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Abstract

Transportation is both a means to access recreation and a form of recreation in itself. Because diverse audiences have differential transportation access and experiences, a spectrum of opportunities should be considered when planning for the provision of adequate, quality transportation options in park settings. In well visited parks with defined facilities, services, and roadways for motor vehicle traffic, use of the Transportation Recreation Opportunity Spectrum (T-ROS) should take into account a variety of indicators to set standards for the visitor experience, managerial contributions, and resource impacts. To explore the utility of the T-ROS framework, and specifically examine the use of three potential indicators (i.e., number of modes, view of scenery, and slope of rode) within a composite index, we used a geospatial analysis in Yellowstone National Park, USA. Results center on areas of differential T-ROS value and what this may mean for park management and extension of the framework. Strengths, limitations, and opportunities for further investigation are also detailed.

Keywords: accessibility; outdoor recreation; park management; transportation; Recreation Opportunity Spectrum

Transportation methods (e.g., private vehicle, public transit, bicycle) and access to them have tremendous impacts on the perceived qualities of park services to visitors (Pettengill, 2013). For example, New York City residents rated transportation accessibility, safety, and information as important facilitators (or, in their absence, hindrances) to their visitation of national park units within the local area (Perry et al., 2015). Visitors to national park units in urban, urban-adjacent, and rural areas across the country also rated similar transportation factors, as well as associated recreation-setting attributes, as important in the quality of their experience (Xiao et al., 2017). Transportation methods may be viewed not just as a means of access, but also as a range of transportation settings that offer diverse recreational opportunities (Xiao et al., 2017). To plan for transportation and to satisfy the diverse recreational demands of visitors in a park, park managers should first understand the spatial distribution of transportation systems (e.g., paved and unpaved roads, bicycle pathways, hiking trails). To do so, the transportation recreation opportunity spectrum (T-ROS) was developed (Pettengill & Manning, 2011). However, it has yet to be benefit from empirical testing. Therefore, the purpose of this project was to use geo-processing methods to analyze spatial distributions of the T-ROS and provide guidance for the siting of new transportation facilities within a specific park. Yellowstone National Park (hereafter, abbreviated as "Yellowstone" or "the park") was chosen as the study site because it is an iconic and highly visited national park in America's National Park Service System, hosting a diversity of transportation modes.

Literature Review

Recreation Opportunity Spectrum (ROS)

Public lands must serve a broad population base with diverse interests and desires for outdoor recreation (Manning, 2011). Demand for diverse recreation opportunities has led to development of several zoning and organizational frameworks designed to help guide park planning and management. Carhart (1961), for instance, developed a scale from "wildness" to "semi-urban" by identifying different recreation habitats that span the wilderness-civilized continuum so that wildland planning could be shaped in ways that reflect the range of settings, activities, and preferences necessary for a quality recreation experience on a large societal or geographic level. Also, the Outdoor Recreation Resources Review Commission proposed a six-fold framework for public lands that ranged from "primitive" to "high-density use" areas with similar intent of purpose (ORRRC, 1962). However, among all developed recreational classification systems, the most widely used and highly advanced framework is the Recreation Opportunity Spectrum (ROS).

The ROS framework is a tool used to support definition and management of diverse outdoor recreation opportunities in parks and public lands. The ROS can be defined by a series of indicators and associated standards, such as density of use, accessibility, and social interactions (Clark & Stankey, 1979). Management agencies such as the U.S. National Park Service and U.S. National Forest Service have incorporated ROS concepts and the framework itself into management considerations for intra and inter-site diversity. The ROS defines a range or spectrum of opportunities that the public or private sectors can provide to meet the diversity of visitor activities, settings, and experience preferences (Driver & Brown, 1975, 1978; Vogelsong et al., 1998). Several studies have explored the relationships between visitors' motivations, activities, experiences, and environmental setting preferences (Virden & Knopf, 1989). Although the relationship between these four variables varies in different study cases, a diverse ROS enhanced the linkage among them. These studies tend to focus on the diversity of visitors (e.g., cluster analyses to examine subgroups, regression analyses to examine relationships among variables) in wilderness and public park settings (Brown & Ross, 1982, McLaughlin and Paradice 1980, Vogelsong et al., 1998). Significant relationships have been found between setting attributes along the ROS continuum and visitors when visitors are grouped by activity type (Cavin et al., 2005; McLaughlin & Paradice, 1980) or by motivation (Floyd and Gramann 1997; Vogelsong et al., 1998).

In addition to facilitating these linkages, the ROS is a conceptual and organizational framework with many other potential applications. First, it provides an inventory to specify recreational opportunities provided by each public land area (Buist & Hoots, 1982). Second, the ROS helps managers to identify recreation opportunities and implement management strategies in terms of activities, environmental settings, and experiences that complement visitor preferences (Driver et al., 1987). Finally, ROS can help visitors to select desired settings and activities according to their preferred experiences along the recreational spectrum on each visit (Buist & Hoots, 1982).

Extending the Opportunity Spectrum

From this basis, ROS has been extended in several recreation related research areas, such as tourism, ecotourism, wilderness, water recreation, and highway experience. As for tourism, Butler and Waldbrook (2003) incorporated the theory of the life cycle of a tourism destination into the concept of ROS and developed a tourism opportunity spectrum (TOS). The framework of TOS consists of six indictors: type and level of access, other non-adventure uses, level of development of tourism infrastructure, social interaction between guests and hosts, acceptability of visitor impacts, and acceptability of visitor regimentation. Dawson (2001) used these developed indictors (see Butler & Waldbrook, 2003; Clark & Stankey, 1979) to compare the characteristics of five TOS settings in a variety of environments and refine setting attributes that may define nature-based tourism and ecotourism, subclasses of experience within the TOS constraints, and indicators of these experiences may be identified and monitored. Further work in combining the ROS and TOS structures included a study to develop an Ecotourism Opportunity Spectrum (ECOS) (Boyd & Butler, 1996). The ECOS ranges from eco specialist to eco generalist and the indicators consist of eight factors: 1) type and level of access, 2) relationships between other resource-related activities, 3) forms of attractions offered, 4) extent, complexity, visibility, number, and type of existing infrastructure, 5) social interaction between other eco-tourists and hosts/local populations, 6) level of knowledge and skill of eco-tourists, 7) acceptance of visitor impacts, and 8) acceptance of management regime.

Beyond land-based tourism considerations, management agencies have also recognized the importance of the ROS in water-based recreation settings. In particular, the U.S. Bureau of Reclamation recognized the importance of the diversity of water recreation demands and formulated a guidebook to describe the Water and Land Recreation Opportunity Spectrum (WLROS) and incorporate the WLROS into water recreation planning (U.S. Bureau of Reclamation, 2009). The WLROS is defined by indicators that include activities, setting attributes, and experiences. This fuller spectrum of water and land recreation was adapted from Brown's ROS framework (1978). The WLROS guidebook also provides steps and strategies to implement WLROS in regional water-based recreational planning.

