

A data-driven and generalizable model for classifying outdoor recreation opportunities at multiple spatial extents

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HIGHLIGHTS

- A data-driven and generalizable model to define and quantify ROS classifications.
- The model yields discrete ROS classifications at any spatial extent.
- All data and code are free and publicly available.
- Identifies distinct types of outdoor recreation opportunities within Utah (USA).

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ABSTRACT

The Recreation Opportunity Spectrum (ROS) framework spatially delineates a landscape into discrete classes believed to provide relatively unique outdoor recreation opportunities. The framework is an integral component of numerous outdoor recreation and tourism planning efforts. However, the effectiveness of the framework as a management tool has been limited given: 1) its dependence on anecdotal perceptions of managers as opposed to objective and reliable metrics; 2) its application at a singular spatial extent; and 3) its limited ability to provide prescriptive guidance on how outdoor recreation should be managed. We present a data-driven and generalizable model to define and quantify ROS classifications at multiple spatial extents. The model is structured around the three setting characteristics (biophysical, managerial, and social) believed to influence the types of outdoor recreation opportunities provided in a particular place. Each characteristic is quantified using free and publicly available data. The model's analytical workflow yields discrete ROS classifications unique to the spatial extent at which it is applied (e.g., statewide, across an entire national forest, across just a ranger district, etc.). We demonstrate the flexibility and utility of the model by applying it to three spatial extents (statewide, regional, and local) within Utah (USA). Each application yields meaningful characterizations of the outdoor recreation opportunities provided across the landscape, allowing the decision makers which operate at each of these extents (e.g., state legislatures [state], regional collaborative initiatives [regional], and land management agency line officers [site-specific]) to make decisions informed by data and a transparent analytical process. The model can serve as a catalyst capable of unifying disparate visitor use management frameworks around common data, and a common model, for classifying the distinct types of wildland recreation settings upon which outdoor recreation opportunities depend.

1. Introduction

As the U.S. population continues to grow, so does the demand for outdoor recreation and tourism on public lands (Miller et al., 2020; Sanchez et al., 2020). Given the operational budgets of many federal and

state land management agencies have not kept pace with this demand, it is unclear whether land managers will be able to continue to provide a diverse array of high-quality outdoor recreation opportunities well into the future (Cervený et al., 2020; Smith et al., 2019). Additionally, there has been a general lack of innovative planning solutions which can be

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applied across multiple administrative entities, compounding the inefficiencies arising from the complex patchwork of land management within the country (Squillace, 2019). Consequently, many land managers and outdoor recreation planners could benefit from planning tools and frameworks that are applicable across administrative boundaries and provide prescriptive guidance on how they can best manage the growing demand for outdoor recreation.

A fundamental first step towards these aspirational goals is to have a way of characterizing the types of outdoor recreation opportunities that are offered across a landscape. The Recreation Opportunity Spectrum (ROS) framework provides guidance on how to characterize outdoor recreation settings based upon the types of opportunities they provide. The framework was originally developed within the U.S. in the late 1960s (see Manning (2022) for a review of the framework's origins) and has since been applied and extended within China (Xiao et al., 2011), Mexico (Pérez Verdín et al., 2008), New Zealand (McCool et al., 2007), Norway (Gundersen et al., 2015), Japan (Oishi, 2013), and South Korea (Kim et al., 2018; Kim & Kim, 2020; Yun et al., 2022). The framework suggests managers can spatially zone a landscape based upon how natural it is, how much managerial presence there is, and how much recreation use it receives (Stankey, 1999). The delineation of ROS classifications is intended to help ensure land managers provide a diversity of opportunities across the landscapes they manage. This is difficult to do when management actions are not coordinated across agencies or at large spatial extents (Manning, 2022).

While the ROS is integrated into the planning and management processes of many federal agencies (both within the U.S. and abroad), it is almost exclusively applied at singular spatial extents, with poor data, and with little to no transparency. In this research, we revitalize the ROS as a modern approach to planning for outdoor recreation use. Our specific objectives are: 1) to define a generalizable model and data sources that can be applied at different spatial extents to quantify outdoor recreation opportunities; and 2) explore how the generalizable model can be applied at three distinct spatial extents (statewide, regional, and site-specific) commonly used to guide outdoor recreation and public land management decisions.

We apply our generalizable model to the state of Utah (USA), where over 75% of the state is managed by federal and state public land management agencies (Trout & Smith, 2023). Utah's diverse public lands, which include the forests of the Wasatch mountains, the high deserts of the Colorado Plateau and the Great Basin, and portions of the Mojave Desert, support an outstanding diversity of outdoor recreation opportunities.

1.1. The ROS framework

1.1.1. Origins, structure, and purpose

The ROS framework operates by spatially delineating a landscape into discrete classes that can be arrayed on a continuum. These classes are almost always based on the biophysical, managerial, and social characteristics of the recreation setting (Manning, 1985). The fundamental assumption, and internal logic, of the ROS framework is that settings can be characterized by how natural they are (biophysical characteristics), how intensively managed they are (management characteristic), and how much use they receive (social characteristics).

The biophysical characteristics of the ROS framework have often been defined by how accessible and natural settings are. Research has used specific indicators such as land cover, remoteness, and the presence of water bodies and viewsheds to define the biophysical characteristics of outdoor recreation settings (Byczek et al., 2018; Cortinovis et al., 2018; Dhama & Deng, 2018; Gundersen et al., 2015; Merry et al., 2018; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Shilling et al., 2012; Tarrant & Smith, 2002).

The managerial characteristics of the ROS framework commonly refers to the presence, amount, and type of built infrastructure that supports outdoor recreation at a site; it also refers to the presence of

restrictions on allowable visitor behavior (Byczek et al., 2018; Cortinovis et al., 2018; Dhama & Deng, 2018). The most often quantified types of recreation infrastructure include campsites, restroom facilities, and visitor centers (Cortinovis et al., 2018; Kil et al., 2014; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002). Use restrictions often include limits on where motorized vehicles are allowed (Dhama & Deng, 2018). However, they may also include limits on mechanized equipment, such as mountain bikes, in designated Wilderness areas. Use restrictions can also include specific limits on the size of groups allowed to use an area or acceptable speeds for motorized travel (e.g., no wake zones in water-based recreation settings).

Finally, the social characteristics of the ROS framework commonly refer to the amount of use recreation settings within a particular ROS class are likely to experience (Cole & Hall, 2009; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002). ROS classes on the more developed end of the spectrum typically receive higher levels of use relative to those closer to the primitive end of the spectrum.

While ROS "classes" have been defined differently across the world, they commonly include 'urban', 'rural', 'roaded natural', 'semi-primitive motorized', 'semi-primitive nonmotorized', and 'primitive' distinctions (ORRRC, 1962). The assumption of the ROS framework is that each of these discrete classes facilitates the provisioning of specific types of outdoor recreation opportunities. For example, opportunities to experience solitude are more likely to occur within an area classified as primitive while opportunities to spend time with close friends and family members may be more prevalent in areas closer to the urban end of the ROS spectrum.

The ROS framework is used by land management agencies to: (1) inventory and quantify the types and outdoor recreation opportunities provided across a landscape (Kliskey, 1998); (2) establish managerial goals, objectives, and carrying capacities for specific types of outdoor recreation settings (Clark & Stankey, 1979); (3) minimize conflict amongst different types of outdoor recreation activities (Daniels & Krannich, 1990); and (4) analyze impacts to recreation opportunities (i.e., the particular class of an ROS setting might be changed as a result of proposed management actions) (Cervený et al., 2011; Harshaw & Sheppard, 2013).

