Tax Forfeited-County" land that represent the same parcel. Therefore, the "BWCAW_Inholdings" shapefile overrepresents the actual area of inholdings. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Legal motorized/mechanized use

- *Sources*—(1) Polyline dataset of semi-primitive motorized/mechanized routes, created by relating institutional knowledge (SNF District Wilderness Staff) to the SNF trail feature class; (2) polygon dataset of BWCAW lakes where motorized

transportation is authorized, derived from the National Hydrography Dataset (www.nhd.usgs.gov).

- *Processing*—The various types of motorized/mechanized routes were ranked with the following values by the project core team to depict the differences in their degree of motorized use:
  - 1 = Trails that only allow the use of portage wheels (mechanized transport of gear)
  - 5 = Trails that allow use of a vehicle or rail car to transport water craft (motorized transport of gear)
  - 10 = Snowmobile trails (motorized transport of humans)

  Lakes with various motor hp restrictions were ranked with the following values by the project core team to depict the differences in their degree of motorized use:
  - 3 = 10 hp
  - 5 = 25 hp
  - 10 = Unlimited (no hp restrictions)

  Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—Motorized ice augers are occasionally used for subsistence ice fishing (as permitted under the Treaty with the Chippewa 1854 Treaty Authority) but were not included in this measure as data were unavailable. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Administrative motorized/mechanized use

- *Sources*—(1) Polyline dataset of fire detection routes (Chippewa and Superior National Forest Dispatch); (2) polygon dataset of moose surveys (Tom Rusch, Minnesota DNR Wildlife Supervisor); (3) polyline dataset of wolf survey flights (Chippewa and Superior National Forest Dispatch); (4) polyline dataset of international boundary patrols (SNF District Wilderness Staff and SNF Law Enforcement); (5) polyline dataset of groomed ski trails (SNF District Wilderness Staff); (6) polygon dataset of lakes stocked with fish, created by relating fish stocking records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov); (7) polygon dataset of lakes where fish spawn collection occurred, created by relating spawn collection records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov); (8) polygon dataset of fish surveys using motorized access, created by relating information on fish survey methodologies (2015 SNF and Minnesota DNR Memorandum of Understanding on fisheries management within the BWCAW) and fisheries records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov).
- *Processing*—All instances of motorized/mechanized use were assigned a value of 1. Layers were converted to individual rasters and added accumulatively. Values were then normalized to 0–255.
- *Cautions*—The polyline of the international boundary does not represent the specific locations or frequency of actual Border Patrol motorized/mechanized use.

Border Patrol does not release their data on nonconforming wilderness uses to the SNF; the SNF will continue to work with the Department of Homeland Security (DHS) to try to obtain this information in a way that meets national security needs. Similarly, the polygon dataset of fish survey locations using motorized access is most likely an underrepresentation of the actual impact. Data indicating whether or not fish surveys used motorized access were unavailable for small, non-remote lakes (i.e., lakes smaller than 450 acres that are accessible by (1) four portages or fewer that are cumulatively less than a mile in distance, (2) less than 15 miles of motorized water travel, or (3) less than 5 miles of non-motorized water travel); however, it is considered possible that fish surveys on these lakes used motorized access. The polygon dataset of moose survey plots does not reflect the actual amount of motorized use as data on the specific flight paths used for both accessing plots and conducting surveys were unavailable. Additionally, data on annual bald eagle nest detection flights and data on occasional U.S. Coast Guard motorized/mechanized use in wilderness were unavailable at the time of mapping. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Emergency motorized/mechanized use

- *Sources*—(1) Polygon dataset of motorized use for law enforcement (Trish Beaudry, SNF Law Enforcement Program Assistant), prescribed fires, fire suppression, and search and rescue; (2) polyline dataset of motorized use for law enforcement (Trish Beaudry, SNF Law Enforcement Program Assistant), prescribed fires, fire suppression, and search and rescue.
- *Processing*—All emergency use locations were assigned a value of 1. Layers were converted to individual rasters and combined together. Overlapping cells were reclassed back to a value of 1, after which values were normalized to 0–255.
- *Cautions*—Emergency motorized use authorized after blowdown events in 1999 and 2014 occurred outside of the timespan used for this measure (2001–2013) and were therefore not included. The circular polygons representing small fires depict the acreage of the fires, but not necessarily the location; the point feature class used as the original source represents the origin of the fire. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Unauthorized motorized/mechanized use

- *Sources*—(1) Point dataset of unauthorized motorized/mechanized use in wilderness (Trish Beaudry, SNF Law Enforcement Program Assistant; Bruce Anderson, Minnesota DNR Assistant Wildlife Manager); (2) polyline dataset of unpermitted commercial tow route.
- *Processing*—Locations of unauthorized/illegal use were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—The NAD83 datum was assumed for the geographic coordinates in the original table. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Weighting

The assigned weight (on a scale of 1 to 10) and the corresponding rationale for each measure under the undeveloped quality are described in table 6.

Table 6—Measure weights and rationales for the undeveloped quality.

Indicator	Measure	Weight	Rationale
Non-recreational structures, installations, and developments	Authorized developments	3	Low weight because non-recreational developments are generally difficult to notice.
	Research installations	1	Lowest weight because there are few research installations in the wilderness.
Inholdings	Developed inholdings	3	Low weight because there are relatively few developments associated with inholdings.
	Infrastructure supporting inholdings	2	Low weight because there are only two areas where inholdings are supported by infrastructure.
	Undeveloped inholdings	1	Lowest weight because undeveloped inholdings appear natural and the threat of development is considered to be low at this time.
Use of motor vehicles, motorized equipment, or mechanical transport	Legal motorized/ mechanized use	10	Highest weight because these nonconforming uses, while legal in the BWCAW under legislated special provisions, are generally prohibited in wilderness areas per Section 4(c) of the Wilderness Act.
	Administrative motorized/ mechanized use	10	Highest weight because of the variety and frequency of motorized and mechanized administrative use.
	Emergency motorized/ mechanized use	2	Low weight because the amount of emergency use of motorized equipment or mechanized transport is relatively small for such a large and heavily used wilderness.
	Unauthorized motorized/ mechanized use	1	Lowest weight because data on unauthorized motorized and mechanized use are limited and because unauthorized use occurs less frequently than authorized use.

Maps

The weighted measures under each indicator were added together using a raster calculator to create three maps: “non-recreational structures, installations, and developments,” “inholdings,” and “use of motor vehicles, motorized equipment, or mechanical transport” (fig. 8). All the measures were then added together using the same process to create the undeveloped quality map (fig. 9).

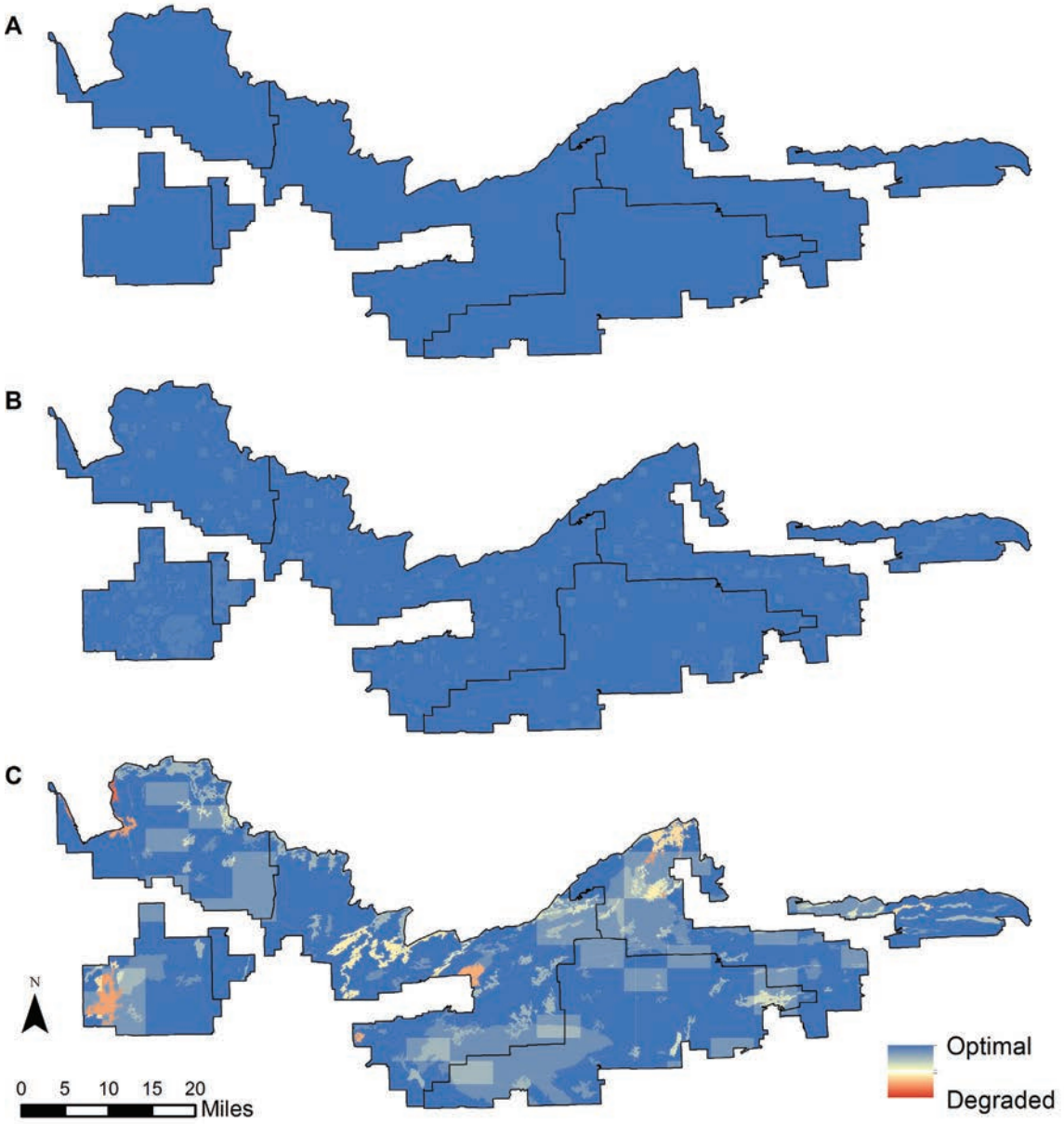

Figure 8—Indicator maps for (A) non-recreational structures, installations, and developments; (B) inholdings; and (C) use of motor vehicles, motorized equipment, or mechanical transport. Blue depicts optimal condition and red depicts degraded condition.