Finally, another application of the ROS in recreation research is the development of a highway experience opportunity spectrum (Brown, 2003). In this research, a new and empirically-supported framework emerged indicating that highways could be viewed as corridors of human values, not just merely transportation pathways. The highway experience opportunity spectrum was defined by: 1) intrinsic scenic byway qualities, 2) capacity, 3) length, 4) remoteness, 5) connectivity, 6) speed, and 7) purpose. Brown's research (2003) incorporated the ROS into a spectrum for transportation and built the basis of a Transportation Recreation Opportunity Spectrum, or T-ROS. The definition of these seven has provided grounds for investigating what indicators may be applicable in different transportation corridor-based recreation opportunities and settings.

GIS Applications in ROS Research

Recently, Geographic Information System (GIS) technology has been used as an advanced tool for ROS-related research. For example, Flanagan and Anderson (2008) utilized GIS tools to map the extent of visitors' wilderness perceptions in the San Juan National Forest. The visitors were divided into four groups based on the concept of purism (i.e., how they define "wilderness"). Maps were created for each group that represented perceived wilderness conditions and respondents compared these conditions with ROS zones. The result indicated that maps of perceived wilderness have potential functions to refine ROS zoning. In the previously mentioned highway experience recreation opportunity spectrum study (Brown, 2003), a map was created with GIS methods to indicate the density of scenic points of different locations on a highway, which reflected the perceived "best" and "worst" highway locations. Also, the WLROS guidebook used GIS to create maps as a WLROS inventory to depict the current type and location of recreation opportunities in the settings. Given the utility of geospatial analysis methods in park and recreation research generally, and ROS research specifically, this has been a noted direction and need for decades (Beeco & Brown, 2013; Nedovic-Budic et al., 1999).

Transportation Recreation Opportunity Spectrum (T-ROS)

Based on the ROS model and the close relationship between transportation and recreation in parks and public land, Pettengill (2013) developed a framework for T-ROS. Pettengill's study incorporated survey data across a spectrum of recreation-oriented roads in northern New England and estimated the standard indicators for a density of use spectrum. The indicators of T-ROS consisted of 1) density of use, 2) landscape character, 3) facilities and service, 4) cost, 5) convenience, 6) corridor design, 7) mode of transport, and 8) trip purpose. Pettengill's work also noted other indicators (e.g., condition of the road) that may be worth exploring and including. As one of the first works in this field of T-ROS, Pettengill's research (2013) built the theoretical basis for a T-ROS framework and provided a solid basis for further quantification of T-ROS indicators. This framework and modes for empirical testing have been incorporated into Federal Lands Highway management considerations (Pettengill & Manning, 2011). It appears, however, that this theoretical basis is yet to be elaborated upon in subsequent studies. As the T-ROS may aid in public lands management to encompass a variety of settings and a variety of visitors, testing and refining this framework is a crucial area for further research. This study, therefore, addresses this need by using GIS-based geospatial analysis to examine the utility of a suite of potential indicators of T-ROS in a well-visited public lands setting.

Research Objectives

Building from this preliminary work on the T-ROS, the present study aimed to test the framework in a park setting with diverse transportation corridors. It primarily focused on 1) analyzing three of the nascent indicators of transportation recreation opportunities (i.e., number of transportation modes, density of points of interest, and condition of the road [steepness of slope]) and 2) summing values of these indicators in an overall metric that allows ranking of T-ROS considerations across different locations. The area of focus for this investigation was Yellowstone National Park (an iconic federally protected land in Wyoming, Montana, and Idaho, U.S.). Because this park provides a diversity of settings, facilitates recreation through a limited number of transportation modes in a bound system of roads and trails, and is highly visited, it was chosen as a complex area in which to test the T-ROS framework. The specific questions considered for this investigation were as follows:

1. What are values of T-ROS in different areas of Yellowstone National Park?
2. What areas have higher concentrations of a diversity of T-ROS values than others?
3. What areas are dominated by a single T-ROS value?
4. Where would be the most suitable spots (i.e., those with the highest T-ROS values) for new public transportation facilities/stops to be located to alleviate vehicle congestion in these areas?
5. If transportation stops were built in these areas, what would be a useful presentation format to visitors for them to determine if utilizing these transportation stops would facilitate or complement their experiences?

Methods

Metadata

Data were downloaded and manipulated from the Wyoming State Geological Survey website (www.wsgs.uwyo.edu/research/yellowstone/gis.aspx), an office hosted by the University of Wyoming (WSGS UWYO). This state agency has created specific geodatabases for Yellowstone National Park. Because these secondary data are readily available and standardized for geographic areas including U.S. national parks, their use did not warrant primary data collection. Data were manipulated by the authors to address the research questions. Digitized park and research features were created from the manipulated data and by map comparisons with the detailed park maps available on the Yellowstone official website (www.nps.gov/yell). All primary data layers utilized are detailed in Table 1 (see Appendix A).

T-ROS Indicators

There are a number of T-ROS indicators, but for the purposes of this project, we are focusing on the ones that are applicable to the Yellowstone study site and research purpose. These pertinent indicators are: 1) number of transportation modes, 2) view of the scenery, and 3) slope of the road. Before analyzing and computing the four indicators, we acquired data from the sources listed in Table 1 and confined (e.g., clipped) them to the Yellowstone boundary. Because this analysis is aimed for park managers, park-defined "Points of Interest" features (e.g., geysers, waterfalls, historic lodges, wildlife viewing areas) were used as the criterion of interest.

Indicator 1: Number of Transportation Modes. Yellowstone has three main delineated modes of transportation: roads (for all vehicle traffic, including snowmobiles), trails (for foot traffic and, in designated areas, stock and pack travel), and bicycle paths (for non-motorized vehicle traffic and foot traffic). First, we separated the bicycle paths from the trails layer by selecting all trail records where biking is allowed and separating these distinctions into two separate layers. Second, we dissolved each layer based on name, so that whole roads, trails, and paths could be examined instead of at a segment-by-segment level (numbering in the tens of thousands). Dissolving is a means to look at an entire feature instead of each discrete section (e.g., a whole trail instead of each section between its intersections with other trails). This resulted in nine roads, 452 hiking trails, and 13 bike paths. Third, we buffered trails (500 m), bicycle paths (500 m), and roads (1000 m) for a reasonable viewing distance from each. Buffering is a means of creating a corridor of consideration around a linear or shape feature and is useful when examining areas proximate to a road, for example, and not more distant areas. This was determined by using the Measurement tool to assess the distance of "Points of Interest" that are known to be visible from roads, trails, and bicycle paths, based on the researchers' direct experience. Fourth, we examined areas where buffers for the three transportation modes intersected or were spatially distinct (through intersecting, joining tables, unioning, and selecting of locations) and created new layers of areas where there are one, two, or all three types of transportation surfaces. This resulted in a spatial depiction of areas where there are one, two, or all three surfaces present. Fifth, we dissolved each transportation surface categorization by name, added a "transportation surfaces" value field (1, 2, or 3), and then joined all three based on name and sum of attributes. This process allows for a categorization of the three types of transportation surfaces in a spatially explicit and spatially cognizant way. We then were able to calculate a value for the overall indicator for each named road, trail, or path by averaging how much of the surface area was in each transportation category and dividing by the total area, resulting in an indicator value from 1-3.