1.1.2. Limitations with the current ROS framework and opportunities for improvement

Although the ROS framework has been used by land management agencies for over 50 years, we argue its effectiveness as a management tool has been limited for several specific reasons. First, the ROS is almost universally applied at a single spatial extent, most commonly an entire national forest (USDA Forest Service) or field office administrative area (Bureau of Land Management). Implementing the tool in this way results in a lost ability to quantify and characterize outdoor recreation settings in a way that is meaningful to how the vast majority of individuals participate in outdoor recreation – evaluating potential destinations that can be visited given time and financial constraints (Joyce & Sutton, 2009). The larger the spatial extent at which recreation opportunities are classified, the harder it becomes to characterize meaningful differences in the ways outdoor recreation settings are perceived and used. It does managers little good to know large portions of the land they manage are classified as 'semi-primitive non-motorized' for example, if they know the lands that fall within that classification provides multiple (potentially conflicting) types of outdoor recreation opportunities. For the ROS to be more effective as a management tool, it needs to have the capacity to quantify and characterize outdoor recreation opportunities at a variety of managerially-relevant extents. By developing a generalizable model and data sources that can be used at various spatial extents, our approach allows the ROS to be used more broadly across an agency, and not solely by the highest levels of planning and management.

Second, the ROS has been inconsistently applied over the years and across different management agencies. Managers and planners have used different measures to define the biophysical, managerial, and social

characteristics of the lands they manage. Often, data quality and availability vary from locale to locale, requiring managers and planners to make subjective decisions about how specific settings should be classified. Subjective judgements on selecting classification criteria can substantially influence the accuracy and function of the ROS. In our generalizable model, we incorporate free and publicly available data to define outdoor recreation opportunities. The data-driven approach increases transparency, which may lead to the tool being more publicly acceptable (Powers & Hampton, 2019).

The final reason why the effectiveness of the ROS as a management tool has been limited is a result of it being used in a descriptive as opposed to prescriptive way. The ROS is almost universally used in a descriptive manner to characterize the types of outdoor recreation opportunities that are currently offered across the landscape. ROS classifications are not used prescriptively to guide the actions of resource managers. The descriptive nature in which the ROS framework is applied leads to its infrequent use. For example, the USDA Forest Service is required to update their ROS classification maps every time they create a new forest plan (approximately every 10 years). The classification maps are the product of existing transportation and outdoor recreation infrastructure as well as managers' assessment of site-specific use levels; they are only infrequently used to determine if proposed management actions would affect existing outdoor recreation opportunities (e.g., via an environmental impact assessment) (Cervený et al., 2011; Harshaw & Sheppard, 2013). For the ROS to be more frequently

and effectively used, we argue that it needs to be applied in a prescriptive manner with outdoor recreation planners, managers, and their constituents collaboratively defining the management objectives for preserving the unique types of recreation opportunities provided within each ROS class. In our analytical examples, we show how the ROS has the capacity to be utilized as a prescriptive management tool.

2. Methods

2.1. A data-driven and generalized model

Our data-driven and generalizable model is illustrated in Fig. 1. Free and publicly- available data are used as indicators of the three characteristics which define outdoor recreation opportunities. Instead of classifying outdoor recreation opportunities along a single continuum as has been done in the past, we provide equal conceptual weight to the biophysical, managerial, and social characteristics that can define a setting *and* assume those characteristics do not covary. A common criticism of the standard ROS framework is it's implicit assumption the biophysical, managerial, and social characteristics covary (Manning, 1985). Eliminating the implicit association between the three setting characteristics results in a hypothetical three-dimensional matrix (Fig. 2) within which any outdoor recreation opportunity can be placed. A remote natural setting with relatively low management presence and little use will be defined as "biophysical (high) – managerial (low) –

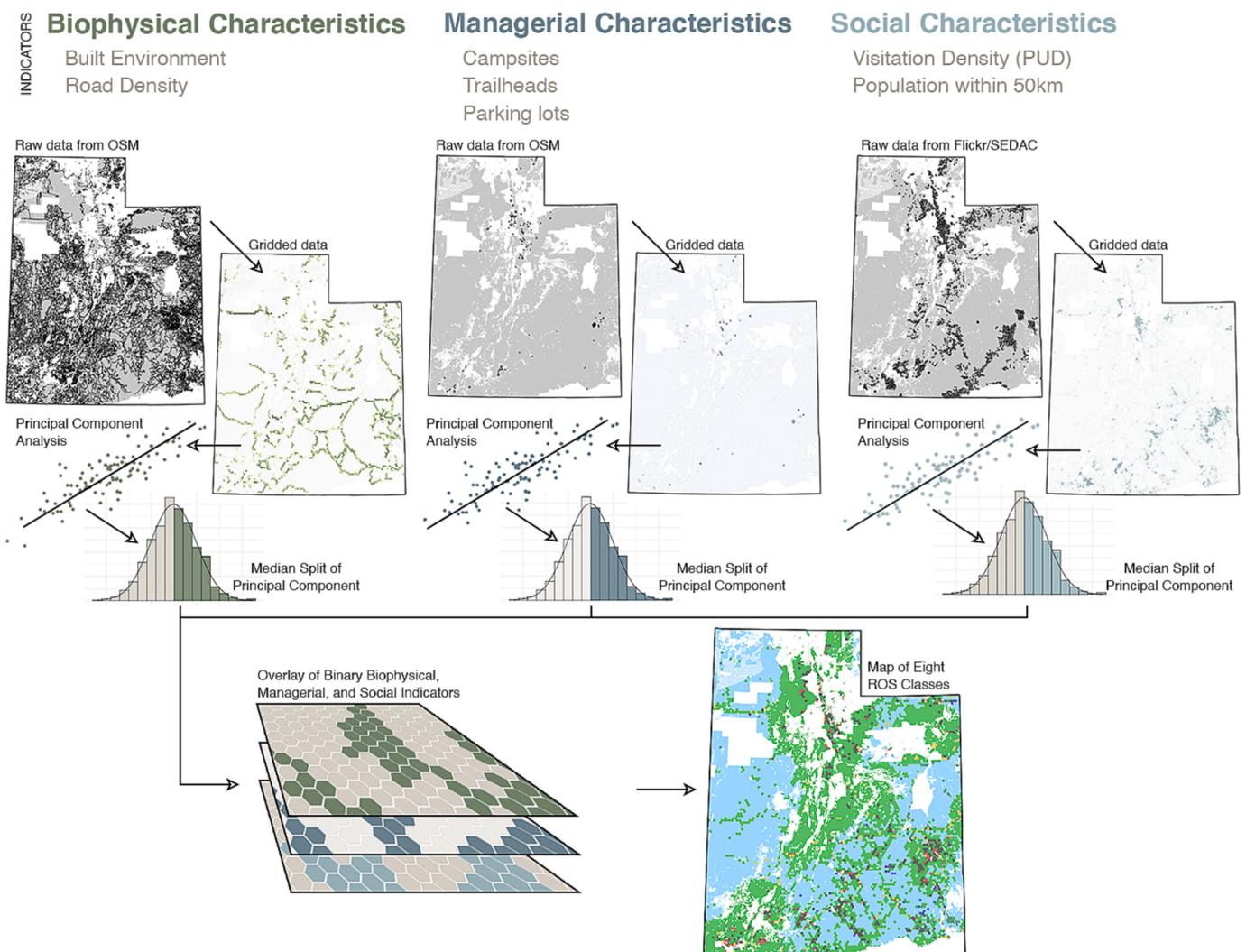


Fig. 1. A data-driven and generalizable methodological workflow for quantifying outdoor recreation opportunities.