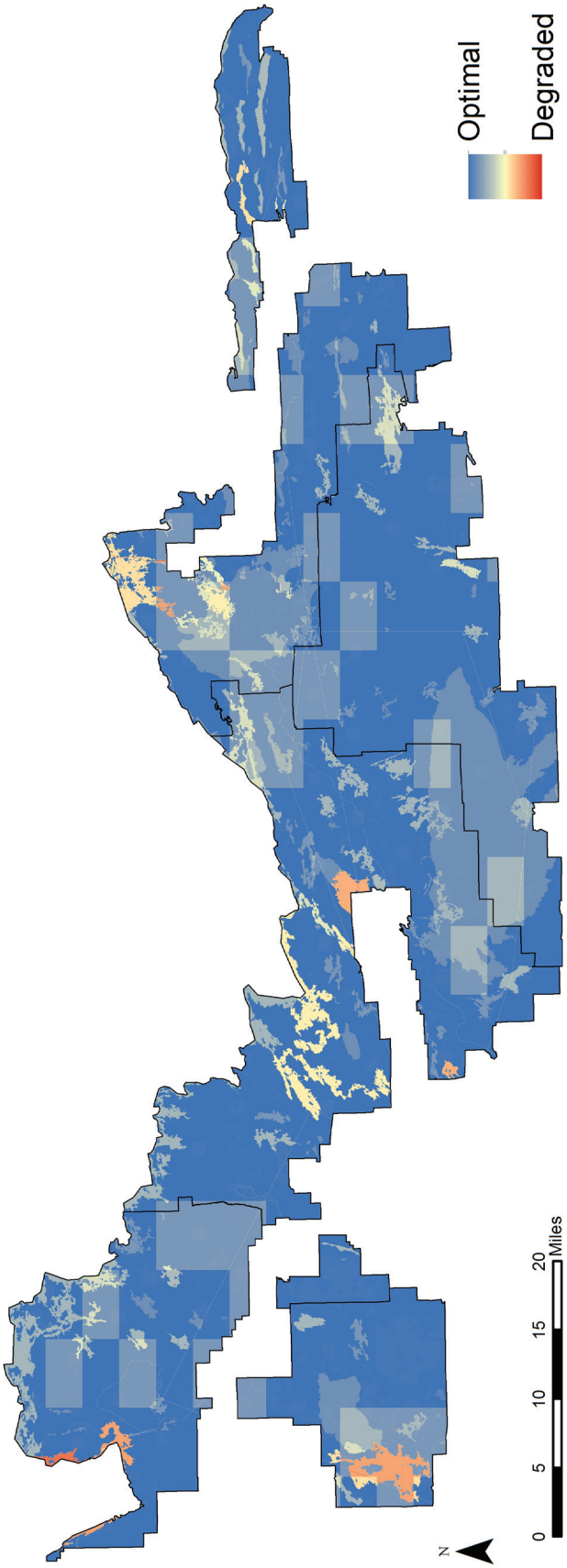

Figure 9—Map of the undeveloped quality of wilderness character. Blue depicts optimal condition and red depicts degraded condition.

Solitude or Primitive and Unconfined Recreation Quality

The solitude or primitive and unconfined recreation quality focuses on the outstanding opportunities that exist in wilderness to experience solitude, remoteness, and primitive recreation free from the constraints of modern society. This quality is degraded by tangible attributes of the setting that reduce these opportunities, such as visitor encounters, signs of modern civilization, recreation facilities, and management restriction on visitor behavior (Landres and others 2008a, 2015).

Indicators and Measures

Keeping it Wild delineates four indicators under the solitude or primitive and unconfined recreation quality. The measures selected for the BWCAW are described below for each of these indicators.

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

- Campsite occupancy—Average nightly occupancy of campsites during the primary use season (May 1–September 30). Campsite occupancy levels correspond with how crowded a travel zone is; areas with higher average occupancies have fewer opportunities for visitors to escape the sights and sounds of other people and experience solitude. The BWCAW is one of the most heavily used wildernesses in the country and overcrowding is of particular concern. Occupancy was calculated using a BWCAW-specific visitor use model to predict the average percentage of occupied campsites in a travel zone. Some travel zones do not meet SNF plan standards for visitor occupancy.
- Administrative motorized noise inside wilderness—Areas affected by the sounds of administrative motorized use. Motorized equipment used in wilderness produces a distinctive human-made noise that decreases visitors' sense of remoteness from modern civilization. For this measure, the Forest Service, Border Patrol, USGS, Minnesota DNR, and State and county search and rescue teams are all considered administrative users. The spatial extent of the soundscape for each type of motorized use—including motorboats, airplanes, helicopters, chainsaws, water pumps, drones, all-terrain vehicles, etc.—was determined based on its frequency, the initial decibel level of the sound produced, and its perceived impact on visitor solitude. In the BWCAW, administrative motorized noise is generated through wildlife surveys, fish stocking, trail grooming, fire scouting and fighting, international border protection, and other motorized uses.
- Campsite noise inside wilderness—The maximum extent of potential noise generated by visitors occupying campsites. Auditory impacts from visitors have a significant effect on solitude, especially in water-based wilderness areas. On calm lakes, the cool air and flat water surface amplify sound such that noise from campsites can be heard on the opposite shoreline; lake campsites were therefore depicted with larger noise radiuses than inland sites for this measure. Out of the more than 1,957 designated sites in the BWCAW, the vast majority are on shorelines.

- Commercial outfitter/guides—Routes frequently used by commercial outfitters and guides. Commercial outfitters and guides often have standardized routes that they both recommend to their clients and use in their commercial operations, and they can therefore influence visitor use patterns and opportunities for solitude. The impact of frequently used routes was determined based on the type of commercial use and the magnitude of its associated effects; for example, motorized services during the primary use season were depicted as having a greater effect on solitude than non-motorized winter use. Guided or outfitted excursions in the wilderness include canoeing, kayaking, motorized boating, dogsledding, skiing, snowshoeing, hunting, and fishing. Outfitters and guides also provide towing services on Loon River, La Croix, Trout, South Farm, Fall, Newton, Basswood, Moose, Newfound, Sucker, Snowbank, Seagull, Saganaga, and Clearwater lakes.
- Viewshed inside wilderness—Line of sight impacts of modern human features inside wilderness. The presence of modern features detracts from a sense of solitude. Viewshed analyses depict the line of sight impacts of modern features within wilderness, as determined by their visibility and size. In the BWCAW, modern human features include inholding buildings (21 features), the Saganaga road, administrative structures and installations (472 features), maintained trails and portages (481 miles), roads and portages that allow motorized use (6 features), dams (31 installations), designated campsites (1,957 sites), border markers (1,014 markers), and a single plaque.
- Encounters—Encounter rates per travel zone. The number of other groups seen or encountered in the wilderness has a large impact on visitor perceptions of solitude. The BWCAW has four management areas (pristine, primitive, semi-primitive non-motorized, and semi-primitive motorized) for which different levels of acceptable encounter rates have been set in the SNF plan. Encounter monitoring in the wilderness began in 2008 and is ongoing; while survey data are still incomplete, the preliminary results appear to indicate that some travel zones do not meet SNF plan standards for their management area.
- High use destinations—Routes and sites that are known to receive high amounts of visitor use. Popular and well-known destinations receive increased visitation compared to the rest of the wilderness and are more likely to experience decreased opportunities for solitude. High use destinations include pictograph sites, portages that lead to waterfalls, geologic features, historical sites, natural overlooks, and day use sites. The BWCAW has 23 high use destinations that include over 50 miles of trails. While some sites are being restored and actively managed, the majority of recreational impacts to these locations fall within SNF plan standards.

Indicator: Remoteness from occupied and modified areas outside the wilderness.

- Entry point congestion—Entry points that have known problems with visitor congestion. Designated entry points restrict the locations where visitors are able to enter the wilderness and sometimes create bottlenecks that cause congestion and overcrowding. When multiple visitor groups attempt to enter the wilderness at the same time and place, they end up racing or competing with each other for designated campsites within connected travel routes. These congestion problems

are not isolated to a specific time (e.g., a morning rush) but instead occur throughout the day. Out of 67 total entry points in the BWCAW, 29 of them are known to have frequent congestion problems.

- Utilitarian noise outside wilderness—Areas of wilderness affected by utilitarian noise originating outside of the wilderness. Sounds of modern human civilization adjacent to wilderness can impact wilderness visitors' sense of remoteness. Sources of utilitarian noise include vehicles and chainsaws; because these noises are intermittent, the spatial extent of each source was determined by the initial decibel level of the sound produced. Currently, external utilitarian noise from access and travel routes affects 114,904 wilderness acres while noise from timber harvest units affects 31 wilderness acres.
- Viewshed outside wilderness—Line of sight impacts from modern human features outside of the wilderness. Features of modern civilization located outside of the wilderness can be visible from inside the area and have an effect on visitor solitude. The viewshed analysis for this measure depicted the areas within wilderness where it is possible to observe modern features on the other side of the boundary; the line of sight distance for each feature was determined by its size and visibility. The viewshed analysis included the following external features: communication towers and repeaters (11 sites), roads (964 miles), trails (481 miles), parking lots (10 lots), border swath and boundary markers (1,014 features), campgrounds (13 locations), private structures and associated development (4,633 features), clearcuts (109 locations), recreation sites (48 features), and border monuments (9 monuments).
- Night sky obfuscation—Anthropogenic light ratio (ALR) across the wilderness. Artificial brightening of the night sky obscures the visibility of stars and lessens visitors' sense of solitude. ALR is the proportion of artificial light compared to the brightness of the night sky (for example, an ALR of 0.3 indicates that it is 30 percent brighter than under natural conditions). The BWCAW is relatively protected from artificial light sources by the public lands surrounding it: SNF (to the south), Voyageur's National Park (west), Quetico and La Verandrye Provincial Parks (north and east, respectively), Canadian Crown Land (northeast), Grand Portage National Monument (northeast), and several State parks (east). The largest sources of light nearby are Duluth, Minnesota (~100 miles to the south, with 86,000 people) and Thunder Bay, Ontario (~100 miles to the northeast, with 108,000 people).
- Recreational noise outside wilderness—Areas of wilderness affected by recreational noise originating outside of the wilderness. Sounds of modern human civilization adjacent to wilderness can impact wilderness visitors' sense of remoteness. The spatial extent of each type of motorized recreational use was determined by the initial decibel level of the sound produced. Sources of external recreational noise that affect the wilderness include OHV routes (affecting 258,658 acres of wilderness), snowmobile trails (affecting 243,900 acres), and lakes with motorized use that are adjacent to non-motorized wilderness management areas (affecting 21,298 acres).

Indicator: Facilities that decrease self-reliant recreation.