Indicator 2: View of the Scenery. Scenery was defined as the park-specified "Points of Interest" locations. First, we converted this vector layer of points to a raster data file using the Feature to Raster tool. This process allows for spatial metrics to be calculated across a landscape because it redefines features (points, lines, and polygons) into grid cells. Second, we looked at the Zonal Statistics as a table; statistics by zone is a means of finding integer values for a raster dataset based on a linked dataset (e.g., vector). Third, we joined the buffer polygon vector data for the three classes and then joined the zonal statistics table to it, allowing a summation of the number of points of interest per polygon. Fourth, we calculated a field for the number of features per polygon area, giving a density. In this manner, we were then able to visually depict the relative scenic value of the proportion of a particular named road, trail, or path, or the category as a whole. We used the Jenks Natural Breaks categorization (i.e., ArcGIS delineated categories, much like a cluster or factor analysis, rather than a researcher-imposed designation of values included/excluded from each category) of splitting the data into three levels of scenic view density (low [1], medium [2], and high [3]).

Indicator 3: Slope of the Road. A raster DEM (digital elevation model; the standard raster-based geospatial file format) at a 10 m distance was used to determine slope. Using the Slope Analysis tool, we determined slope for the Yellowstone landscape. Next, we used the Zonal Statistics as a Table, with the raster slope input and the vector polygon buffers for roads, trails, and paths, to determine the slope of each named transportation surface. Using this process, of examining data by its zonal attributes, we were then able to combine like slope categories. We joined these three resulting tables and were able to plot the average slope per polygon. Again using the Jenks Natural Breaks categorization, we divided the slope into three classes of relative steepness: steeper (1), moderate (2), and flatter (3).

T-ROS Value. A value of 3-9, representing the summed range of values for the three indicators detailed above, was created as a new calculated field for each named road, trail, and path. Values were divided by Jenks Natural Breaks into three classifications of T-ROS categories: low (3-5), medium (6-7), and high (8-9).

Network Analysis: Potential Transit Stop Locations

The researchers limited the park facilities for this investigation to park visitor and information centers. No publically accessible files for this information are available online. Therefore, we created a new layer with the 16 visitor centers and entrance stations. First, we created a new feature class in ArcCatalog in our geodatabase for visitor and information centers, using the same coordinate system as the rest of the data. Second, we used the Editor extension to create points for the 16 centers. This was done by carefully comparing a detailed PDF map of the park and its visitor center locations to the roads layer already in our dataset. We added the points where each visitor center is and then added attribute data for the name of each center. Third, we built a network database using the roads (but not trails or paths) data. Fourth, we created a point feature class layer of seven points on the main road that have high T-ROS values in that location or leading onto trails and paths from that location. We selected these particular points because if management were to put in a transit system, these spots may be key features for visitors to see and also may be priority areas to alleviate traffic congestion at (without constructing additional facilities like larger parking lots). Fifth, we used the Network Analyst tool to examine a network dataset of the most efficient bus routes from visitor centers to the potential transit stops, using a cut-off service area distance of 20 km. Finally, we looked at the service areas of the seven transit stops within 1, 5, 10, and 20 km radii. This resulting map depicts what features are within certain distances from each bus stop. Therefore, a visitor would be better able to judge whether it is more practical to take the bus and walk to features s/he wants to see or whether these features are too far or too scattered throughout an area and therefore taking a personal vehicle and parking closer to these features would be more efficient.

Results

T-ROS Indicators and Composite Index

In completing the spatial analysis of the three T-ROS values, a composite index of the total T-ROS was created and areas of higher and lower values were ascertained. Figure 1 (see Appendix B) depicts the first T-ROS indicator, illustrating travel corridors that are accessible by one, two, or three modes of transportation. Although pedestrians and bicycles are allowed on roads with vehicles, and pedestrians are allowed on bicycle paths with bicycles, we considered the most conservative interpretation of the allowed modes of transportation in this analysis. As Figure 1 shows, areas with all three transportation modes are spread throughout the park's travel infrastructure, with areas of two transportation modes also found across the park landscape and areas of one mode only concentrated on roads without path and trail intersections and remote trails. Figure 2 (see Appendix C) depicts the density of points of interest along each travel corridor. Not surprisingly, many of the roads and trails have been constructed in or near areas of high concentrations of points of interest. One area in particular, in the west-southwest, has a high concentration of points of interest for the length of the travel corridor. As the final component of the T-ROS investigation, Figure 3 (see Appendix D) depicts the third indicator, steepness of slope, for Yellowstone's travel corridors. As this scale was reversed, with the lower slopes having the higher T-ROS value for ease of movement, Figure 3 illustrates that most of the park's travel corridors are, on average, of relatively lower incline. As this is a comparative measure, it is important to note that what is an average incline or decline for a trail, bicycle path, or road may not be low, medium, or high when compared to corresponding corridors outside of the park. However, Figure 3 does correspond to the topography of the area, with the less steep corridors on the Yellowstone Caldera Plateau and the steeper corridors on the northern edge of the plateau, transitioning to lower elevations beyond the Supervolcano's visible boundaries. Each of these figures, 1-3, show the areas of relatively higher and lower values of the individual T-ROS indicators.

When mapped together as a composite index on a summed scale with a maximum of 9, the total T-ROS value of travel corridors within Yellowstone becomes clearer. Figure 4 (see Appendix E) depicts this composite mapping of the total T-ROS indicators. As illustrated, most of the lengths of travel corridors in the park have a medium T-ROS value. Few of the corridors have a low or a high value. Those with the highest T-ROS values (8 or 9) are also seen to be the ones that have the greatest number of transportation modes, the highest density of points of interest, and the lowest slopes in Figures 1, 2, and 3, respectively.

Together, these four maps address our first three research questions. They not only depict what the total T-ROS value is for each location within Yellowstone (research question 1) but also examine the three individual indicators and illustrate how each may be a different value for a particular place and each thus influence the overall value of a particular place. Inherently, in examining these differences in the three indicators and in the composite index, these maps also help illustrate which areas have concentrations of higher T-ROS values (research question 2) and potentially more transportation diversity and which areas have lower concentrations of higher T-ROS values, indicating areas that are potentially dominated by a single indicator or no indicators (research question 3). Figure 4 provides the overarching T-ROS metric, which can be of use when examining what areas have different T-ROS values throughout Yellowstone National Park (research question 1), where there are higher T-ROS values (research question 2), and where there are lower T-ROS values (research question 3). Figures 1-3 offer a more comprehensive look into how each indicator contributes to this overall metric. Therefore, these four maps provide two levels of detail to the first three research questions.