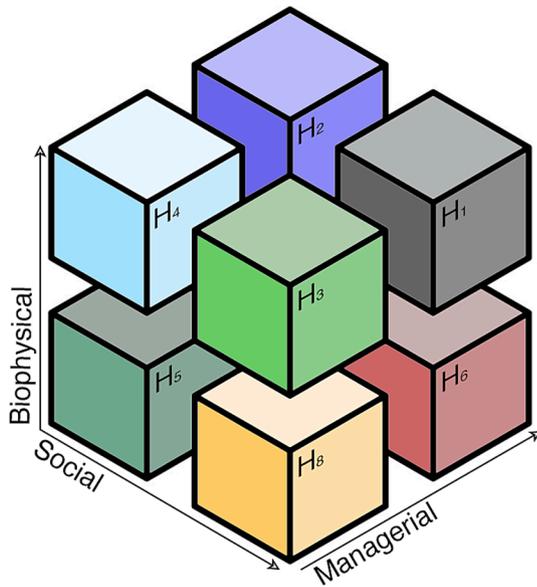


Fig. 2. Eight discrete classes of recreation opportunities based on high/low classifications of the biophysical, managerial, and social characteristics of a recreation setting.

social (low)”. Allowing each of the three dimensions of an outdoor recreation setting to have two levels (high and low), allows the three-dimensional conceptualization to distinguish between eight classifications of outdoor recreation opportunities. These eight hypothetical classifications are described in detail in Table 1. As an example, areas that receive a substantial amount of use (“high” on social characteristics) with numerous facilities and other infrastructure (“high” on managerial characteristics) that are easily accessible via roadways (“low” on biophysical characteristics) will be categorized into an H₆ ROS classification. We argue that providing equal conceptual weight to the biophysical, managerial, and social characteristics that define a setting allows us to more accurately capture the diversity and variability in

outdoor recreation settings and the opportunities they provide. This approach also allows the model to define ROS classifications at multiple spatial extents, providing land managers with a more flexible tool to guide the wide-range of decisions they make; these decisions can range from site-specific (e.g., “should we install restroom facilities at this particular trailhead?”) to landscape-scale (e.g., “where should motorized recreational use be allowed?”). The approach is based on objective and transparent analyses of the biophysical, managerial, and social characteristics of public lands.

2.2. Study area and spatial extents analyzed

Our study area covers all public lands in Utah; this is inclusive of lands managed by the National Park Service, the USDA Forest Service, Bureau of Land Management, the Utah Division of State Parks, and other public lands managed by either federal or state agencies. Utah contains five popular U.S. national parks (Arches, Bryce Canyon, Canyonlands, Capitol Reef, and Zion) as well as several other national park units, large proportions of five national forests (Ashley, Dixie, Fishlake, Manti-LaSal, and Uinta-Wasatch-Cache), as well as lands managed by the Bureau of Land Management. Public lands in Utah contain exceptionally diverse landscapes which support a wide range of outdoor recreation opportunities.

The first spatial extent we analyzed was the entire state, a scale at which identifying distinct ROS classifications is meaningful for entities with state-wide mandates (e.g., the Utah Office of Tourism and the Utah Division of Outdoor Recreation). The second spatial extent we analyzed was the four-county region (Garfield, Iron, Kane, and Washington) in the southwestern portion of the state. This region includes a diverse set of public lands that consist of different landscapes (desert, forested land, and canyons, etc.) and different managing agencies. The region includes Bryce Canyon and Zion National Parks, the Dixie National Forest, as well as numerous state parks. The region is experiencing rapid growth in the demand for outdoor recreation opportunities; this is driven in-part by urban growth near the city of St. George (Smith & Miller, 2020). The final spatial extent we analyzed was the Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest. Like the southwestern region of the state, the Salt Lake Ranger District is experiencing rapid growth in

Table 1
The eight discrete classes of recreation opportunities based on high/low classifications of the biophysical, managerial, and social characteristics of a recreation setting.

| ROS setting characteristic | Hypothetical opportunity classifications | | | | | | | |
|--|---|--|---|---|--|---|--|--|
| | H ₁ | H ₂ | H ₃ | H ₄ | H ₅ | H ₆ | H ₇ | H ₈ |
| Biophysical | high | high | high | high | low | low | low | low |
| Managerial | high | high | low | low | low | high | high | low |
| Social | high | low | high | low | low | high | low | high |
| Descriptions of each classification | | | | | | | | |
| | More natural settings with more managerial presence and heavy use | More natural settings with more managerial presence and little use | More natural settings with less managerial presence and heavy use | More natural settings with less managerial presence and little use | Less-natural setting with less management presence and little use | Less-natural setting with more managerial presence and heavy use | Less-natural setting with more managerial presence with little use | Less-natural setting with less managerial presence and heavy use |
| Management implications for each classification | | | | | | | | |
| | Assure existing infrastructure minimizes ecological degradation from visitor use; continue to invest in maintenance and infrastructure; Assure existing infrastructure supports large and diverse groups. | Ensure investments in maintenance and infrastructure preserve activities with low visitor use densities. | Invest in infrastructure to minimize ecological degradation from visitor use. | Preserve opportunities for activities with low visitor use densities. | Monitor use for possible increases in demand and associated environmental impacts. | Continue to invest in maintenance and infrastructure; Assure existing infrastructure supports large and diverse groups. | Reallocate management resources to areas with more demand. | Invest in infrastructure to meet demand. |

the demand for outdoor recreation opportunities driven by the urbanization of the Salt Lake Valley (Smith & Miller, 2020).

2.3. Data collection and processing

We compiled a list of potential indicators for the biophysical, managerial, and social characteristics of public lands based upon previous research mapping recreation opportunities (Table 2). We acquired data for 11 potential indicators from disparate sources (Table 3) and aggregated these data to a hexagonal grid. A 5 km (long diagonal length) spatial grid was chosen over smaller or larger grids because it can identify, and differentiate between, nearly all types of non-linear recreation settings (e.g., campsites, marinas, trailheads, etc.). Biophysical characteristics were measured using indicators of naturalness and remoteness while managerial characteristics were measured using the amount of built infrastructure within each grid cell. Specific types of infrastructure considered are noted in Table 3. Social characteristics were quantified with publicly available social media and the setting’s nearby population density.