- Authorized facilities—The locations of designated and maintained recreation facilities. Authorized facilities diminish the need for outdoor skills and decrease opportunities for self-reliance and primitive recreation. Given the high visitation levels in the BWCAW, the Forest Service has installed many recreational facilities to prevent damage to aquatic ecosystems and other natural resources. Wilderness recreational facilities maintained by the Forest Service include five docks and more than 1,957 designated campsites with latrines and fire grates.
- Trails and associated features—Maintained trails and portages. Areas without maintained routes offer extensive opportunities for primitive recreation, such as route-finding or bushwhacking; in contrast, areas with developed trails and portages reduce the need for these types of outdoor skills and promote reliance on managed facilities. Trails frequently have additional constructed features that make visitor experiences easier or more comfortable in wet conditions, including boardwalks, bridges, puncheons, turnpikes, etc. The wilderness contains over 453 miles of maintained portages and trails, many of which contain these types of associated trail features.
- Motorized/mechanized routes—Travel routes that allow motorized use, including tow routes and portages that permit mechanized or motorized travel. In contrast to non-motorized areas that encourage a primitive type of recreation, motorized and mechanized routes allow the use of assisted transportation. For this measure, the degree of impact was considered to be high for portages allowing the use of motorized transport or railcars, moderate for tow routes, and low for trails allowing the use of portage wheels. In the BWCAW, there are 18 tow routes, 2 motorized portages (both on Loon River), 2 portages that allow motorized and mechanized use (Prairie Portage and the Vermillion-Trout Lake portage) and 4 areas that permit the use of portage wheels (portages along the international boundary, Four-Mile Portage, and the Fall-Newton-Pipestone and Back Bay portages into Basswood Lake).
- Wireless coverage—The extent of wireless telephone coverage in the wilderness. The ability to use cell phones to connect with modern civilization while in remote locations diminishes visitors' sense of risk, challenge, and self-reliance. Wireless coverage (for Verizon, T-Mobile, AT&T, and Sprint) extends into the wilderness mainly in the Kawishiwi Ranger District and the Trout unit of the La Croix Ranger District.
- Visitor-created facilities—The locations of known visitor-created recreation facilities. Once created, facilities developed by visitors tend to receive continued use and can become established amenities that decrease opportunities for primitive recreation. Visitor-created facilities include non-designated campsites and fire rings, excessive amounts of camp furniture at designated sites, hunting structures, social trails, cairns, landing jetties, rock cribs, etc. While visitor-created facilities are generally eliminated as soon as they are discovered by SNF staff, there are currently 140 known facilities in the wilderness.

Indicator: Management restrictions on visitor behavior.

- BWCAW rules and regulations—The restrictiveness of regulations for each management area. Rules and regulations for visitors confine and diminish their

sense of freedom. As one of the most heavily used wilderness areas in the NWPS, the BWCAW has many types and levels of visitor restrictions to prevent damage to natural resources and protect opportunities for solitude. Types of regulations include Forest Orders (e.g., prohibitions on cans and glass, prohibitions on pack or saddle animals—except sled dogs—on portages and trails), use restrictions (e.g., group size limits, mandatory permits, reservation system and fees), access restrictions (e.g., mandatory quotas and entry points, closed sites), legislated requirements (e.g., motorized watercraft quotas and hp limits, BWCAW air-space reservation), and special management area limitations (e.g., mandatory pristine management area reservations in addition to standard wilderness reservations). The four management areas of the wilderness have different levels of visitor restrictions. In semi-primitive motorized, semi-primitive non-motorized, and primitive management areas, visitors are required to camp at designated sites. In pristine management areas, in contrast, campsites are not designated or maintained, and visitors are free to choose the location of their site. Visitors are therefore less confined in pristine management areas, despite the additional reservation necessary to access them, than in the rest of the wilderness.

Data Gap Measures

Additional measures under this quality were identified by SNF staff but were excluded for a variety of reasons. For each data gap measure, the indicator, description, and rationale for their dismissal are listed below.

Administrative travel routes

- *Indicator*—Remoteness from sights and sounds of people inside the wilderness.
- *Description*—Administrative routes used by SNF staff. In contrast to visitor use, which is limited by a quota system to preserve opportunities for solitude, there are no explicit restrictions on the amount of administrative use. While SNF staff generally use the same travel routes as visitors, they may occasionally use unofficial access routes as well. Administrative routes include those traveled by all biological or forest technicians for botany, heritage, air and water quality, fisheries, wildlife, fire, visitor/law enforcement, and other wilderness purposes.
- *Rationale for dismissal*—Except for wilderness rangers, most biological or forest technicians have no direct contact with the public while in the wilderness. Although rangers do make public contacts and check permits, these interactions do not seem to have a negative impact on visitors' sense of solitude; to the contrary, BWCAW visitors complain that there are too few contacts with SNF staff.

Visitor motorized noise inside wilderness

- *Indicator*—Remoteness from sights and sounds of people inside the wilderness.
- *Description*—Areas affected by the sounds of motorized recreation. Visitors are prohibited from using motorized equipment in most wilderness areas; where special exemptions have been made, the noise of motorized recreation decreases visitors' sense of remoteness from modern civilization. Recreational use of motorboats and snowmobiles in certain areas of the wilderness was authorized by the Wilderness Act of 1964 and Boundary Waters Canoe Area Wilderness Act of 1978.

- *Rationale for dismissal*—Data on legal motorized recreation in the semi-primitive motorized management area are not available. The administrative motorized use noise measure serves as a proxy for this data gap measure.

Data Sources, Processing, and Cautions

A wide variety of data sources were used to create the solitude or primitive and unconfined recreation quality map. These datasets included both vector and raster data in a range of different scales and with high variability in accuracy and completeness (table 7). The data sources, data processing information, and cautions are listed below for each measure. The viewshed model (used for two measures) is described first as it has a level of complexity beyond the other measures.

Table 7—Solitude or primitive and unconfined recreation quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is across the wilderness) were evaluated for each measure by SNF staff familiar with these data.

Measure	Source	Type	Scale	Accuracy	Completeness
Campsite occupancy	(1) BWCAW_TravelZones; (2) BWCAW_Vissim work	Polygon and Excel spread-sheet	1:24,000	Medium	Medium
Administrative motorized noise inside wilderness	(1) AuthorizedMotorUseLakes; (2) FireDetectionRoute_LN; (3) international_bdny; (4) MooseHelicopterSurveyAr-eas2013_14; (5) ski_trail; (6) snowmobile; (7) WolfSurveyFlight_LN; (8) BWCAW_StockedLakes1988_201; (9) BWCAW_SpawnTake; (10) BWCAW_DNR_MotorSur-veyLks1978_2013	Polyline and Polygon	1:40,000	Medium	High
Campsite noise inside wilderness	Campsites	Point	1:24,000	High	High
Commercial outfitter/guides	CommercialOutfitterUseUpdate	Polyline	1:63,360	Medium	High
Viewshed inside wilderness	See Table 8				
Encounters	(1) BWCAW_TravelZones; (2) encounters database	Polygon and Excel spread-sheet	1:24,000	Medium	Medium
High use destinations	(1) HighUseDestination; (2) HighUseRoute	Point and Polyline	1:63,360	High	High
Entry point congestion	EntryPointTravelImpact	Polygon	1:24,000	Medium	High
Utilitarian noise outside wilderness	(1) Sound_Roads; (2) Sound_TimberHarvests	Polygon	1:24,000	Medium	Low
Viewshed outside wilderness	See Table 8				
Night sky obfuscation	boundarywatersALR	Raster	900m	Medium	High

Measure	Source	Type	Scale	Accuracy	Completeness
Recreational noise outside wilderness	(1) Sound_ATVs_Version2; (2) Sound_MotorBoats; (3) Sound_Snowmobiles	Polygon	1:24,000	Medium	Medium
Authorized facilities	(1) OpenCampsites; (2) Docks	Point	1:24,000	High	High
Trails and associated features	TrailsPortagesUpdate	Polyline	1:24,000	Low	Low
Motorized/ mechanized routes	AuthorizedAdminRoute	Polyline	1:24,000	High	High
Wireless coverage	MN_Wireless	Polygon	30m	High	High
Visitor-created facilities	(1) SocialTrail; (2) UserCreatedFacilities	Point and Polyline	1:63,360	Low	Low
BWCAW rules and regulations	Management_area	Polygon	1:24,000	High	High

Viewshed inside wilderness and Viewshed outside wilderness

The line of sight visual impacts of modern anthropogenic features inside and outside the BWCAW were modeled using a custom-built software tool. This tool analyzed a variety of inputs—including terrain, land cover, road networks, and all modern human developments occurring in and around the wilderness—to delineate the impacts of modern human features on visitor solitude. To account for edge effects[11] from visible human features immediately outside the wilderness boundary, the viewshed analysis was extended into a 15-kilometer buffer zone around the wilderness.

Viewshed analyses such as these have traditionally been 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. Previous work on the effects of human features on perceptions of wilderness, carried out at national and global scales, has focused on simple distance measures (Carver 1996; Lesslie 1993; Sanderson and others 2002). Recent improvements to viewshed modeling algorithms have utilized measures of the visibility of anthropogenic features in 3D landscapes using digital terrain models[12] (Carver and Wrightham 2003; Fritz and others 2000). These algorithms calculate the line of sight between a person standing anywhere on a landscape and a particular feature (e.g., a building or radio antennae), and they account for places where this line of sight is interrupted by intervening higher ground.

Incorporating these improvements, Washtell (2007) has shown that it is possible to both dramatically decrease processing times and improve overall accuracy through judicious use of a voxel-based landscape model[13] and a highly optimized ray-casting algorithm.

[11] A problem created during spatial analysis when patterns of interaction or interdependency across borders of the bounded region are ignored or distorted (ESRI 2015).
[12] Digital terrain models are 3D representations of the earth's surface that contain elevation data.
[13] A voxel is a volumetric pixel.

This 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 integrating this approach 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. With this approach (called a "viewshed transform"), an inverse square distance function is used in calculating the significance of visible cells. Put simply, this tool determines the relative viewshed value for each cell by calculating the proportion of the features that can be seen and the distance between the cell and the particular features. Thus, the smaller the proportion of the feature in view and the further away it is, the lower the viewshed value for the particular cell. The greater the proportion of the feature in view and the closer it is, the higher the viewshed value of the particular cell.

In summary, the approach described above represents a maturation of traditional cumulative viewshed techniques (Carver and others 2008) and is used to:

1. Calculate the viewshed for every single feature;
2. Incorporate estimations of the proportional area of each feature that is visible; and
3. Run separate viewshed calculations for categories of features with different viewshed distances, which can then be combined together to create overall viewshed maps.

Sources—The viewshed transform tool was used to conduct the viewshed analyses for modern human features inside and outside the BWCAW. Viewshed analyses rely on the ability to calculate the line of sight from one point on a landscape to another. It has been shown that the accuracy of a viewshed analysis produced in GIS is strongly dependent on the accuracy of the terrain model used and the inclusion of intervening features or "terrain clutter" (Fisher 1993). While previous studies have made use of a digital surface model (DSM)[14] for obtaining terrain clutter data (Carver and others 2008), the large spatial extent of the BWCAW and the relative lack of anthropogenic features allows feature information to be collated and formatted manually. A resolution of 30 meters for feature inputs was considered adequate for this analysis. The USGS 10-meter Digital Elevation Model (DEM) was resampled to 30 meters to provide the base terrain elevation data. The DEM was then augmented with surface data, including both land cover data and anthropogenic features. The land cover data were created by assigning heights (provided by Kathleen McTighe, SNF Silviculturist) to the different classes in the original land cover dataset (Wolter and others 1995). Modern anthropogenic features in and adjacent to the BWCAW were identified by the project core team; viewshed distance and height information were then assigned for each feature (table 8).

[14] Digital surface models are a type of terrain model that include objects on the surface of the earth, such as buildings, vegetation, or other features.