Transit Stop Suitability Assessment and Public Interpretation

Results from the second portion of the analysis center on the suitability for transit stops on park roads at the high T-ROS value locations (research questions 4 and 5). These are the most suitable spots for public transportation stops and perhaps the start of a networked system of stops in the park, providing information in relation to research question four. As Figure 5 (see Appendix F) depicts, a transit stop at each of the high T-ROS value locations would be able to be serviced by a bus route from a visitor center within a 20-kilometer radius. This means that visitors would be able to park their cars at a certain visitor center and take a shuttle bus to a high T-ROS value location within a 20-kilometer distance, alleviating vehicle congestion at these locations. Thus, Figure 5 depicts spots suitable for new public transportation facilities/stops that may be of most use to a diversity of visitors (research question 4).

To illustrate what this means for visitors and how they might plan their experience using or not using this proposed system of transit stops, Figure 6 (see Appendix G) depicts what points of interest are within a 1, 5, 10, and 20 kilometer radius of the transit stops at high T-ROS value locations (research question 5). From a map such as this, visitors may assess what scenic spots they want to see, how far these spots are from a certain transit location, assess their time and fitness constraints, and plan accordingly. For example, a family with small children may only want to take the public transit option if all of the sights they want to see are within a 1-kilometer distance of that stop. Similarly, a backpacker who would want to start at a trailhead that is beyond a certain distance from a transit stop may not want to utilize the public transportation option and have to add additional distance to his or her hike. Figure 6 presents a general map for visitors to determine if utilizing these transportation stops would facilitate or complement their experiences and thus adds knowledge to answering research question five.

Implications

This research has relevance for both research and management. As a preliminary examination of some of the aspects identified as components of a T-ROS metric, and tested in a well-known and well-visited national park, this project identified spatially explicit areas in which a higher or lower T-ROS value for its components (i.e., indicators) and overall could be mapped. This work extends past efforts that identified these indicators but did not map their locations within a given park. In identifying areas with higher and lower T-ROS values, this work allows for more detailed investigations and stratifications of park use by T-ROS value. It provides a quantified, spatially explicit foundation for further investigations into how the spectrum of transportation recreation opportunities may be a limiting or enhancing feature of visitors' perceptions of experience at various locations.

The T-ROS framework proposed by Pettengill (2013) includes a variety of indicators. This investigation focused on ones related to landscape character, facilities/services, and mode of transport. The results suggest that there are areas of the park where these particular indicators may have differential impacts to the resource, facilities, and experiential aspects of the setting (Manning, 2011). Areas with a high concentration of features and multiple modes of transportation available may be more heavily impacted by a variety of uses and visitor densities. Consideration of what areas have higher T-ROS values, such as the Old Faithful Geyser Basin, is important not only when looking toward future facilities planning but also when considering current impacts. Identifying these areas may complement current knowledge about conditions in these particular locations and what management actions (e.g., limiting use, increasing supply, hardening the resource, changing visitor behavior) may be appropriate (Manning, 2011). In this way, examinations of T-ROS, and findings such as presented here, extend knowledge of not only the diversity of experiences that may be available within a recreation setting, but also in what areas we may expect to find greater or lesser impacts. Although the ROS framework has been a design for diversity for decades, examining transportation as a form of access and recreation extends understanding of how this particular aspect may be examined and quantified on the landscape. Given the importance of transportation in the visitor experience (Perry et al., 2015; Xiao et al., 2017), this investigation provided insight on how a T-ROS framework (specific indicators and overall metric) may be applied in a particular recreation setting.

The findings of the present study also have relevance to management. As this project was undertaken as a general and preliminary test of the framework, there are many aspects that have been generalized and may not apply to every situation. For example, when looking at T-ROS values in their park, managers may want to assess whether or not slope is a defining and limiting factor for the recreation experience. Although slope may be an important factor in hiking and bicycling experiences, it may be a lesser factor in vehicle experiences and park managers may want to examine the extent to which this aspect is weighted for each travel corridor type. They may also want to add indicators for vehicle roads that may not apply to other corridors, such as the road surface type, condition, and seasonal closures. On the issue of weighting, park managers may also decide that not all points of interest should be equally weighted. In this project, all points of interest were assumed to carry the same scenic and destination value. However, managers may want to work with researchers to examine the equal-weighting scheme. There are undoubtedly some park features that are more attractive for visitation, or elicit a longer time commitment for visitation, than others. Identifying these features (through managerial and visitor use data) may help tailor the T-ROS approach presented here to account for a range of site attractions from points that are a concentration of smaller features clustered together near multi-use travel corridors to features that are singular points of spectacular interest.

Aside from issues of indicator inclusion and weighting, managers may use the information presented to see what areas have higher T-ROS values and perhaps concentrate on building bus stops in these areas to alleviate congestion or the need for greater infrastructure. As more parks are considering how to lessen vehicle traffic, this may become increasingly important in designing looped transportation systems, especially in a park as large as Yellowstone. Placing bus stops only in areas of high T-ROS values should not be seen as the only priority, though. Understanding the visitors' wants and needs is foremost in creating and maintaining a positive visitor experience. Therefore, it is also important to devote attention to the areas that may have lower T-ROS values but may be gateways or methods to areas that are more remote, have a single transportation mode, are steeper, and have more dispersed scenic spots. Enhancing the visitor experience may require more detailed signage, less frequent but still available transportation services, and a greater understanding of how visitors utilize the area. As the entire spectrum of transportation recreation opportunities is valuable and provides a range of options for visitors, it is not our intent to suggest that parks should strive for all high value T-ROS locations. However, understanding the diversity of these locations and how they may be spatially presented to visitors may aid in fulfilling management goals and providing greater visitor satisfaction.

Limitations

As with any investigation, this work had constraints. Although these constraints may affect the findings, they are also opportunities for further research into T-ROS. A subset of potential T-ROS indicators were chosen for this project. This selection was made to constrain the scope of the work, align with publicly available data, and provide a suite of indicators. Past research has identified other indicators that could be useful to empirically test, such as density of use, cost, convenience, corridor design, and trip purpose (Pettengill, 2013; Pettengill & Manning, 2011). Investigating these indicators may produce different or more nuanced T-ROS metrics. Furthermore, testing any indicator in a different park setting may produce different metrics, especially if Jenks Natural Breaks (i.e., comparative classes) are used as typology set points. Perhaps a weighting scheme on a park-specific basis and in line with management objectives and visitor use patterns would more appropriately capture differences and priorities not realized in an equal-weight scenario. We did not consider such a weighting scheme. Combining data sources, such as visitor use surveys, management interviews, and spatial analysis, rather than relying on a single type of data (GIS data in this case) would lend insight into what weights may be appropriate, what indicators may be yet unexplored, and how preferences for different indicators and T-ROS values overall may vary by visitor group (e.g., demographics, motivations). Finally, this investigation was confined to the boundaries of Yellowstone National Park. As ROS may be considered as both an intra and inter-site examination of diversity, it would be prudent to look beyond the administrative boundaries of the park unit and toward the larger geographic region to examine on what scales the range of T-ROS values are represented. Refinement of the T-ROS metric may yield a standardized scale for comparison across indicators and settings and warrants further consideration as studies progress.