For social media, we acquired data from two platforms, Flickr and Panoramio, using each platform’s API. Flickr is one of the most commonly used social media data sources to quantify recreation use (Wilkins, Wood, et al., 2021) and Panoramio has been used in several seminal papers (e.g., van Zanten et al., 2016). We acquired data from both platforms for 2006 – 2014. Geotagged posts were transformed to ‘photo-user-days’ (PUD), a common metric in social media analytics that filters all social media posts to only one per use per day in a specific geographic area (Wilkins, Wood, et al., 2021; Wood et al., 2013). PUDs were aggregated to the 5 km hexagonal grid to minimize the potential for a boundary effect (see Zhang et al. (2021) for sensitivity analyses across different grid sizes). Boundary effects are misrepresentations of spatial data caused by arbitrary boundaries (grid cells in the case of the analysis reported here) being imposed on spatial data that represents unbounded spatial phenomena (Yamada, 2009). Previous analyses of

Table 2
Common characteristics of the recreation opportunity spectrum planning framework.

| ROS Setting Characteristic | Variables | References |
|----------------------------|--|---|
| Biophysical | Naturalness/remoteness: distance(areas) to major urban areas | Byczek et al., 2018; Cortinovia et al., 2018; Dhami & Deng, 2018; Merry et al., 2018; Shilling et al., 2012 |
| | Accessibility (density of roads) | Dhami & Deng, 2018; Gundersen et al., 2015; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002 |
| Managerial | Area under restrictive management (e.g., wilderness, National Park Service lands) | Byczek et al., 2018; Cortinovia et al., 2018; Dhami & Deng, 2018 |
| | Density of infrastructure (e.g., visitor centers, showers, dump stations, internet access, trailheads, parking lots, etc.) | Cortinovia et al., 2018; Kil et al., 2014; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002 |
| Social | Visitation density (or social encounter), population density. | Cole & Hall, 2009; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002 |

Note. Our model focuses primarily on land-based outdoor recreation opportunities, although there is a literature which has applied the ROS to water-based systems (e.g., Byczek et al., 2018; Cortinovia et al., 2018; Maes et al., 2012; Merry et al., 2018; Paracchini et al., 2014; Peña et al., 2015; Rahman et al., 2020; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002).

these data revealed they capture approximately 70% of the variation in visitation data reported by public land management agencies (Zhang et al., 2021).

We used Pearson’s correlation coefficients to identify high correlations ($r > 0.50$) and generate a parsimonious set of variables representing the three ROS characteristics (the full correlation matrix is shown in Figure A in the Supplementary Materials). We retained at least two measures for each characteristic. Overall, variables representing biophysical and social characteristics were not highly and significantly correlated to each other. The biophysical characteristics of outdoor recreation settings are represented by the proportion of a grid cell with a land cover classification of ‘built environment’ and the length (km) of roads within the grid cell. For the variables representing managerial characteristics, we found the number of showers, toilets, and the presence of drinking water were highly and positively correlated with the number of trailheads ($r > 0.5$). We subsequently dropped these variables, retaining only the number of trailheads. The final set of variables representing the managerial characteristics of outdoor recreation settings were: (1) the number of campsites; (2) the number of trailheads; and (3) the number of parking lots. Both the social media count (PUD) and the population within 50 km of a setting were retained to measure the social characteristics of outdoor recreation settings.

2.3.1. Principal component analysis

Standardized variables for each ROS classification were reduced to a single indicator using a Principal Component Analysis (PCA). We used a minimum Eigenvalue of 1.0 as the criteria for determining if the first principal component explained more variation than any one indicator alone (Holland, 2008); this was the case for all three ROS classifications.

2.3.2. Identification of discrete ROS classifications

Distinct ROS classifications are identified by transforming derived principal components into dichotomous “high-low” variables based on median values. These dichotomous classifications are then combined to generate unique combinations of the three measures that represent the biophysical, managerial, and social characteristic of each settings; these unique combinations map to the eight discrete hypothetical ROS classifications proposed above (Table 1). For example, if a grid cell was “low” on the biophysical characteristic, “high” on the managerial characteristic, and “high” in social characteristic, it will be categorized in the H₆, which refers to intensely managed urban-proximate setting with heavy use.

3. Results

3.1. Descriptive statistics

Descriptive statistics for each variable representing biophysical, managerial, and social characteristics, across each of the three spatial extents, are presented in Table 4. The results of the PCA for each ROS setting, by the spatial extent of analysis, is shown in Table 5. There was little difference in terms of factor loadings across the three extents of analysis, suggesting the indicator variables are robust across the different spatial extents of application. The visualizations and spatial distribution of the aggregated ROS classification are presented in Figs. 3, 4, and 5. Percentages of ROS classification at each spatial extent are provided in Table 6.

3.2. ROS classifications by spatial extent

3.2.1. Statewide

As shown in Fig. 3, outdoor recreation opportunities provided across all public lands in Utah are predominantly (49.3%) classified as H₄ (more natural settings with less managerial presence and little use). The vast majority of these lands are managed by the Bureau of Land Management, which manages the greatest proportion (43.5%) of public

Table 3
Data and measurements related to the ROS framework.

| ROS Setting Characteristic | Variables | Data Sources | Descriptions | Measurements |
|----------------------------|---------------------------|---|---|--|
| Biophysical | Naturalness | <i>OpenStreetMap (OSM)</i> | A spatial layer of built environment | Proportion of built environment in each grid cell ^a . |
| | Remoteness | <i>OpenStreetMap (OSM)</i> | A spatial layer of paved road | Total length of paved road in each grid cell. |
| Managerial | Campsites | <i>OpenStreetMap (OSM)</i> | A spatial layer shows campsites (fee required). | Number of campsites (fee required) in each grid cell. |
| | Dump/sanitary stations | <i>OpenStreetMap (OSM)</i> | A spatial layer shows all dump/sanitary stations on Utah's public lands. | Amount of dump/sanitary stations in each grid cell. |
| | Showers | <i>OpenStreetMap (OSM)</i> | A spatial layer shows all showers on Utah's public lands. | Number of showers in each grid cell. |
| | Toilets | <i>OpenStreetMap (OSM)</i> | A spatial layer shows all toilets on Utah's public lands. | Number of toilets in each grid cell. |
| | Drinking water | <i>OpenStreetMap (OSM)</i> | A spatial layer shows availability of drinking on Utah's public lands. | Availability of drinking water in each grid cell. |
| | Trailheads | <i>OpenStreetMap (OSM)</i> | A spatial layer shows all the accessible trail heads on Utah's public lands. | Number of trailheads in each grid cell. |
| | Parking lots | <i>OpenStreetMap (OSM)</i> | A spatial layer shows all parking lots on Utah's public lands. | Amount of parking lots in each grid cell. |
| Social | Visitation density (PUDs) | <i>Flickr (2006—2014) and Panoramio (2006—2014)</i> | A rasterized layer shows visitation level to Utah's public lands. | Amount of visit in each grid cell. |
| | Population density | <i>Socioeconomic Data and Applications Center (Center for International Earth Science Information Network - CIESIN - Columbia University, 2018)</i> | A rasterized layer shows population density in a 50 km range near public lands. | Amount of population in a 50 km proximity of each grid cell. |

Note. We excluded several indicators (e.g., distinct types of land cover, managing agency, etc.) that do not follow the internal logic of the ROS framework whereby settings can be arrayed along a continuum from more to less natural (biophysical), more to less intensively managed (managerial), and more to less used (social). Future research and applications of our approach may find some of these variables worth exploring given the unique need of the application. However, for our analyses we utilize indicators that are applicable in all applications.