Processing—Two data inputs are required for the viewshed model: (1) a terrain layer and (2) a viewshed feature layer. The terrain layer is a model of the environment being analyzed. The feature layer is used to identify the features being analyzed in the terrain model and sets their associated viewshed distances. The major processing tasks performed for the terrain layer are summarized chronologically below:

1. The USGS 10-meter DEM was resampled to 30 meters.
2. The height information was related to the land cover dataset (Wolter and others 1995).
3. The land cover dataset was converted to raster at 30 meters, setting the pixel values to the height information.
4. All viewshed features (listed in table 8) were converted to raster at 30 meters, setting the pixel values to the height information.
5. The viewshed features were combined together using the Mosaic to New Raster tool[15]. The merge order was set from the tallest features to the shortest (such that taller features are given priority when features overlap).
6. The combined viewshed features were added to the land cover raster using the Mosaic to New Raster tool, giving priority to the viewshed features (such that features always override the land cover heights wherever they occur).
7. The above raster was added to the DEM using the raster calculator.
8. The raster was converted to a floating point grid (as required by the viewshed software).

The major processing tasks performed for the viewshed feature layer are summarized chronologically below:

1. All viewshed features (listed in table 8) were converted to raster at 30 meters, setting the pixel values to the height information.
2. The viewshed features were combined together for each viewshed distance category (120 meters, 500 meters, 1 kilometer, 5 kilometers, and 15 kilometers) using the Mosaic to New Raster tool.
3. Each of the rasters for the viewshed distance categories was converted to a floating point grid (as required by the viewshed software).

The software was used to analyze the viewshed distance categories for both features inside wilderness (three categories) and features outside wilderness (four categories) (see table 8). When necessary for the analysis of a distance category, the viewshed landscape was split into a number of overlapping tiles such that they could be simultaneously analyzed by a cluster of desktop computers.

The model outputs for the different viewshed distances were combined using the MINIMUM function in ArcGIS to produce grids of viewshed impacts for features inside and adjacent to the wilderness. Raster values were normalized to 0–255. The normalized values were then inverted to reflect high degradation of solitude near human features and lower degradation further away from those features (fig. 10).

[15] Merges multiple raster datasets into a new raster dataset (ESRI 2015).

Cautions—The viewshed model replicates the natural environment using a number of rules and compromises. While necessary for the purposes of this analysis, these compromises should be carefully considered when discussing results.

1. For this analysis, a "pessimistic" resampling was done to generate the 30-meter feature inputs guaranteeing that features smaller than this area were included[16] and that the viewsheds produced an accurate representation of the visual impacts of these features.
2. Categorizing the anthropogenic features in and adjacent to the BWCAW into specific viewshed distances requires careful consideration as to how well each type of feature may blend in with the local background. For example, border markers are largely unnoticeable at a distance because of their shape and profile; they were therefore assigned a maximum viewshed distance of 120 meters. Larger and more prominent features, such as the communication towers and repeaters, were assigned a maximum viewshed distance of 15 kilometers.
3. The viewshed analysis may not realistically represent certain resampled feature inputs. For example, utility poles and powerlines in the Saganaga corridor are represented in the model as a solid 2-meter high "wall," even though those features are significantly less visible than a wall would be.
4. The current version of the viewshed tool places the "person" in the analysis on top of all the viewshed features (such as vegetation or buildings), as opposed to placing them in among those features. Areas where the vegetation exceeds 3 meters must therefore be removed manually from the output. This limitation is being addressed for future versions of the software.

[16] Resampling 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 meters building in a 30 x 30 meters grid cell that was otherwise not classified as a feature would not be recorded on resampling. The "pessimistic" resampling 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.

Table 8—Modern human features impacting viewshed.

Features INSIDE wilderness	Data source	Viewshed distance (kilometers)	Height (meters)	Accuracy	Completeness
Inholding buildings and associated developments	StructureNonFS	1	3, 4, or 6	High	High
Administrative buildings and docks	AuthorizedPhysicalDevlopment	1	3 or 4 = buildings; 1.5 = docks	High	High
Trails/portages (water bars, tread, turnpike, puncheon)	TrailsPortagesUpdate	0.5	1	Low	Low
Motorized portages/ roads	MotorizedPortages	1	1.5	High	High
Dams	DamsBWCAW.shp	1	2	High	High
Campsites	OpenCampsites	1	2	High	High
Eagle Mountain plaque	AuthorizedPhysicalDevlopment	0.5	2	Medium	High
Border markers	AuthorizedPhysicalDevlopment	0.12	1	Medium	High
Power line poles and associated roads	InholdingSupportFeature	0.5	2	High	High
Features OUTSIDE wilderness	**Data source**	**Viewshed distance (kilometers)**	**Height (meters)**	**Accuracy**	**Completeness**
Communication towers/repeaters	TowersPublic15k	15	Antenna height	Medium	High
Roads	SNF_Road5k	5	2	High	High
Trails	TrailOutWithin5k	0.5	1	High	High
Parking lots	ParkingLot	5	2	High	High
Border swath/markers	AuthorizedPhysicalDevlopment	0.12	1	Medium	High
Campgrounds	CampgroundWithin5k_PL	5	2.5	High	High
Private structures and associated developments	StructuresWithin5k_PT; QueticoStructures	5	6	Medium	Low
Clearcuts	Clearcuts2009_2013	5	1	High	Medium
Recreation sites	RecSiteWithin5k	5	2	High	High
Border monuments	BorderMonument	0.5	1	Medium	High

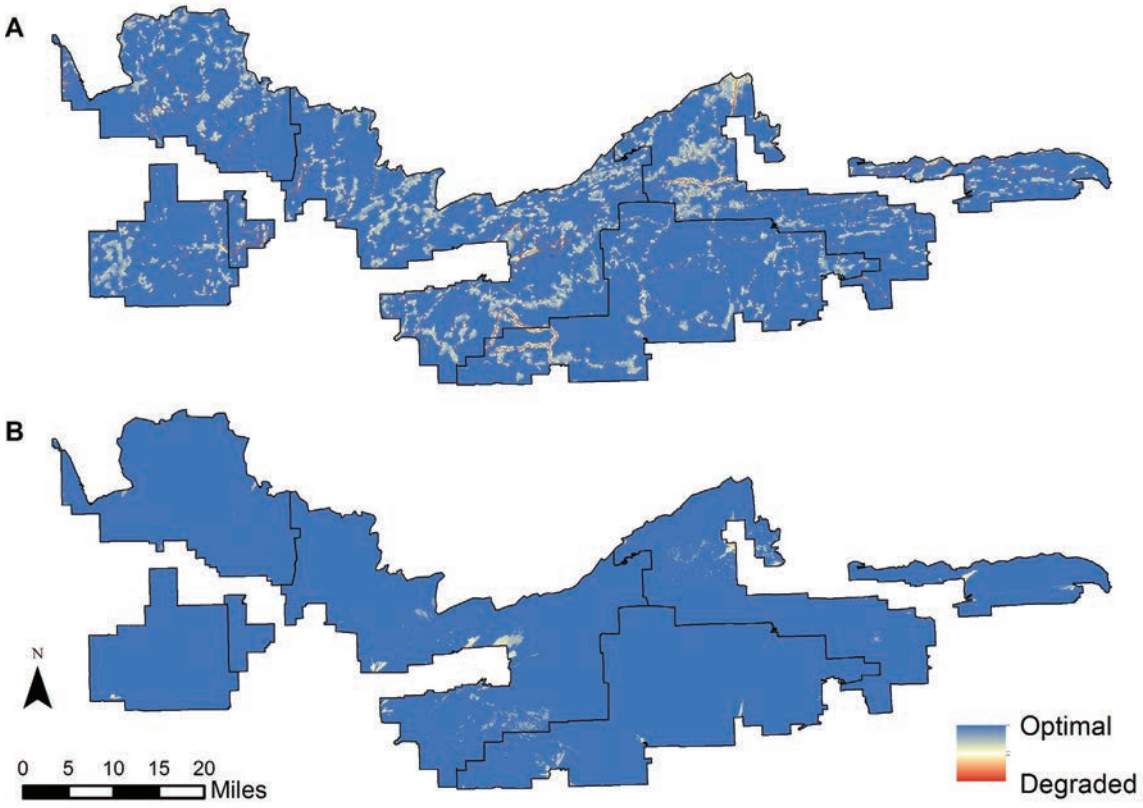

Figure 10—Viewshed impacts for (A) features inside the wilderness and (B) features outside the wilderness. Blue depicts optimal condition and red depicts degraded condition.

Campsite occupancy

- *Sources*—(1) Polygon dataset of BWCAW travel zones; (2) BWCAW travel simulation model (VisSim3.0). The VisSim3.0 is based on actual itineraries contributed by over 11,000 BWCAW visitor groups after their trips in 2011, and it accounts for the unique travel patterns of visitors as they choose from 61 entry points and travel through 95 backcountry travel zones and Quetico Provincial Park. The model was run 5 times to simulate 5 scenarios of campsite occupancy across the wilderness over the course of the primary use season (May 1–September 30); the average predicted occupancy for each travel zone was calculated from the 5 datasets produced (Ann Schwaller, SNF Wilderness Specialist).
- *Processing*—The model output was joined to the travel zones dataset; values were assigned to each travel zone from the average modeled data. The layer was converted to raster and the values were normalized to 0–255.
- *Cautions*—A number of assumptions are inherent to the travel simulation model. If a travel zone is full or closed, a simulated group will move to the next travel zone on their itinerary (if possible) and stay an extra day in the new zone to maintain the same overall trip length. If the closed zone is the last or only zone on the group's itinerary, the trip will be cut short. If no zones on the assigned itinerary are available, the group will be assigned a new itinerary. The model does not account for camping in undesignated areas or for two or more groups camping at

a single site; however, these behaviors can be simulated by increasing the visitor capacities of the travel zones where these situations are known to occur.

Administrative motorized noise inside wilderness

- *Sources*— (1) Polygon dataset of BWCAW lakes where motorized use is authorized, derived from the National Hydrography Dataset (www.nhd.usgs.gov); (2) polyline dataset of fire detection routes (Chippewa and Superior National Forest Dispatch); (3) polyline dataset of international boundary patrols (SNF District Wilderness Staff and SNF Law Enforcement); (4) polygon dataset of moose surveys (Tom Rusch, Minnesota DNR Wildlife Supervisor); (5) polyline dataset of groomed ski trails (SNF District Wilderness Staff); (6) polyline dataset of snowmobile trails (SNF District Wilderness Staff); (7) polyline dataset of wolf survey flights (Chippewa and Superior National Forest Dispatch); (8) polygon dataset of lakes stocked with fish, created by relating fish stocking records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov); (9) polygon dataset of lakes where fish spawn collection occurred, created by relating spawn collection records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov); (10) polygon dataset of fish surveys using motorized access, created by relating information on fish survey methodologies (2015 SNF and Minnesota DNR Memorandum of Understanding on fisheries management within the BWCAW) and fisheries records (Lyn Bergquist, Minnesota DNR GIS Program Coordinator) to the National Hydrography Dataset (www.nhd.usgs.gov).
- *Processing*—All sources of administrative motorized noise were buffered to account for the distance sound travels. The buffer distances for aircraft overflights (5 kilometers or 0 kilometers) were determined through group consensus based on the experiences of SNF District Wilderness Staff. For snowmobile and motorboat use, the buffer distances (686 meters and 976 meters, respectively), were determined by inputting a starting decibel into a sound attenuation formula (vetted by Dan Mennitt, Colorado State University Research Scientist) to determine how far the sound must travel to be reduced to the level of "secluded woods." The administrative noise sources were ranked with the following values by the project core team to depict the differences in their perceived impacts to visitor solitude:
    - 3 = International boundary flights (5 kilometer buffer)
    - 3 = Moose survey flights (no buffer)
    - 5 = Wolf survey flights (5 kilometer buffer)
    - 5 = Ski trail grooming with snowmobiles (686 meter buffer)
    - 5 = Fish survey and stocking flights (5 kilometer buffer)
    - 6 = Fish survey and spawn collection with motorboats (976 meter buffer)
    - 8 = Fire flights (5 kilometer buffer)
    - 10 = Snowmobile trails (686 meter buffer)
    - 10 = Lakes authorized for motorized use (976 meter buffer)

  Layers were converted to individual rasters and added accumulatively. Values were then normalized to 0–255.