Future Directions

The research questions here may be expanded upon in future research by tests in different locations, with an expanded set of indicators and/or weights on current indicators, and with particular user groups. Park size and park-identified points of interest may factor into the T-ROS values seen and to have a transferrable set of indicators and overall metric would require input from various locations and situations to compute a robust set of attributes that could be presented as a T-ROS body of concepts, or theory, that is applicable in a variety of settings. Further research questions and hypotheses may identify additional indicators that should also factor into T-ROS computations and perhaps identify weights of one indicator to another that are generally consistent among situations. Differential weighting of the indicators based on their centrality to a quality visitor experience and/or the feasibility of management intervention could refine the metric to better capture the importance of different parts of the recreation setting (i.e., facilities/management, resource, and social/experiential; Manning, 2011). This weighting and refinement would require spatial analyses paired with visitor use preferences (e.g., qualitative interviews, quantitative questionnaires). Other pertinent avenues of further research include whether these are land management focused (e.g., across National Park Service lands, across Forest Service lands) or ecosystem focused (e.g., across mountainous portions of parks, across prairie portions of parks, across portions of parks with high water body concentrations). Finally, there may be an element of user group preference in the calculation of these metrics. Although it is useful to have a metric that would satisfy the average visitor with the average use patterns, in reality, no visitor is completely average. Therefore, it would be beneficial to furthering this body of work to examine how different user groups interact with these T-ROS indicators, what relative weightings they place on each, and how this may vary both spatially and temporally depending on use patterns.

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Appendix A

Table 1. Metadata on the file layers used in the completion of this analysis. All files have been originally produced or clipped to the Yellowstone National Park boundary.

File Name	Description	Coordinate Projection	Datum	Resolution	Currency	Data Type	Source	Derived Attributes
Driving_ only	Roads for vehicle traffic	Transverse Mercator	NAD 1983 UTM Zone 12N	USGS High Resolution Criteria	2010	Vector	WSGS UWYO	1000 m buffer; intersections with other travel corridors
Hiking_ only	Trails for foot traffic	Transverse Mercator	NAD 1983 UTM Zone 12N	USGS High Resolution Criteria	2010	Vector	WSGS UWYO	500 m buffer; intersections with other travel corridors
Biking_ only	Pathways for non-motorized bicycle traffic	Transverse Mercator	NAD 1983 UTM Zone 12N	USGS High Resolution Criteria	2010	Vector	WSGS UWYO	500 m buffer; intersections with other travel corridors
Indicator_ Join123	T-ROS computed values	Transverse Mercator	NAD 1983 UTM Zone 12N	USGS High Resolution Criteria	2013	Vector	Researcher-created intermediate data	Values for T-ROS indicators 1 -3; T-ROS composite metric
Pts_ Interest	Park-defined natural and cultural features	Transverse Mercator	NAD 1983 UTM Zone 12N	USGS High Resolution Criteria	1981	Vector	WSGS UWYO	Created raster version of the data
Visitor_ Center	Primary visitor centers park entrances	Transverse Mercator	NAD 1983 UTM Zone 12N	USGS High Resolution Criteria	2013	Vector	Researcher digitized based on park maps	Facilities in Closest Facility Analysis
Bus_ Stop	High T-ROS value locations on driving roads	Transverse Mercator	NAD 1983 UTM Zone 12N	USGS High Resolution Criteria	2013	Vector	Researcher digitized based on T-ROS metric	Incidents in Closest Facility Analysis and Facilities in Service Area Analysis
Boundary	Yellowstone National Park's official administrative boundary	Transverse Mercator	NAD 1983 UTM Zone 12N	USGS High Resolution Criteria	2008	Vector	WSGS UWYO	Used for clipping features
Dem10	Elevation of the park	Transverse Mercator	NAD 1983 UTM Zone 12N	10 m	2009	Raster	WSGS UWYO	Slope calculation

Appendix B

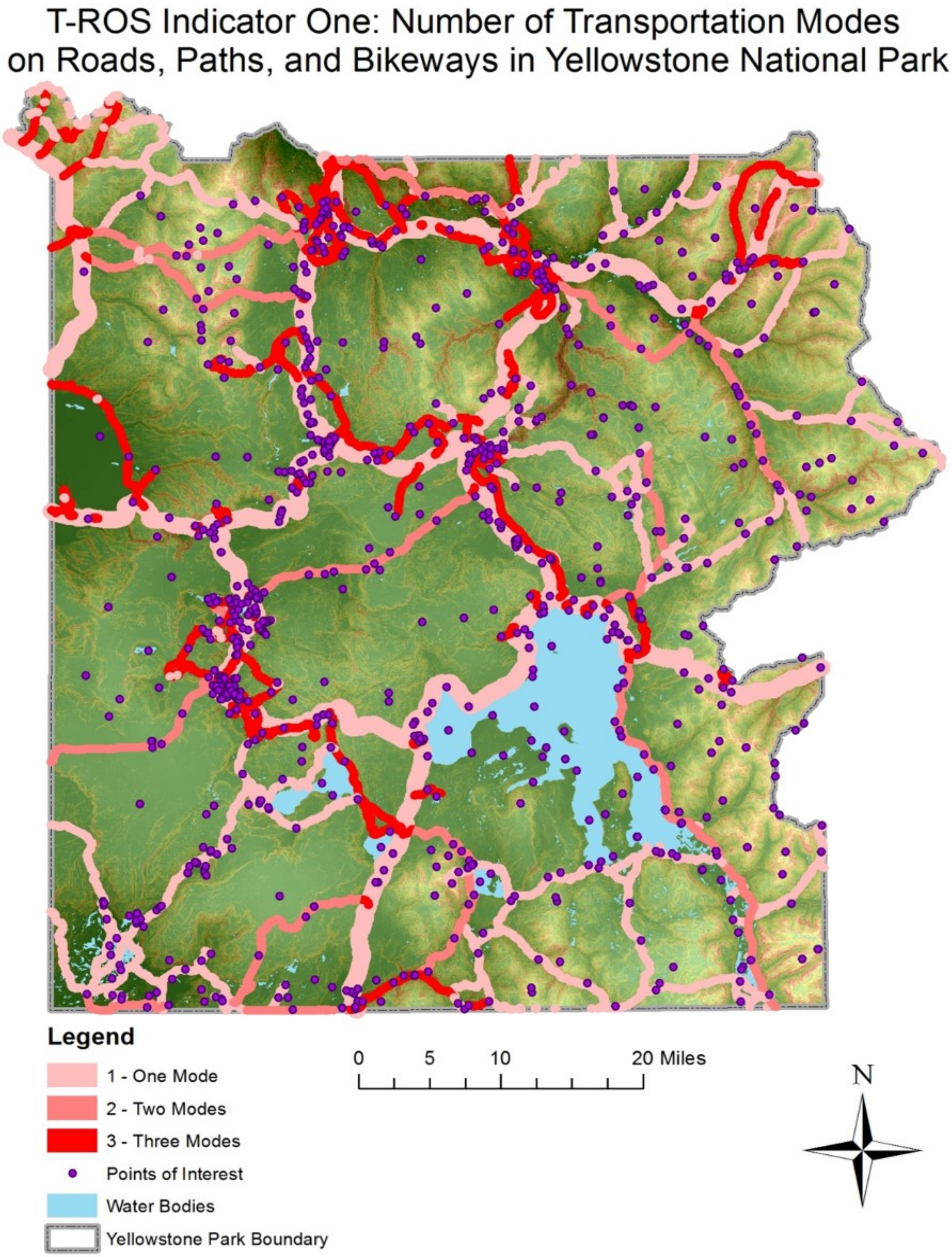

Figure 1. The number of transportation modes on trails, bicycle pathways, and all roads (paved and unpaved) in Yellowstone National Park. The darker the shade of red, the more modes of transportation are allowed along any defined travel corridor.