^a Built environment is a combined spatial layer that includes commercial, residential, and industrial development as defined in the Open Street Map (OSM) land use and landcover database.

lands within the state (Smith & Miller, 2020). More natural settings with less managerial presence and heavy use (H₃) are also relatively common across the state, occurring on 43.4% of the state's public lands. These opportunities occur on more accessible and urban-proximate lands managed by both the Bureau of Land Management and the USDA Forest Service. This pattern can be seen around the rapidly growing southwestern region, and along Interstate 15 which stretches up the center of the state (Fig. 3). Intensely managed, more natural settings with heavy use (H₁) tend to be concentrated in outdoor recreation and tourism 'hotspots' throughout the state (Zhang et al., 2021). This pattern can be seen in the concentration of H₁ classified public lands in the state's five national parks and in the heavily visited and intensely managed ski resorts located in the Wasatch Mountains east of Salt Lake City (Fig. 3). Less-natural settings with little to no management presence only occur rarely, on 1.69% of public lands throughout the state. These areas are dispersed but tend to be located at scenic viewpoints located on major transportation routes and along scenic byways (Fig. 3). Intensely managed, less-natural settings with heavy use (H₆) are also relatively rare (occurring on only 1.0% of the state's public lands). These areas, like those classified as H₁ are within the high-volume traffic areas of national parks (e.g., Zion Canyon) as well as in high-volume traffic areas near outdoor recreation hotspots (e.g., Bureau of Land Management lands surrounding Moab); they are also concentrated in heavily visited and developed settings within national forests (e.g., ski resorts).

3.2.2. Regional

At the regional extent, Fig. 4 shows the ROS classification for the southwestern region of the state. The spatial distribution of classifications is similar, by in large, to the patterns seen across the state as a

whole. Nearly a majority of the region's public lands (47.33%) are classified as more natural with little to no management presence and low use (H₄). Most of these areas occur in the eastern half of the state and are predominantly managed by the Bureau of Land Management and the USDA Forest Service. Nearly as much of the region's public lands (43.3%) are classified as H₃, more natural with little management presence and high levels of use. These areas occur closer to cities, towns, and transportation corridors relative to those classified as H₄, suggesting urban proximity is associated with higher use levels which would be expected. Nearly 4% of the region's public lands are classified as more natural, with more of a managerial presence and high levels of use (H₁). These areas occur primarily within Bryce Canyon National Park and Cedar Breaks National Monument (Fig. 4). The other ROS classifications were less common (<2% of the region's public lands). There is a concentration of H₂ settings along the Hole in the Rock Road located in eastern Kane County. These areas are characterized as more natural, with more managerial presence, and relatively little use. The Zion Canyon corridor within Zion National Park is classified as less-natural, with more of a managerial presence, and heavy use (H₆). This classification of public land also occurs in locations adjacent to cities and towns throughout the region (e.g., around St. George).

3.2.3. Local

The ROS classification of the Salt Lake Ranger District shows a distinct pattern. More natural settings with little use (H₄) are concentrated in areas further away from metropolitan areas with the Central Wasatch mountains above Salt Lake City being classified as either more natural settings with more managerial presence and heavy use (H₁) or more natural settings with less managerial presence and heavy use (H₃).

Table 4
Descriptive statistics for each of the three spatial extents examined.

| ROS Characteristic | Statewide | | | Southwestern Utah ¹ | | | Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest | | |
|--|-----------|------------------------|-----------|--------------------------------|--------------------------|-----------|--|----------------------------------|------------|
| | Total | Mean (range) | Std. Dev. | Total | Mean (range) | Std. Dev. | Total | Mean (range) | Std. Dev. |
| Biophysical | | | | | | | | | |
| Built Environment (km ²) | 6.67 | 0.03 (0–0.46) | 0.07 | 1.5 | 0.00 (0–0.43) | 0.01 | 0.24 | 0.00 (0.14–0.24) | 0.01 |
| Proportion of built environment in each cell (%) | | 0.04 (0–100.00) | 1.37 | | 0.01 (0–7.16) | 0.2 | | 1.36 (0–100.00) | 10.54 |
| Road density (km) | 6,457.86 | 0.01 (0–5.24) | 0.15 | 1313.40 | 0.02 (0–5.23) | 0.19 | 53.68 | 0.03 (0–2.56) | 0.26 |
| Managerial | | | | | | | | | |
| Campsites | 1,062 | 0.09 (0–117) | 1.72 | 177 | 0.07 (0–51) | 1.57 | 112 | 1.02 (0–24) | 3.91 |
| Dump/sanitary stations | 121 | 0.01 (0–34) | 0.48 | 31 | 0.01 (0–31) | 0.63 | 3 | 0.03 (0–3) | 0.29 |
| Showers | 154 | 0.01 (0–42) | 0.56 | 20 | 0.01 (0–19) | 0.39 | 3 | 0.03 (0–3) | 0.29 |
| Toilets | 473 | 0.04 (0–42) | 0.86 | 57 | 0.02 (0–20) | 0.6 | 48 | 0.44 (0–21) | 2.40 |
| Drinking water | 325 | 0.03 (0–28) | 0.66 | 41 | 0.02 (0–20) | 0.56 | 63 | 0.57 (0–24) | 3.24 |
| Trailheads | 65 | 0.01 (0–3) | 0.09 | 17 | 0.01 (0–2) | 0.09 | n/a | n/a | n/a |
| Parking lots | 6,961 | 0.57 (0–166) | 4.69 | 1,727 | 0.71 (0–166) | 5.53 | 559 | 5.08 (0–88) | 13.60 |
| Social | | | | | | | | | |
| Visitation density (PUDs) | 102,098 | 8.39 (0–2,450) | 56.45 | 35,015 | 14.30 (0–2,450) | 87.14 | 4,759 | 43.26 (0–749) | 96.18 |
| Population density (50 km) | 5,026,028 | 6,083 (0–1,002,401) | 18,710.93 | 837,671 | 85,585.57 (0–304,105) | 73,067.89 | 2,812,516 | 565,644.80 (70,504–1,002,401) | 329,304.00 |

Note. Data are aggregated or calculated across 5 km hexagonal grid cells, n = 12,169.

¹ Defined as the four-county region comprised of Garfield, Kane, Iron, and Washington counties.

Table 5
Results of the principal components analysis for setting classification for each of the three spatial extents examined.

| ROS Characteristic | Statewide | Southwestern Utah ¹ | Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest |
|----------------------------|-----------|--------------------------------|--|
| Biophysical | | | |
| Built Environment | 0.71 | 0.71 | 0.71 |
| Road density (km) | 0.71 | 0.71 | 0.71 |
| Proportion of variance (%) | 52.07 | 51.66 | 51.01 |
| Managerial | | | |
| Campsites | 0.61 | 0.70 | 0.71 |
| Trailheads | 0.38 | 0.07 | n/a |
| Parking lots | 0.70 | 0.71 | 0.71 |
| Proportion of variance (%) | 44.79 | 55.67 | 64.89 |
| Social | | | |
| Visitation density (PUDs) | 0.71 | 0.71 | 0.71 |
| Population density | 0.71 | 0.71 | 0.71 |
| Proportion of variance (%) | 53.11 | 50.65 | 67.84 |

¹ Defined as the four-county region comprised of Garfield, Kane, Iron, and Washington counties.

4. Discussion

4.1. The generalized model for defining and mapping recreation opportunities

As noted above, the ROS has almost exclusively been used to

establish classifications at a single spatial extent (e.g., a field office or ranger district). Our model allows for the rapid development and evolution of ROS classifications at a variety of spatial extents. This utility is needed as there are a variety of different agencies, offices, and interests involved in planning for, developing, or managing outdoor recreation settings. These entities work within, and across, a variety of spatial extents, including the ones used as examples here.