- *Cautions*—The polyline of the international boundary does not represent the specific locations or frequency of actual Border Patrol motorized/mechanized use. The Border Patrol does not release their data on nonconforming wilderness uses to the SNF; the SNF will continue to work with the DHS to try to obtain this information in a way that meets national security needs. Similarly, the polygon dataset of fish survey locations using motorized access is most likely an underrepresentation of the actual impact. Data indicating whether or not fish surveys used motorized access were unavailable for small, non-remote lakes (i.e., lakes smaller than 450 acres that are accessible by [1] 4 portages or fewer that are cumulatively less than a mile in distance, [2] less than 15 miles of motorized water travel, or [3] less than 5 miles of non-motorized water travel); however, it is considered possible that fish surveys on these lakes used motorized access. The polygon dataset of moose survey plots does not reflect the actual amount of motorized use as data on the specific flight paths used for both accessing plots and conducting surveys were unavailable; no buffer was assigned to this noise source as the polygon itself was considered to provide sufficient representation of the known sound impacts. Additionally, data on annual bald eagle nest detection flights and data on occasional U.S. Coast Guard motorized/mechanized use in wilderness were unavailable at the time of mapping. Linear buffers for administrative noise sources offer a rough estimation of sound impact and do not account for variability introduced by terrain or vegetation. Sounds from administrative noise are not constant and activity is variable; therefore wilderness areas depicted as being affected by administrative noise may or may not be impacted at any given moment. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Campsite noise inside wilderness

- *Sources*—Point dataset of campsite locations in the BWCAW (Teresa Hanson, SNF GIS Analyst, and Ann Schwaller, SNF Wilderness Specialist).
- *Processing*—Campsite noise was buffered 100 meters on land and 500 meters over water to account for differences in how sound travels. These buffer distances were determined through group consensus based on the experiences of SNF District Wilderness Staff. Buffered campsite locations were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—Linear buffers for campsite noise offer a rough estimation of sound impact and do not account for variability introduced by terrain or vegetation. Sounds from visitors at campsites are not constant and activity is variable; therefore, wilderness areas depicted as being affected by campsite noise may or may not be impacted at any given moment. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Commercial outfitter/guides

- *Sources*—Polyline dataset of outfitter/guide routes in the BWCAW (SNF District Wilderness Staff).

- *Processing*—The various types of outfitter/guide routes were ranked with the following values by the project core team to depict the differences in their season of commercial use and the magnitude of their effects on other visitors:
    - 1 = Winter dogsled
    - 3 = Summer recreation
    - 4 = Summer recreation and winter dogsled
    - 7 = Summer recreation with motorized towing
    - 8 = Summer recreation with motorized towing and winter dogsled

  The layer was converted to raster and the values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Encounters

- *Sources*— (1) Polygon dataset of BWCAW travel zones; (2) SNF encounter database (a Microsoft Excel spreadsheet with records of encounter rates per travel zone, SNF District Wilderness Staff and Ann Schwaller, SNF Wilderness Specialist).
- *Processing*—The database was joined to the travel zones dataset; values were assigned to each travel zone from the data in the database. The layer was converted to raster and the values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

High use destinations

- *Sources*— (1) Point dataset of high use destinations (SNF District Wilderness Staff); (2) polyline dataset of high use routes, created by relating institutional knowledge (SNF District Wilderness Staff) to the SNF trail feature class.
- *Processing*—High use points were buffered by 250 meters to reflect increased visitation around these destinations. Locations of destinations and routes of high use were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Entry point congestion

- *Sources*—Polygon dataset of busy/congested entry point lakes and portages, created by relating institutional knowledge (SNF District Wilderness Staff and Ann Schwaller, SNF Wilderness Specialist) to the National Hydrography Dataset (www.nhd.usgs.gov) and the SNF trail feature class.
- *Processing*—Congested entry points were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Utilitarian noise outside wilderness

- *Sources*—Polygon datasets of utilitarian noise impacts inside wilderness from: (1) roads outside wilderness; (2) timber harvest locations outside wilderness. Both datasets were created by buffering point datasets of noise sources; buffer distances were determined using a sound attenuation model to calculate the distance it takes the starting decibel levels (of [1] vehicles on different road surfaces and [2] timber harvest operations) to be reduced to natural ambient noise levels (Menge and others 1998, 2002; Teresa Hanson, Forest GIS Analyst).
- *Processing*—Areas of utilitarian noise impacts inside the wilderness were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—It is conservatively assumed that the median (L50) ambient sound level in the analysis area is 34 A-weighted decibels (dBA, the relative loudness of sounds as perceived by the human ear) during the day (Federal Hardrock Mineral Prospecting Permit Environmental Impact Statement, page 92) (USDA Forest Service 2012). Sounds from utilitarian sources are not constant and activity is variable; therefore, wilderness areas depicted as being affected by utilitarian noise may or may not be impacted at any given moment. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Night sky obfuscation

- *Sources*—Raster dataset of a TIFF (tagged image file format) image depicting the average ALR across the wilderness, obtained from the NPS Natural Sounds and Night Skies Division (Dan Duriscoe, NPS Physical Scientist). The dataset is based on a GIS model of anthropogenic sky luminance (calibrated to other ground-based measures) utilizing data from the 2001 World Atlas of Night Sky Brightness (which depicts zenith sky brightness, i.e., the brightness of the sky directly above the observer). A neighborhood analysis was applied to the original data to determine the anthropogenic brightness over the entire sky; the modeled anthropogenic sky brightness data were then presented as a ratio (ALR) over the natural level of sky brightness.
- *Processing*—The raster dataset was re-projected and values were normalized to 0–255.
- *Cautions*—There is a moderate level of uncertainty with the modeled data.

Recreational noise outside wilderness

- *Sources*—Polygon datasets of recreational sound impacts inside wilderness from: (1) vehicle routes outside wilderness; (2) motorized lakes outside wilderness, derived from the National Hydrography Dataset (www.nhd.usgs.gov); (3) snowmobile routes outside wilderness. All three datasets were created by buffering point datasets of noise sources; buffer distances were determined using a sound attenuation model to calculate the distance it takes the starting decibel levels of (1) OHVs, (2) boats, and (3) snowmobiles to be reduced to natural ambient noise levels (Menge and others 1998, 2002; Teresa Hanson, SNF GIS Analyst).

- *Processing*—Areas of recreational noise impacts inside the wilderness were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—It is conservatively assumed that the median (L50) ambient sound level in the analysis area is 34 dBA during the day (Federal Hardrock Mineral Prospecting Permit EIS, page 92) (USDA Forest Service 2012). Sounds from recreational sources are not constant and activity is variable; therefore, wilderness areas depicted as being affected by recreational noise may or may not be impacted at any given moment. The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Authorized facilities

- *Sources*—(1) Point dataset of Forest Service-maintained docks in the BWCAW (SNF District Wilderness Staff); (2) point dataset of Forest Service-maintained designated campsites in the BWCAW (SNF District Wilderness Staff and Ann Schwaller, SNF Wilderness Specialist).
- *Processing*—Locations of campsites and docks were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Trails and associated features

- *Sources*—Polyline dataset of Forest Service-maintained trails and portages in the BWCAW (SNF District Wilderness Staff).
- *Processing*—Locations of trails and portages were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Motorized/mechanized routes

- *Sources*—Polyline dataset of mechanical/motorized portages and tow routes, (SNF District Wilderness Staff and Ann Schwaller, SNF Wilderness Specialist).
- *Processing*—The locations of mechanical/motorized portages and tow routes were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Wireless coverage

- *Sources*—Polygon dataset of wireless coverage in the BWCAW, obtained from the National Broadband Map (U.S. Department of Commerce 2015).

- *Processing*—Data were queried to select the following four major cellular networks: Sprint, Verizon Wireless, T-Mobile, and AT&T. Areas of wireless coverage were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Visitor-created facilities

- *Sources*—(1) Polyline dataset of social trails (SNF District Wilderness Staff); (2) point dataset of campsites with visitor-created facilities, created by relating institutional knowledge of known unauthorized facilities (SNF District Wilderness Staff) to the BWCAW campsite dataset.
- *Processing*—Locations of visitor-created facilities were assigned a value of 1. Layers were converted to individual rasters and added together. Values were then normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

BWCAW rules and regulations

- *Sources*—Polygon dataset of management areas in the BWCAW.
- *Processing*—Pristine management areas (less restrictive) were assigned a value of 1, and remaining management areas were assigned a value of 2. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Weighting

The assigned weight (on a scale of 1 to 10) and the corresponding rationale for each measure under the solitude or primitive and unconfined recreation quality are described in table 9.

Maps

The weighted measures under each indicator were added together using a raster calculator to create four maps: "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" (fig. 11). Two supplementary maps of opportunities for solitude (created by adding together the measures under the first two indicators) and opportunities for primitive and unconfined recreation (created by adding together the measures under the last two indicators) were also produced for management purposes (fig. 12). All the measures were then added together using the same process to create the solitude or primitive and unconfined recreation quality map (fig. 13).

Table 9—Measure weights and rationales for the solitude or primitive and unconfined recreation quality.

Indicator	Measure	Weight	Rationale
Remoteness from sights and sounds of people inside the wilderness	Campsite occupancy	8	High weight because campsite occupancy is a planning indicator for the BWCAW, and because it correlates with current ecological and social impacts.
	Administrative motorized noise inside wilderness	8	High weight because the BWCAW has a considerable amount of regular administrative motorized use.
	Campsite noise inside wilderness	6	Medium weight because the BWCAW has a significant number of designated campsites and high visitor use; visitors have complained about the impact of campsite noise carrying across the water.
	Commercial outfitter/guides	6	Medium weight because commercial use is prevalent in three of the four management areas.
	Viewshed inside wilderness	5	Medium weight because most features in the wilderness are obscured by thick vegetation and are less noticeable from the main travel routes.
	Encounters	4	Low weight because encounter monitoring is ongoing and data are not yet complete.
	High use destinations	3	Low weight because the number of high use routes and sites is relatively low, and the recreational impacts generally do not exceed SNF plan standards.
Remoteness from occupied and modified areas outside the wilderness	Entry point congestion	5	Medium weight because congestion is problematic for less than half of all entry points.
	Utilitarian noise outside wilderness	3	Low weight because only a small portion of the lands adjacent to the BWCAW are sources of significant utilitarian noise.
	Viewshed outside wilderness	3	Low weight because many features are obscured by thick vegetation and less noticeable from the main visitor travel routes.
	Night sky obfuscation	3	Low weight because impacts to the night sky are relatively low.
	Recreational noise outside wilderness	2	Low weight because only a small portion of the lands adjacent to the BWCAW are sources of significant recreational noise.
Facilities that decrease self-reliant recreation	Authorized facilities	10	Highest weight because of the large number of designated campsites, all of which have recreational facilities.
	Trails and associated features	7	High weight because trails and portages are prevalent throughout the wilderness and many have associated constructed features.
	Motorized/mechanized routes	4	Low weight because there are only a limited number of tow routes and portages allowing motorized or mechanized use.
	Wireless coverage	2	Low weight because the ratio of wireless coverage to wilderness acres is low. The weight could increase in the future if existing towers are improved or new towers are erected.
	Visitor-created facilities	1	Lowest weight because most user-created facilities are eliminated/naturalized by SNF staff upon discovery.
Management restrictions on visitor behavior	BWCAW rules and regulations	5	Medium weight because the numerous management regulations currently in place are considered necessary for the protection of other wilderness values.