Appendix C

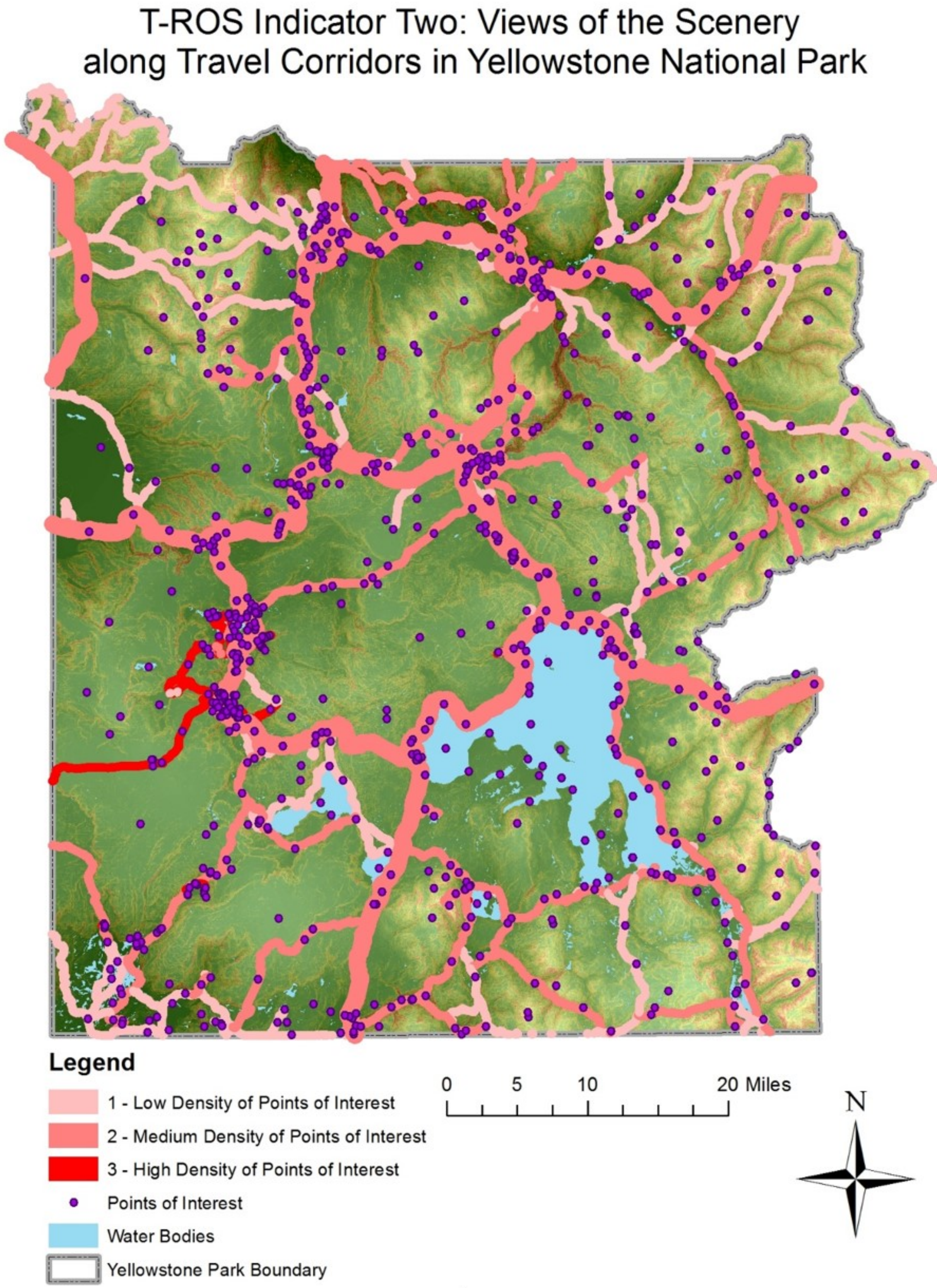

Figure 2. The density of park-defined points of interest (purple) within a 1000 m buffer of roads, 500 m buffer of bicycle paths, and 500 m buffer of trails. The darker the shade of red, the higher the density of these points is within the buffer for any given defined travel corridor.