At the state-level, state offices or divisions of outdoor recreation are becoming increasingly involved in the disbursement of state funds to develop outdoor recreation infrastructure (Sausser et al., 2019). State offices of tourism also play an active role in shaping where outdoor recreation happens within a state through their influential marketing campaigns (Drugova et al., 2020). Having statewide ROS classifications can enable organizations like these to think more strategically about where investments in outdoor recreation infrastructure are needed. Specifically, the ROS classification can be used to target investments in infrastructure to areas with heavy use and very little, if any, management presence (H₃ and H₈). Our application to the state of Utah shows these areas occur proximate rapidly urbanizing regions (namely the St. George area and the southern Wasatch Front) (Fig. 3). These areas also occur on the periphery of well-known outdoor recreation and tourism ‘hot spots’ (namely the greater Moab area). Focused investments in infrastructure would be warranted here to meet the existing demand for outdoor recreation and also to minimize environmental impacts that could happen without the appropriate infrastructure (Hammit et al., 2015).

At the regional level, ROS classifications can help land managers develop shared priorities that cross administrative boundaries. In our example from southwestern Utah, ROS classifications are not randomly distributed. More natural settings with less of a management presence are concentrated in the eastern half of the region in areas managed by the Bureau of Land Management. Areas with more management presence and visitor use are concentrated in the western half of the county, particularly in and around Bryce Canyon and Zion National Parks.

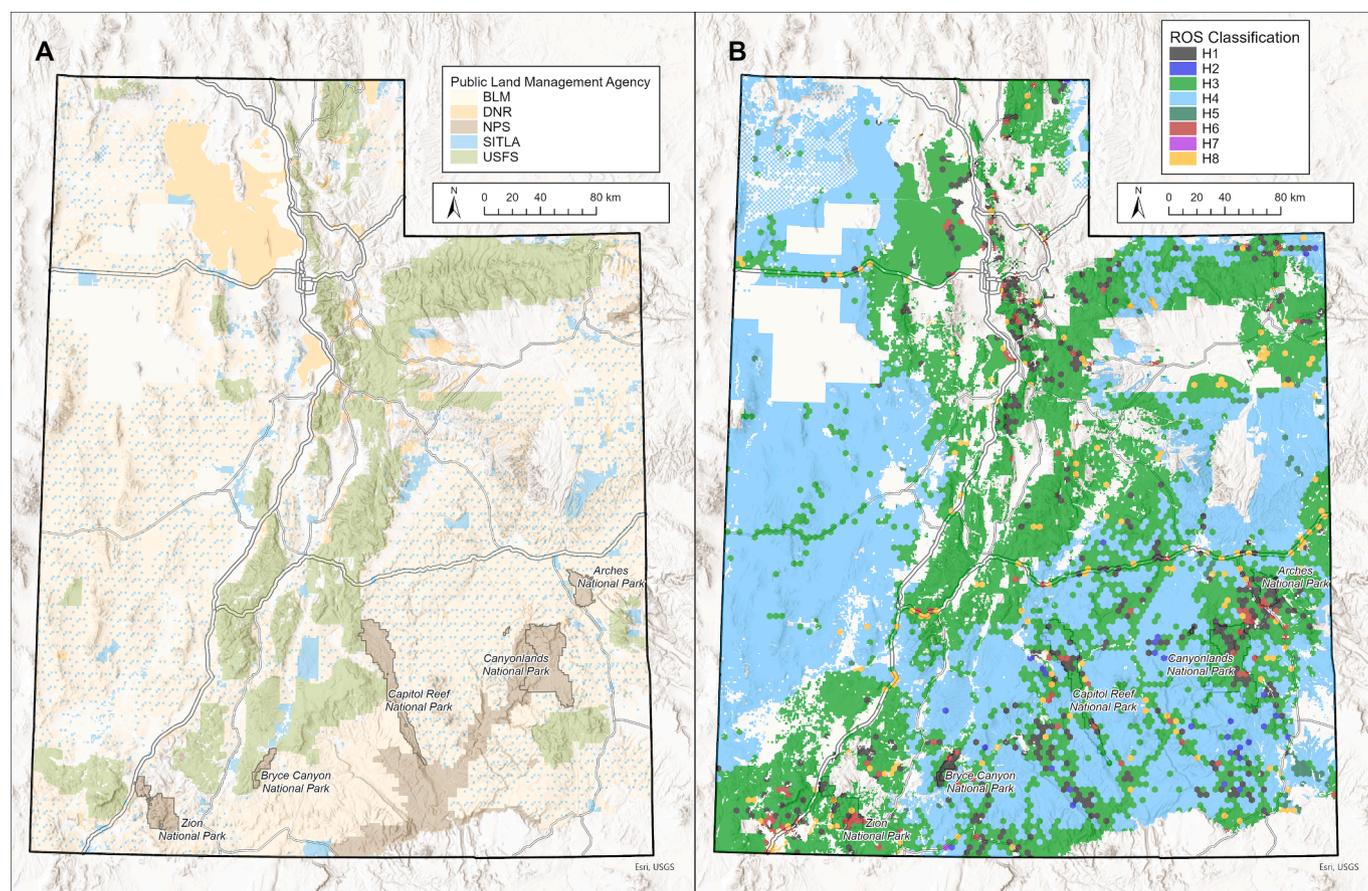


Fig. 3. Recreation opportunity spectrum (ROS) classifications for all public lands in Utah.

Visualizing ROS classifications across administrative boundaries like this can help outdoor recreation planners and managers see if outdoor recreation planning and management decisions within their particular administrative unit are needed given the regional scope of outdoor recreation opportunities that are provided. The managers of the Dixie National Forest, for example, may be more inclined to monitor use for possible increases in demand and associated environmental impacts knowing Bureau of Land Management lands between the forest and sprawling municipalities have relatively high use levels (i.e., H₁, H₃, H₆, or H₈) (Fig. 4, Panel B).

ROS classifications can be similarly useful at the local level, as they can be used to guide investments in capital improvement projects as well as inform more routine management efforts. Our application to the Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest revealed a clear differentiation between the heavily used and heavily managed Central Wasatch (H₁ and H₃) and the lesser used and lesser managed Stansbury Mountain Range (H₂ and H₄). Knowing this, the ranger district's outdoor recreation planners and managers would be well served to ensure any investments in infrastructure within areas classified as H₁ or H₃ preserve opportunities for activities with low visitor use densities (e.g., backcountry hiking and camping). These areas may experience an increase in use if outdoor recreationists who typically use the Central Wasatch become displaced due to crowding.

The management implications noted here are just a few of the ways ROS classifications can be used in a proactive manner to guide the decisions of outdoor recreation planners and managers. We have provided guidance for each of the ROS classifications in Table 1. These management implications are intended to provide initial guidance for planners and managers using the model to differentiate between outdoor recreation settings that provide different types of outdoor recreation opportunities. When the model is applied across administrative boundaries,

this initial guidance can help align management objectives. This can lead to a system of public lands that provide complimentary outdoor recreation opportunities and reduce the burden of managers and planners thinking they must provide all types of outdoor recreation opportunities across all the lands they manage.

4.2. Limitations and future research

Although our data-driven and generalizable model provides a consistent method that can be used by different agencies to define and quantify ROS classifications at different extents, we are aware of several limitations associated with the use of free and publicly available data worth noting.