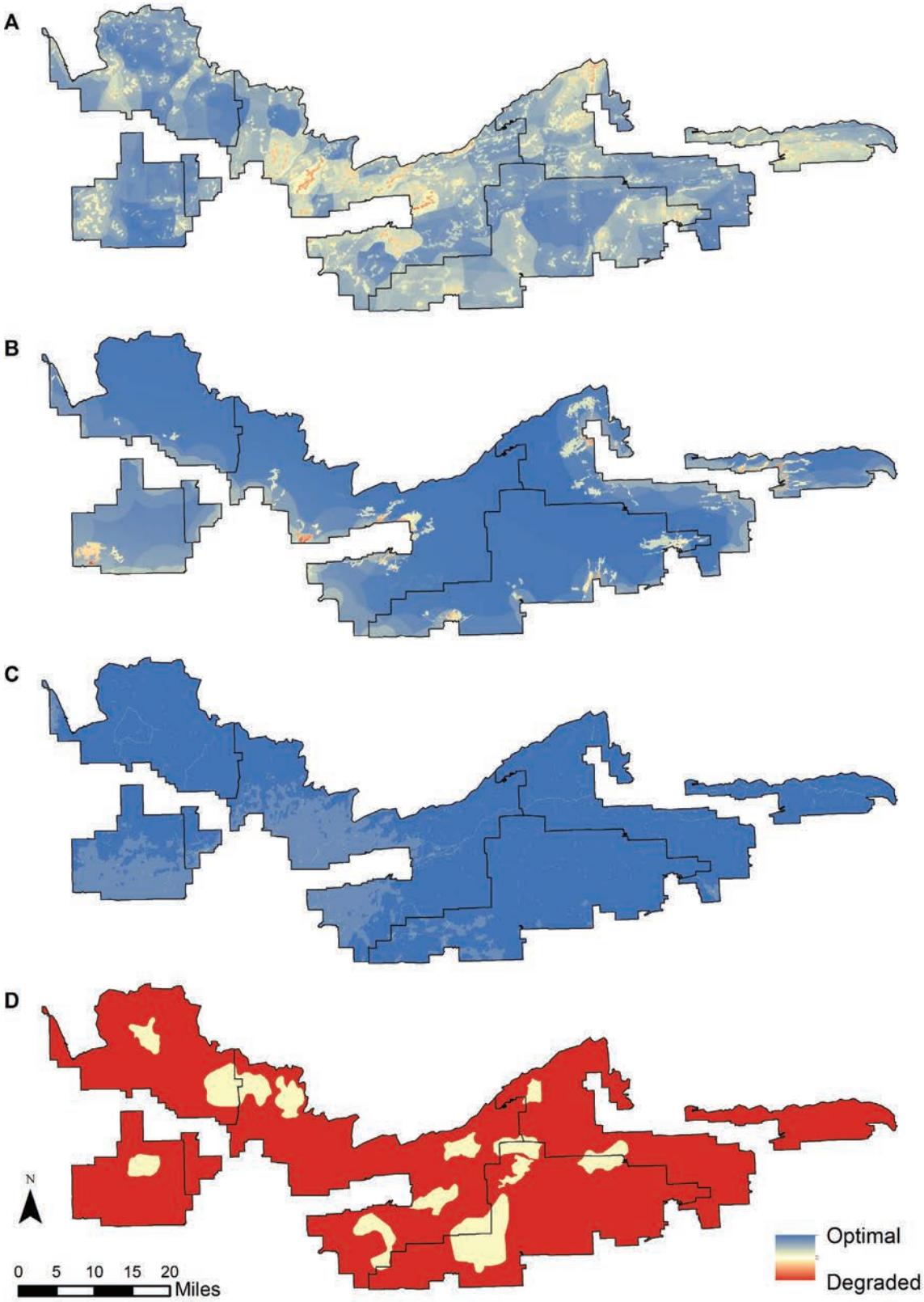

Figure 11—Indicator maps for (A) remoteness from sights and sounds of people inside the wilderness, (B) remoteness from occupied and modified areas outside the wilderness, (C) facilities that decrease self-reliant recreation, and (D) management restrictions on visitor behavior. Blue depicts optimal condition and red depicts degraded condition.

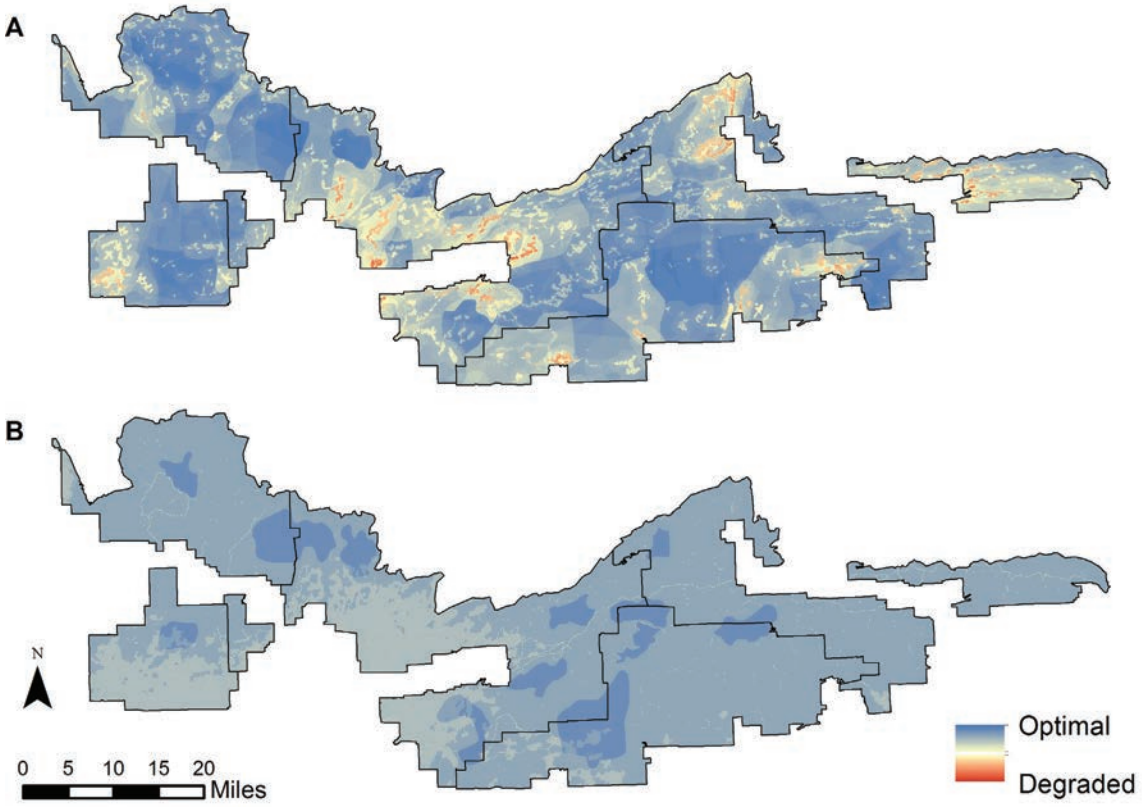

Figure 12—Combined indicator maps for (A) opportunities for solitude inside wilderness, and (B) opportunities for primitive and unconfined recreation inside wilderness. Blue depicts optimal condition and red depicts degraded condition.

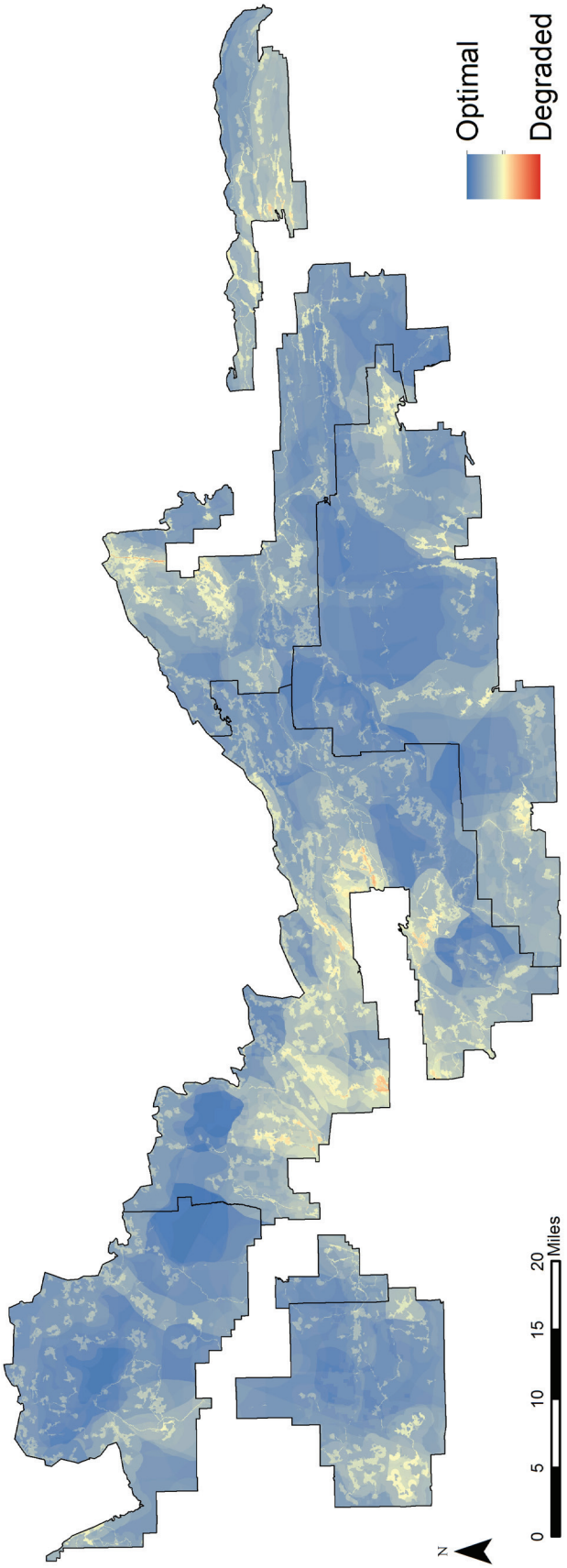

Figure 13—Map of the solitude or primitive and unconfined recreation quality of wilderness character. Blue depicts optimal condition and red depicts degraded condition.