Appendix D

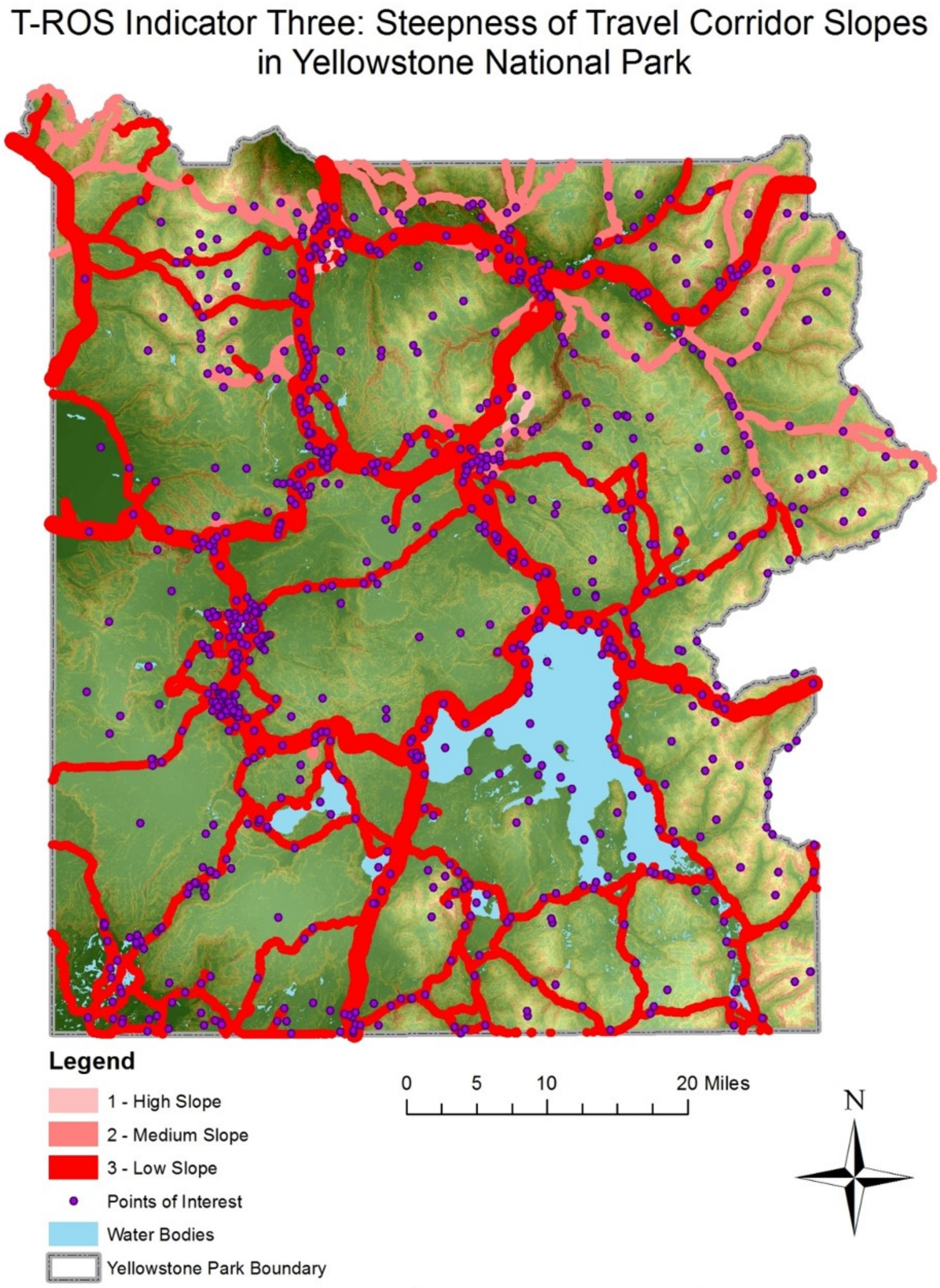

Figure 3. The steepness of slopes on the travel corridors in Yellowstone National Park. The darker the shade of red, the lower the slope of a defined travel corridor.

Appendix E

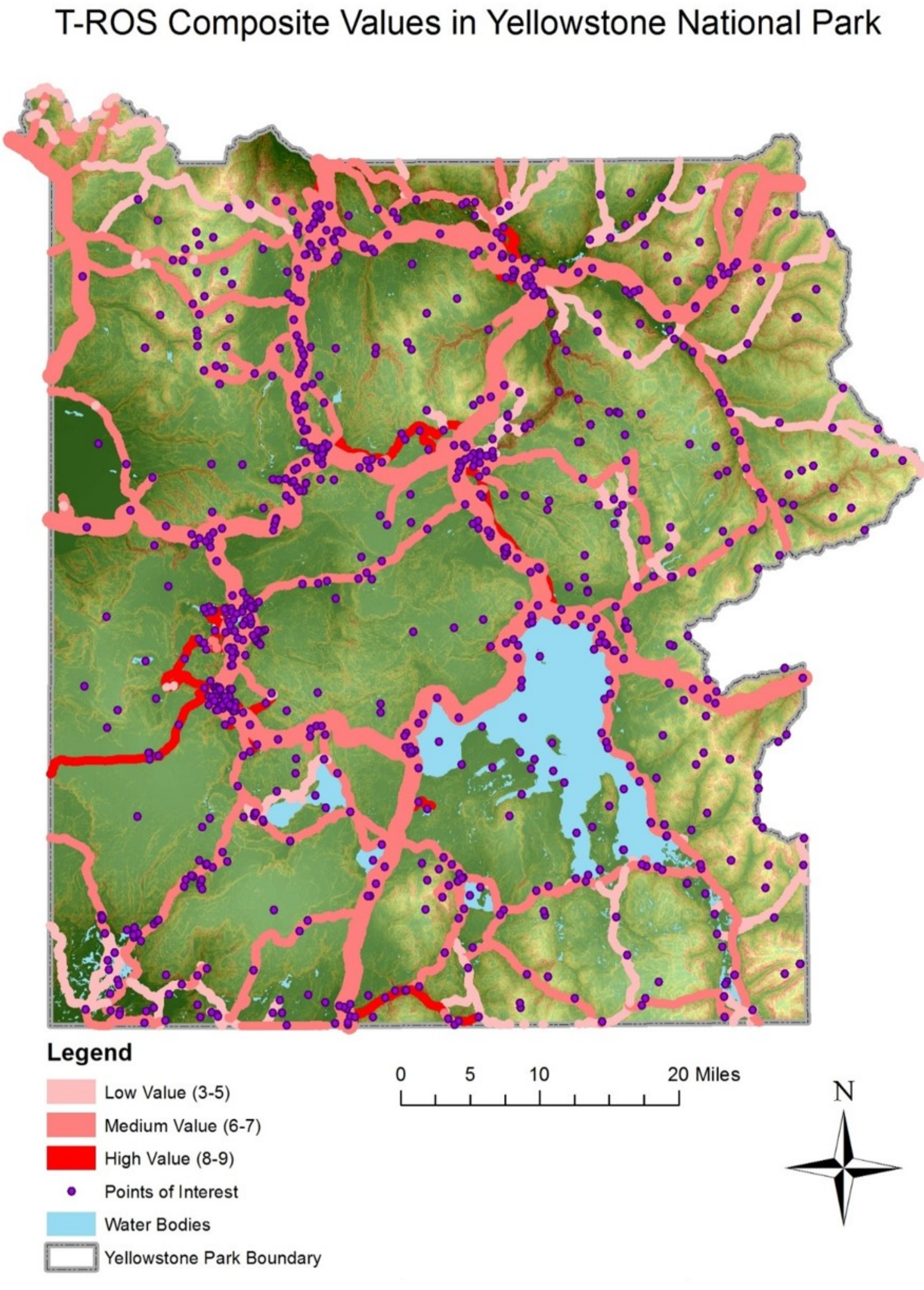

Figure 4. T-ROS composite values of travel corridors within Yellowstone National Park. The darker the shade of red, the greater the T-ROS value. Individual components that lend to an overall score are mapped in Figures 1-3.