First, implementing our model requires skilled personnel with the capacity to understand statistical programming software (e.g., R). Training and hiring personnel with these skills can be costly to federal agencies, state legislatures, regional planning initiatives, and other public land management agencies. To mitigate this concern, and to make the model more accessible and ease adoption, we have made all data and code used to conduct the analysis demonstrated here publicly available at a persistent DOI (Zhang & Smith, 2023).

Second, the use of social media data to estimate outdoor recreation and tourism use has been met with skepticism by some (see Wilkins et al. (2021) for a detailed review). Primarily among these concerns is the ability of social media to represent the many types of visitors to public lands. Social media users are more likely to be younger, more educated, and have higher incomes relative to non-users (Heikinheimo et al., 2017). Another concern is that social media, aggregated across multiple years as we have done here, presents only a cross-sectional depiction of the social characteristics of recreation settings. Future work could explore the possibility of taking advantage of the temporally-dynamic

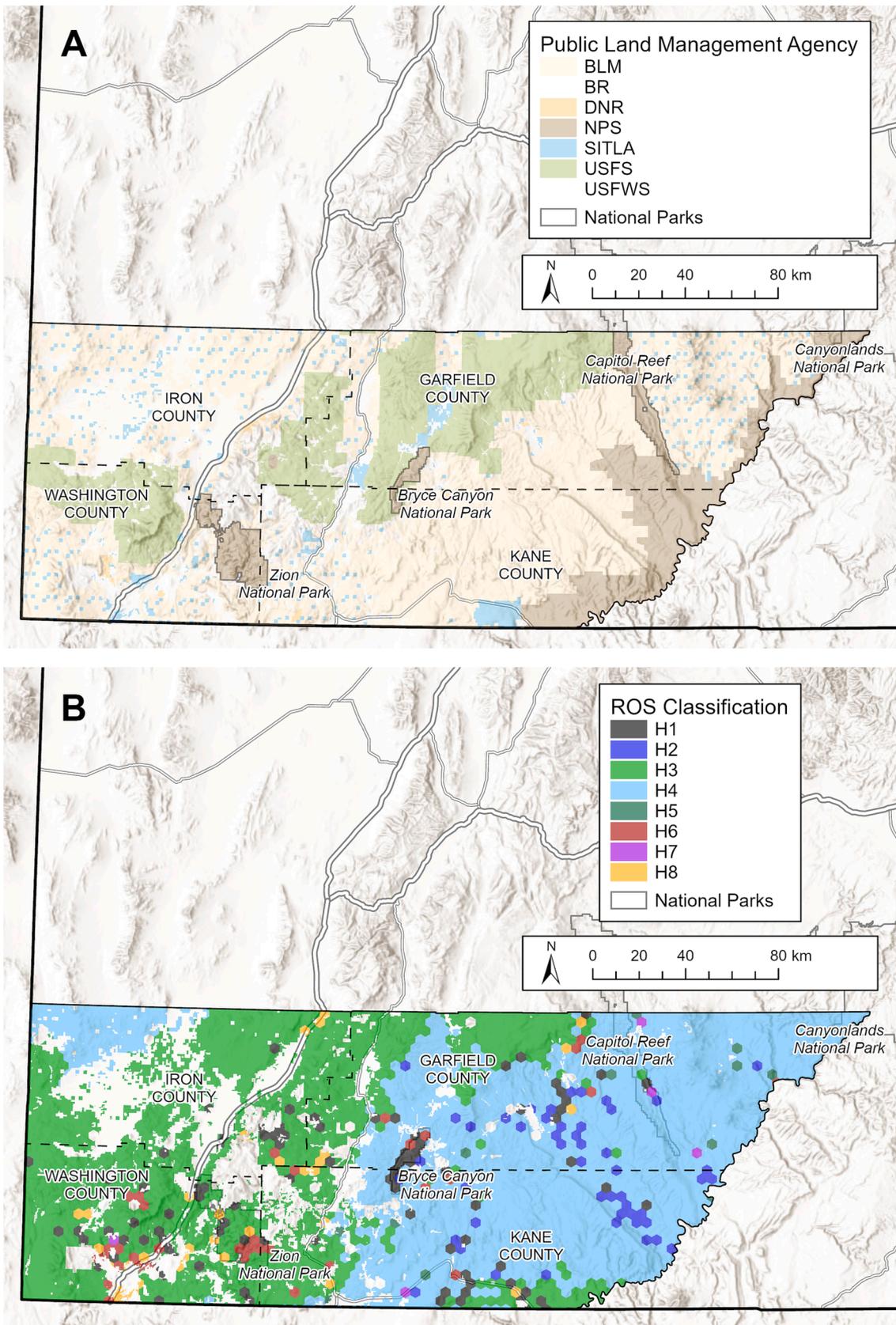


Fig. 4. Recreation opportunity spectrum (ROS) classifications for Southwestern Utah (Defined as the Four-county Region Comprised of Garfield, Kane, Iron, and Washington Counties).