Other Features of Value Quality

The other features of value quality centers on unique and tangible features of a wilderness that are integral to the wilderness character of that place. These features may include cultural resource sites, paleontological sites, or any other features not included under the other four qualities that have ecological, geological, scientific, educational, scenic, or historical value (Landres and others 2012, 2015). This quality is degraded by loss or damage to other features integral to wilderness character.

Indicators and Measures

Two indicators were selected for this quality based on the other features of value present in the BWCAW. These indicators are: "prehistoric cultural resources integral to wilderness" and "historic cultural resources integral to wilderness." The measures selected for the BWCAW are described below for each of these indicators.

Indicator: Prehistoric cultural resources integral to wilderness.

- Unauthorized disturbances to prehistoric cultural resources—Campsites where prehistoric sites have potentially been impacted. Prehistoric cultural resources that are integral to wilderness character cannot be recovered once they are damaged or lost. Cultural resources are at risk from both unintentional activities (such as erosion or compaction caused by heavy use of a site) as well as deliberate unauthorized actions (such as looting or vandalism). Designated campsites frequently overlay prehistoric sites in the BWCAW, and there are currently 170 cultural resource sites co-located with modern campsites that exhibit moderate or high impacts from visitor use. For this measure, prehistoric sites that have already been impacted by soil loss were depicted as being more degraded than unevaluated sites at risk of disturbance. Of the 170 sites, 41 have already lost site integrity and are no longer eligible for the National Register of Historic Places; the remaining 129 sites have not yet been evaluated.

Indicator: Historic cultural resources integral to wilderness.

- Unauthorized disturbances to historic cultural resources—The locations and conditions of intact historic structures. Historic sites integral to wilderness character are irreplaceable cultural resources. Evidence of historical occupation can be found throughout the BWCAW, but relatively few structures remain intact. In addition to being important cultural resources, these buildings are also used for administrative purposes. The Kekakabic and La Croix Guard Stations, Crooked Lake Boathouse, and Prairie Portage Cabin are all eligible for the National Register of Historic Places, while the Beatty Portage Cabin and Little Saganaga State Cabin have not yet been evaluated.

Data Gap Measures

Additional measures under this quality were identified by SNF staff but were excluded for a variety of reasons. For each data gap measure, the indicator, description, and rationale for their dismissal are listed below.

Authorized disturbances to prehistoric cultural resources

- *Indicator*—Prehistoric cultural resources integral to wilderness.
- *Description*—SNF management activities may occasionally degrade prehistoric cultural sites. Such actions may include campsite or portage restoration projects, latrine digging, and other general maintenance work.
- *Rationale for dismissal*—Authorized actions that impact prehistoric sites are partially addressed by a different measure under the untrammeled quality. The Forest Service completes minimum requirements analyses for all projects in wilderness that include an assessment of impacts to cultural resources integral to wilderness character.

Authorized disturbances to historic cultural resources

- *Indicator*—Historic cultural resources integral to wilderness.
- *Description*—SNF management activities may occasionally degrade historic cultural sites. Such authorized actions may include remodeling historic buildings or permitting administrative uses that interfere with the historical integrity of a site.
- *Rationale for dismissal*—The Forest Service completes minimum requirements analyses for all projects in wilderness that include an assessment of impacts to cultural resources integral to wilderness character. The Forest Service also follows Secretary of the Interior standards for the treatment of historic structures.

Data Sources, Processing, and Cautions

The other features of value quality datasets are all vector data, of fine scale, with high levels of accuracy and completeness (table 10). The data sources, data processing information, and cautions are listed below for each measure.

Table 10—Other features of value quality datasets. Accuracy (how well the dataset represents the measure) and completeness (how complete the dataset is across the wilderness) were evaluated for each measure by SNF staff familiar with these data.

Measure	Source	Type	Scale	Accuracy	Completeness
Unauthorized disturbances to prehistoric cultural resources	ExposedSoils_Heritage	Point	1:24,000	High	High
Unauthorized disturbances to historic cultural resources	Cabins	Point	1:24,000	High	High

Unauthorized disturbances to prehistoric cultural resources

- *Sources*—Point dataset of campsites with exposed soil where prehistoric sites have or may have been impacted, created by relating institutional knowledge of campsites with exposed soil (SNF District Wilderness Staff) and prehistoric site locations (SNF heritage staff) to the BWCAW campsite dataset.
- *Processing*—Evaluated prehistoric sites known to have been impacted by soil loss were assigned a value of 2, and unevaluated prehistoric sites with exposed soil were assigned a value of 1. The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Unauthorized disturbances to historic cultural resources

- *Sources*—Point dataset of historic cabins and outhouses in the BWCAW.
- *Processing:* The various historic structures were ranked on a scale of 1 (excellent) to 5 (poor) to depict the differences in their condition and eligibility for the National Register of Historic Places (Lee Johnson, SNF Archaeologist). The layer was converted to raster and values were normalized to 0–255.
- *Cautions*—The information contained in these data is dynamic and may change over time. The data are not better than the original sources from which they were derived.

Weighting

The assigned weight (on a scale of 1 to 10) and the corresponding rationale for each measure under the other features of value quality are described in table 11.

Table 11—Measure weights and rationales for the other features of value quality.

Indicator	Measure	Weight	Rationale
Prehistoric cultural resources integral to wilderness	Unauthorized disturbances to prehistoric cultural resources	10	Highest weight because prehistoric cultural sites are irreplaceable and at a high risk for damage or loss.
Historic cultural resources integral to wilderness	Unauthorized disturbances to historic cultural resources	10	Highest weight because few historic structures remain intact in the wilderness.

Maps

The weighted measures under each indicator were added together using a raster calculator to create two maps: "management of prehistoric cultural resources integral to wilderness" and "management of historic resources integral to wilderness." All the measures were then added together using the same process to create the other features of value quality map. Although the measures selected for this quality contributed to the overall map of threats to wilderness character, the indicator and quality maps are excluded from this report due to the sensitive nature of the cultural resource data.

Map of Threats to Wilderness Character

Interpreting the map products generated by this project requires a clear understanding of the methods that were used and their associated limitations. For example, the maps for the natural and solitude or primitive and unconfined recreation qualities used both vector and continuous raster data sources and are distinctly different in appearance from the maps for the qualities that only used vector data sources. Furthermore, some datasets were depicted as being spread uniformly across an area when in reality the impact was concentrated to specific locations within that area (e.g., visitor use was depicted evenly across each travel zone even though certain campsites receive more use than others). In addition, it is important to bear in mind that the maps were generated through the analysis of a multitude of datasets; to understand why certain areas are degraded one must "drill down" into the individual qualities, indicators, and measures.

The methodology described in the previous sections produced maps for each of the 53 weighted measures; these were then added together accumulatively to produce a single map of threats to wilderness character in the BWCAW (fig. 14). The map of threats to wilderness character represents a grid of values (approximately 5 million pixels at a 30 meter resolution), and it uses a blue-red color ramp and the "minimum-maximum" stretching technique to best represent those values for display and discussion. An equal interval reclassification[17] of the overall map was performed to transform the range of values for all pixels onto a scale of 0 (most degraded condition, highest cumulative threat level from all measures) to 100 (optimal condition, no threats to wilderness character). These values were then split into 10 equal categories (i.e., 0–10, 11–20, 21–30, etc.) to clearly emphasize the variation in the magnitude of threats to wilderness character across the BWCAW (fig. 15).

The histogram of the distribution of pixel values (fig. 16) shows that most pixels fall within the 71–80 or 81–90 categories, indicating that the majority of the wilderness has high quality wilderness character that has not been substantially impacted by threats. Overlaying the map of threats to wilderness character with a map of BWCAW waterbodies reveals that patterns and variations in the magnitude of threats are strongly linked to lakes for both high quality and degraded areas. The lowest quality categories are highly correlated with lakes that allow motorized use, especially those that are wilderness entry points. The lowest four categories (0–40) are primarily clustered around the end of the Gunflint Trail (Saganaga and Seagull lakes) and the Fernberg Road (Snowbank, Parent, Moose, Newfound, Found, Basswood—especially Pipestone Bay, Newton, Fall, and South Farm lakes). Additional areas within these categories include lakes in the Trout Lake and Vento units (Trout, Clearwater, Duncan, and East Bearskin lakes), Paulson Lake (south of Seagull Lake), and a small portion of Knife Lake (near Thunder Point). Of the 17 lakes within the lowest 4 categories, 12 allow motorized use (encompassing more than half of all motorized lakes in the wilderness), 8 are motorized entry point lakes, and an additional 6 are easily accessible via a short portage from an entry point.

[17] 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 2015).

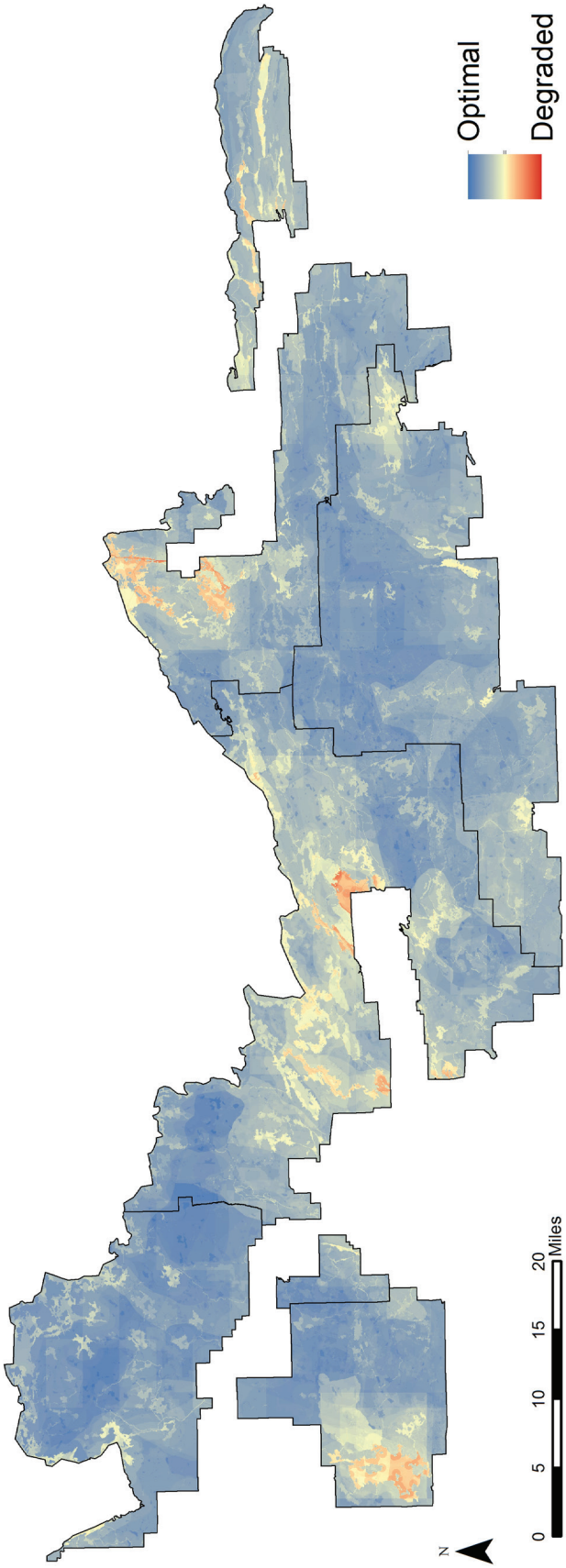

Figure 14—Map of threats to wilderness character in the BWCAW. Blue depicts optimal condition and red depicts degraded condition.