Appendix F

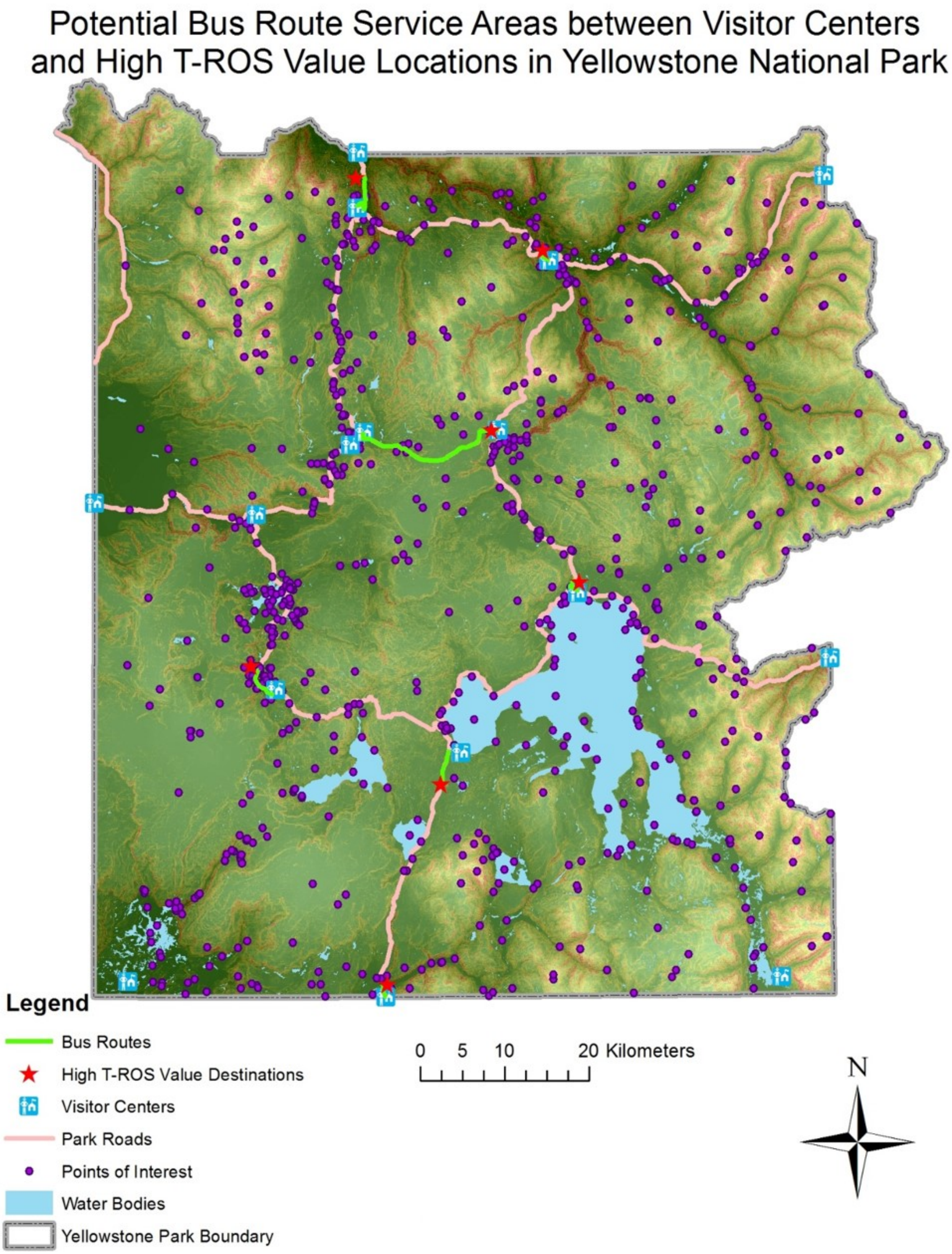

Figure 5. Potential bus routes on roads between visitor centers within a 20-kilometer distance of a high T-ROS value destination in Yellowstone National Park.

Appendix G

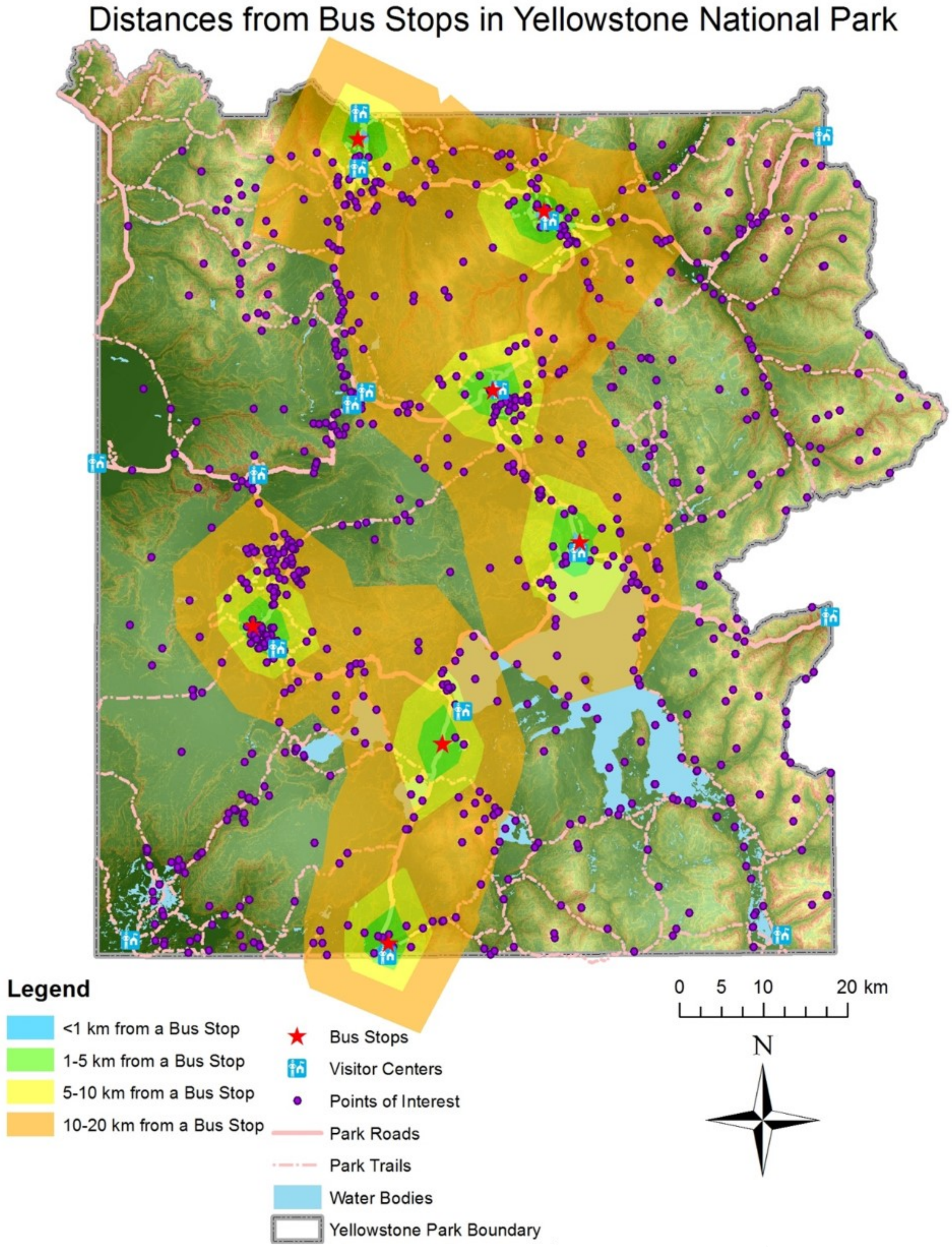

Figure 6. Points of interest within a 1, 5, 10, and 20-kilometer radius of the transit stops at high T-ROS value locations in Yellowstone National Park.