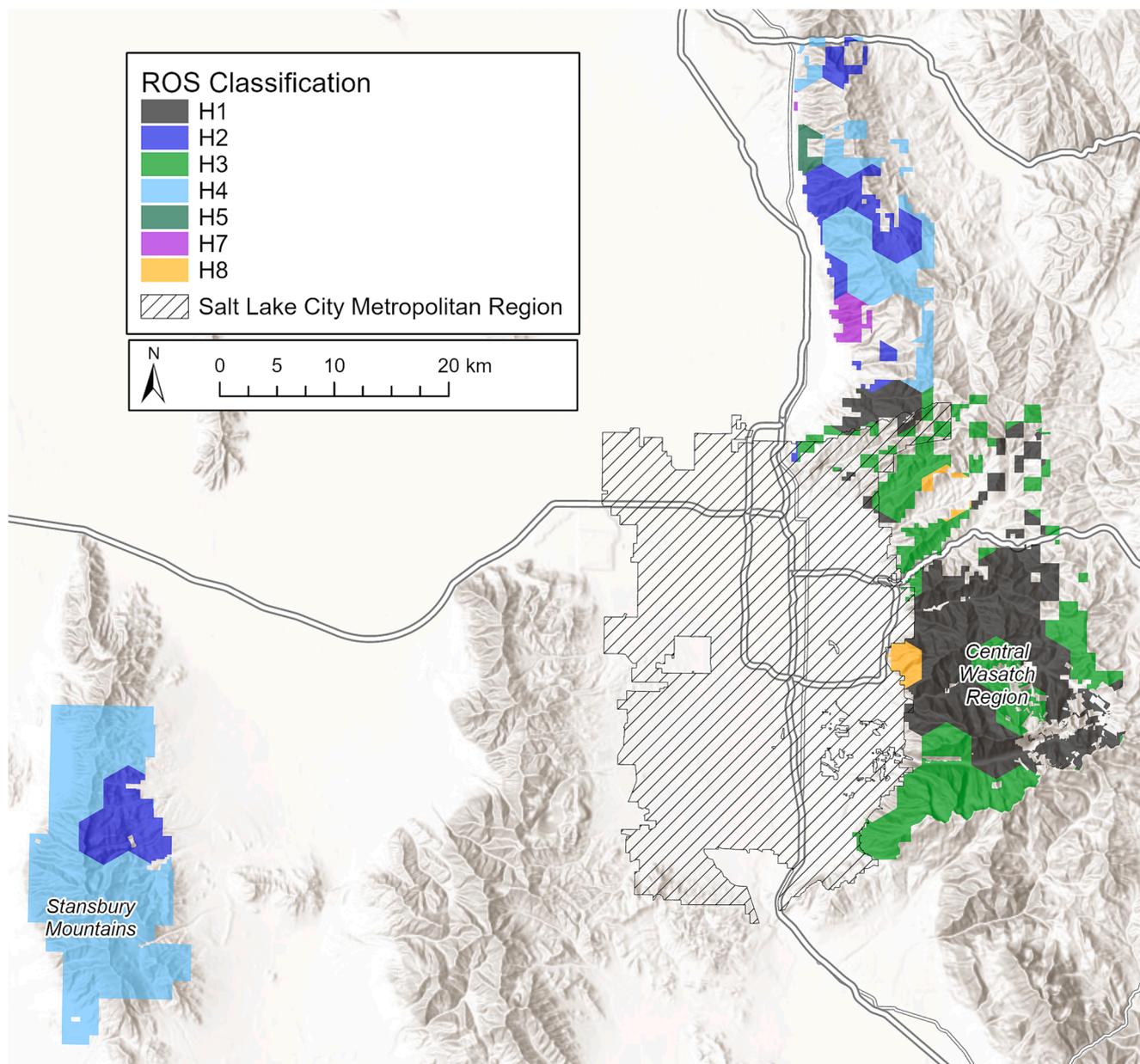


Fig. 5. Recreation Opportunity Spectrum (ROS) Classifications for the Salt Lake Ranger District.

nature of social media to generate seasonal, and possibly even predictive, estimates of visitor use; this line of research has made notable advances in recent years (e.g., Wilkins, Chikamoto, et al., 2021). Despite these limitations, previous work has demonstrated social media provide a relatively good indicator of the overall number of recreation visits occurring on public lands (again see Wilkins et al. (2021)). Specific to our application, Zhang et al. (2021) found social media captured approximately 70% of the variation in recreational visits to national parks, national forests, and state parks within Utah.

The third limitation of this study is the quality (i.e., positional accuracy, completeness, logical consistency, thematic and temporal accuracy, etc.) of free and publicly available data. OpenStreetMap is a crowdsourced data curation project where registered contributors can create and edit the project’s geospatial data (openstreetmap.org). Because OpenStreetMap data are user generated, their quality varies as well. Existing literature suggests the quality of OpenStreetMap data is heterogeneous across space (Minghini & Frassinelli, 2019). Given this, we encourage those applying our model to their own regions, forests, or

field offices, to verify the quality of OpenStreetMap data with authoritative data if they exist.

Fourth, our model focuses specifically on terrestrial outdoor recreation settings. This was a deliberate decision given the vast majority of outdoor recreation settings in the state are land-based. As a result, we are unable to say much about the spatial distribution of water-based outdoor recreation settings. Future research efforts could extend the model developed here to water-based systems by identifying the variables and associated metrics that best characterize a wide-variety of water-based recreation areas (e.g., remoteness may be measured by distance to shore and managerial variables may include variables such as fueling stations and marinas). An extension of this work along these lines would be consistent with the long tradition of extending the ROS to unique case studies (see Manning (2022) for a review of the many unique extensions of the ROS framework).

More generally, future research can certainly refine and adapt the model we have developed and presented here. New data sources will become available, and these should be integrated into the model in an

Table 6
Percentages of setting classifications for each of the three spatial extents examined.

| Setting Classification | Description | Statewide | Southwestern Utah ¹ | Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest |
|------------------------|--|-----------|--------------------------------|--|
| H ₁ | More natural settings with more managerial presence and heavy use | 3.92 | 3.80 | 20.00 |
| H ₂ | More natural settings with more managerial presence and little use | 0.25 | 1.96 | 10.00 |
| H ₃ | More natural settings with less managerial presence and heavy use | 43.41 | 43.28 | 28.18 |
| H ₄ | More natural settings with less managerial presence and little use | 49.33 | 47.33 | 36.36 |
| H ₅ | Less-natural setting with less management presence and little use | 0.43 | 0.53 | 1.82 |
| H ₆ | Less-natural setting with more managerial presence and heavy use | 0.95 | 1.39 | 0.00 |
| H ₇ | Less-natural setting with more managerial presence with little use | 0.01 | 0.20 | 1.82 |
| H ₈ | Less-natural setting with less managerial presence and heavy use | 1.69 | 1.51 | 1.82 |

¹ Defined as the four-county region comprised of Garfield, Kane, Iron, and Washington Counties.

exploratory fashion. In addition to use of new data sources, analysts may find it useful to integrate specific variables that are useful in the context of their own application. For example, accessibility and the connection to public transportation systems may be an indicator of the biophysical characteristics of urban-proximate outdoor recreation settings (Komossa et al., 2020; Larson et al., 2018). We also suggest future research applying our model considers “ground truthing” with land managers to determine if the classifications derived from the model align with their experiences managing those landscapes; this will be an important step to confirm the accuracy and replicability of the model.

5. Conclusion

Our scientific understanding of how to best provide and manage outdoor recreation settings has begun to follow the broader trend across

the social sciences in which new, large, and often spatial datasets are used to address standing challenges within the field. For example, social media have been used to gauge the use and spatial distribution of visitation to public lands (e.g., Toivonen et al., 2019; Van Berkel et al., 2018; van Zanten et al., 2016; Wilkins et al., 2021; Wood et al., 2013). New data sources and analytical methods are also allowing researchers to quantify the outdoor recreation potential of landscapes (Komossa et al., 2018), which is purposefully similar to using the ROS framework to quantify recreation opportunities. Our data-driven and generalizable model capitalizes on the seemingly ubiquitous availability of data and leverages it to reconsider one of the most foundational resource management frameworks used by park and protected area managers around the world.

The model was purposefully constructed to ensure it could be reproduced across geographic locations and landscapes similar to Utah, USA. All data come from free and open-source datasets. Assembling the model in this way obfuscates previous limitations of the ROS framework, namely that it was informed primarily by the beliefs and perceptions of recreation planners and other managers. The use of free and open-source datasets can also help ensure management plans are developed through a transparent and replicable process. Addressing the “replication crisis” and supporting the “credibility revolution” are cornerstones of the movement towards open, accessible, and replicable science (Engzell & Rohrer, 2020). Our generalizable model can ameliorate the variability in how ROS classifications are developed, leading to more consistent classifications across land management units and agencies. As the data used in the model are available worldwide, developing a standard approach for classifying outdoor recreation opportunities is possible.

We have developed a model that can define and quantify ROS classifications at multiple spatial extents. The model is structured around the same three setting-characteristics (biophysical, managerial, and social) that have proven themselves as an integral component of numerous outdoor recreation and tourism planning efforts worldwide. Our model’s analytical workflow yields discrete ROS classifications unique to the spatial extent to which it is being applied (e.g., statewide, across an entire national forest, across just a ranger district, etc.). The model is also flexible across different applications. For each application shown here, we demonstrated how the model can yield meaningful characterizations of the outdoor recreation opportunities provided across the landscape. These extent-specific ROS characterizations are useful to distinct types of audiences (e.g., state legislatures, regional collaborative initiatives, and land management agency line officers). Importantly, we have also demonstrated how these classifications can be used in a prescriptive, as opposed to descriptive, way. The model can serve as a catalyst capable of unifying disparate visitor use management frameworks around common data, and a common model, for classifying the distinct types of wildland recreation settings upon which outdoor recreation opportunities depend.

6. Author note

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

I have shared the link to our data/code in the body of the manuscript.

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