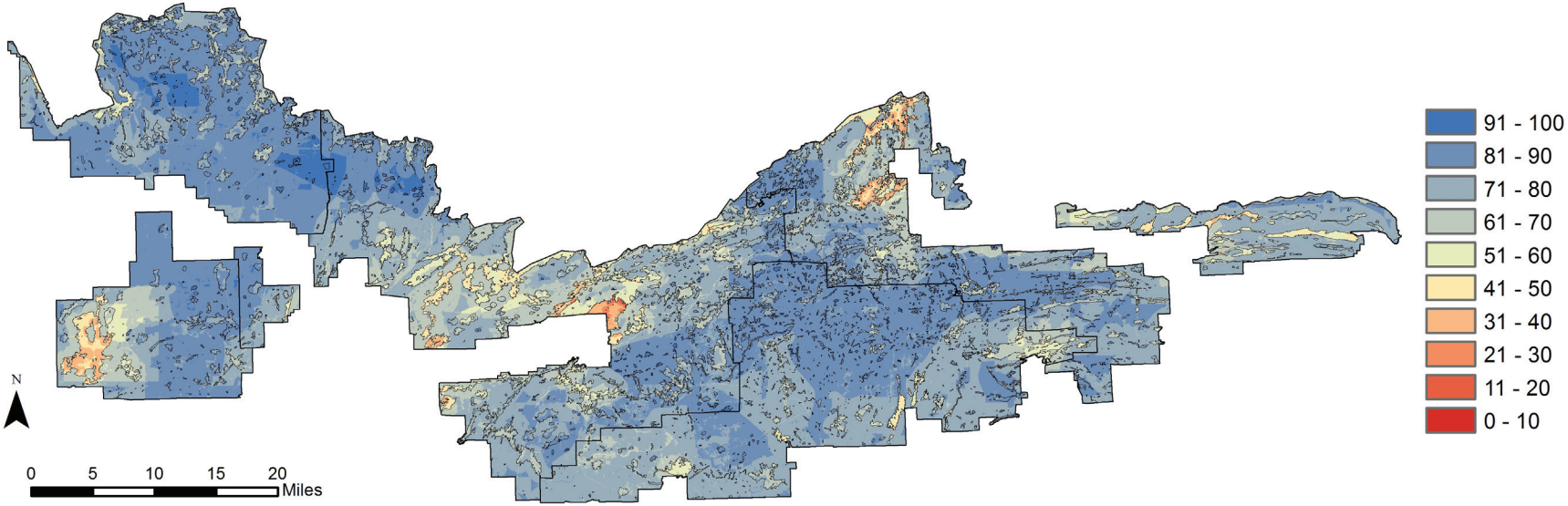

Figure 15—Map of threats to wilderness character in the BWCAW reclassed into ten equal categories. Lakes were overlayed to facilitate the discussion of threats to wilderness character. Blue depicts optimal condition and red depicts degraded condition.

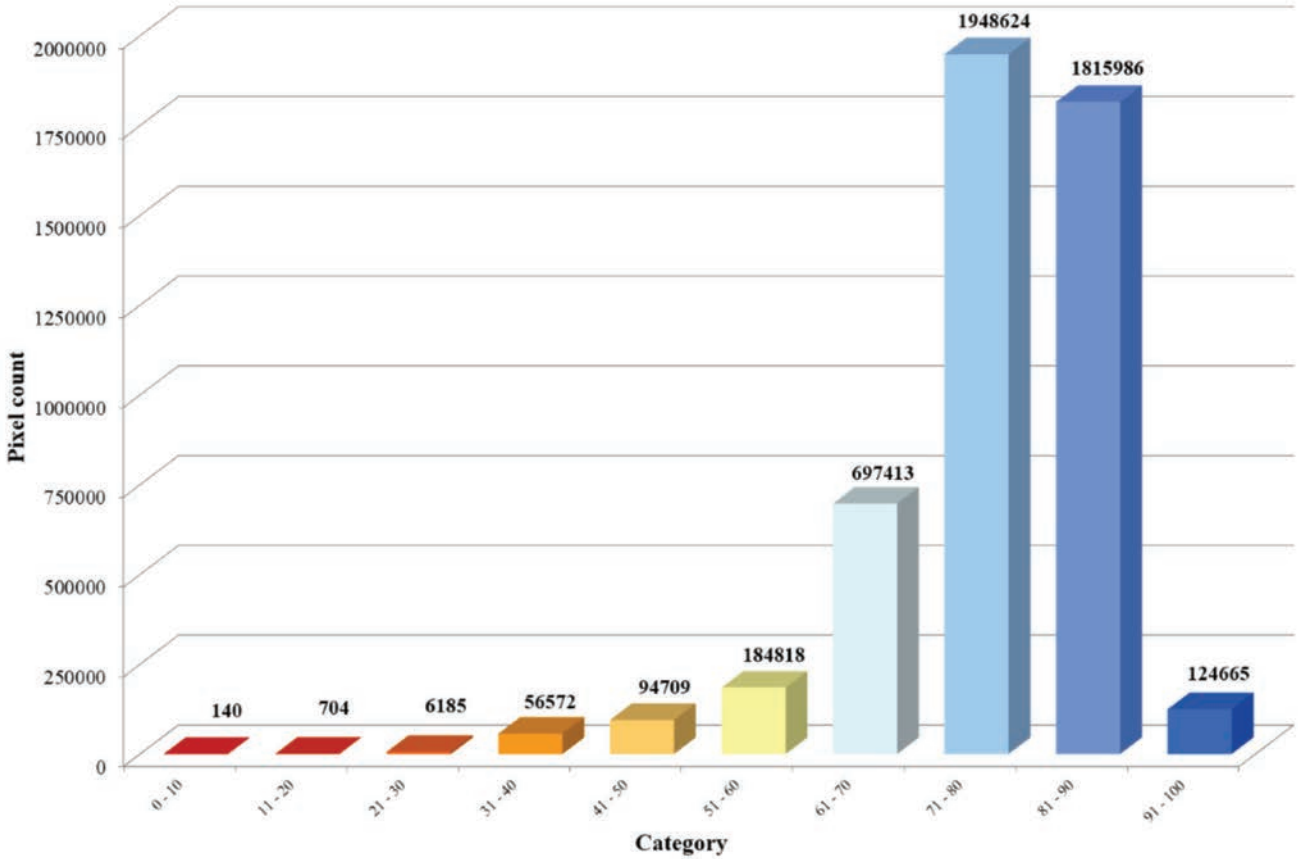

Figure 16—Histogram of the values of the map of threats to wilderness character. Blue depicts optimal condition and red depicts degraded condition.

In contrast, the highest quality categories are primarily found away from entry points and travel routes, especially in areas with fewer and smaller lakes and within pristine management areas. The three largest areas within the highest category (91–100) are found in the La Croix and western Kawishiwi districts (from west to east, these are: the area between Finger and Hustler lakes, the area east of Stuart Lake, and the area south of Crooked Lake's Thursday Bay). In addition to these larger areas, hundreds of individual lakes spread across the wilderness are also within the highest category. These lakes tend to be smaller in size and more difficult to access: many lack designated sites or maintained portages, and dozens are so small as to be unnamed. While some of these high quality individual lakes are on the western side of the BWCAW, the majority are concentrated in the center of the wilderness around the northern portion of the Tofte District. Other areas with high quality lakes include the southeastern Kawishiwi District and the northwestern Gunflint District. In general, smaller lakes and areas that are more difficult to access have fewer threats to wilderness character than larger lakes and areas near popular entry points.

Improvements

The map products presented in this report could be improved in a number ways. The maps are highly dependent on the wide range of spatial datasets that depict threats to wilderness character. Improving the data quality of the existing datasets (by improving

data accuracy or completeness) or adding datasets for the data gap measures would benefit future iterations of the maps. For example, a wider availability of improved land cover maps and a higher resolution DSM would increase the accuracy and effectiveness of the viewshed model, and thereby improve future maps of the solitude or primitive and unconfined recreation quality.

The issue of data quality also highlights the need for effective and holistic management of the SNF spatial data. Clear communication among staff, as well as with external agencies, researchers, and others working in wilderness, would allow for improvements in the quality and availability of wilderness datasets; this in turn would result in more effective and efficient wilderness stewardship. By raising awareness of data needs among field staff and encouraging the use of GPS units to record spatial data, new datasets could be created and existing datasets could be ground-truthed for accuracy or otherwise improved; it would be particularly useful, for example, to test the output of the viewshed models against observations in the field. Furthermore, regular meetings between GIS specialists and wilderness staff would ensure the preservation of institutional knowledge in the form of spatial datasets. While generally successful in these areas, increased collaboration and involvement would allow SNF staff and partner organizations to better realize how they can contribute to—and benefit from—spatial data and GIS applications.

This mapping approach also highlighted the difficulties in accounting for "value added" features of the landscape. While some features or actions may have a positive influence on wilderness character (thereby adding value), all the measures used for this mapping project quantify loss or degradation from an ideal condition. For example, if the presence of a threatened species such as Canada lynx had been used as a measure (such that areas, or pixels, where the species had been sighted were assigned a higher value), all areas without lynx sightings—even if they were not suitable habitat—would have been devalued. This issue is further complicated by features and actions that have both positive and negative impacts to wilderness character. For example, although the purpose of many BWCAW regulations is to protect natural resources (such as rules governing the use of designated campsites, the disposal of fish or food remains, the prohibition on burning trash, etc.), they also confine visitor freedom. In this case, the BWCAW rules and regulations measure quantifies these management restrictions for their negative impact to the solitude or primitive and unconfined recreation quality, without accounting for the value added to wilderness character by the preservation of the natural quality. A future improvement to this mapping approach would be to find a way to quantify features and actions that add value to wilderness character, rather than only including those that degrade wilderness character.

Final Concerns About Mapping Threats to Wilderness Character

A major concern of this work is that end users will ascribe false levels of accuracy to the map products. The tendency to attribute higher levels of reliability and precision to maps because they look accurate is common to almost all GIS analyses. The maps produced through this project are only an estimate of selected measures of wilderness

character and their spatial variability and pattern; they are not a final determination of wilderness character in the BWCAW. Underscoring this point, the maps do not portray the symbolic, intangible, spiritual, and experiential values of wilderness character that are unique to individual persons, locations, and moments. Wilderness researchers and managers have debated the merits of even attempting to quantify or map threats to wilderness character; while some emphasize the need to develop indicators that can be used to aid wilderness monitoring, management, and long-term planning (e.g., Landres 2004), others point out that quantitative analyses do not reflect important qualitative attributes of wilderness character, such as how wilderness affects each of us in different ways (e.g., Watson 2004). Although the maps do not depict all nuances of wilderness character, they still provide useful information on tangible threats. Ultimately, the maps should be viewed as a tool that wilderness stewards can use to further refine the effectiveness of their efforts to "preserv[e] the wilderness character of the area" and perpetuate the "enduring resource of wilderness" (Wilderness Act of 1964).

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