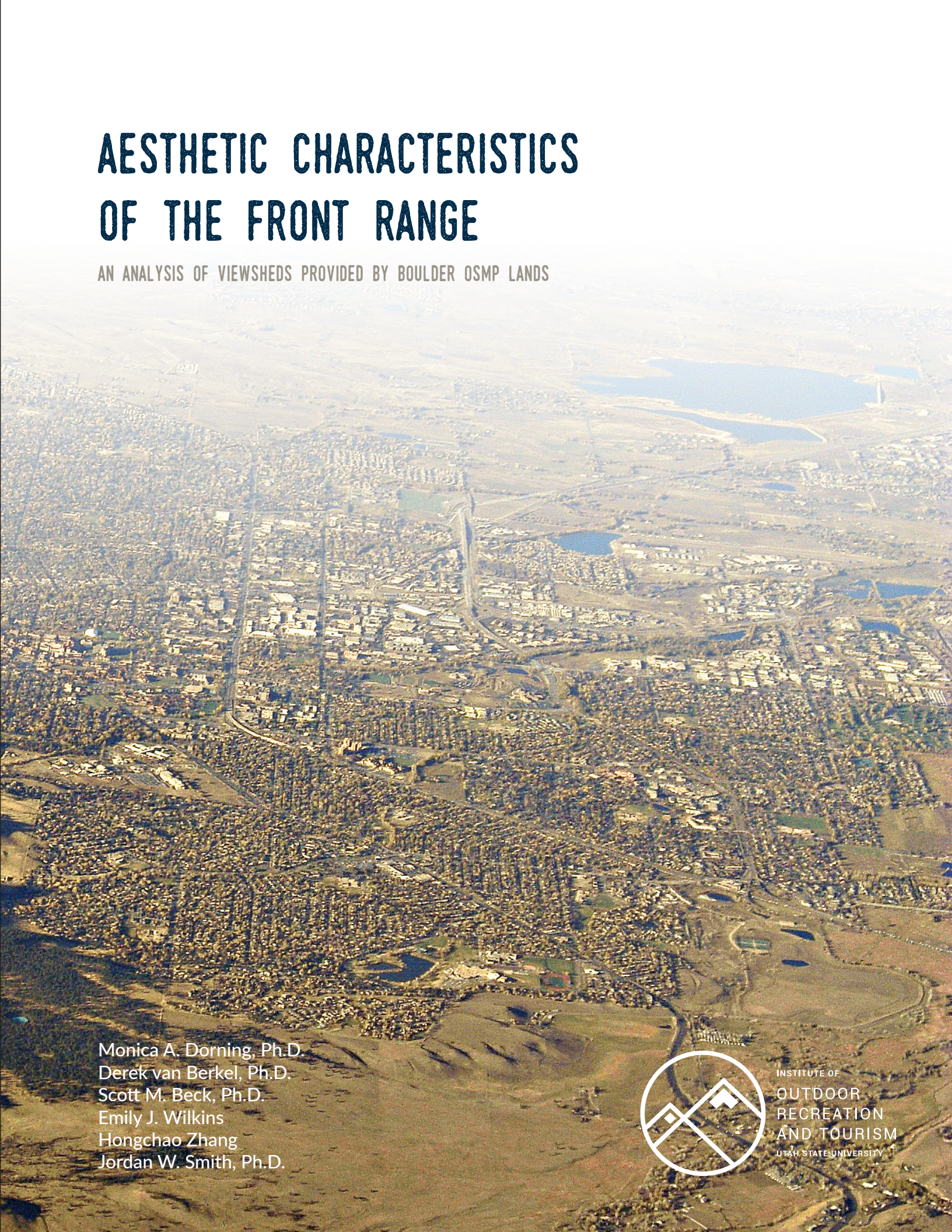
AESTHETIC CHARACTERISTICS OF THE FRONT RANGE

AN ANALYSIS OF VIEWSHEDS PROVIDED BY BOULDER OSMP LANDS



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PREPARED FOR

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INTRODUCTION

Research Aim

The city of Boulder's Open Space and Mountain Parks (OSMP) lands offer residents and visitors a variety of unique recreational, scenic, and cultural experiences that are often captured and shared publicly via social media. Given the diversity of OSMP lands, visitor experiences likely differ based on the aesthetic and biophysical features that can be viewed from these landscapes. For instance, the peaks of the iconic Flatirons provide visitors with different scenic views than the low-lying grasslands in the southeastern area of the city. Furthermore, visitor use and enjoyment of OSMP lands could be directly related to the landscape features that are visible from these different locations. Understanding how visible landscape features vary across OSMP lands can help managers target their planning efforts to improve the quality of outdoor recreation experiences, and potentially identify new locations for outdoor recreation infrastructure (e.g., trails, pavilions, etc.) that offer the ability to see the regions most desirable landscape features. The goals of this study were to: (1) identify points in the landscape where users are often inspired to take photographs; (2) map the landscapes most often viewed by visitors; (3) summarize the types of landscape features viewed from OSMP lands; and (4) determine how these landscape features vary across LCAs. We assume photographs taken from OSMP lands are a good indication of the aesthetic preferences of visitors.

The findings presented in this report are part of a larger project, Identifying the Benefits of Cultural Resources and Iconic Views Through Social Media, which identifies visitors aesthetic preferences for landscape features on OSMP lands using photographs posted to social media. In our initial report, Landscape Values and Aesthetic Preferences Across the Front Range, we summarized OSMP users' preferences for different landscape features using data collected through an on-site questionnaire (Wilkins et al., 2018).

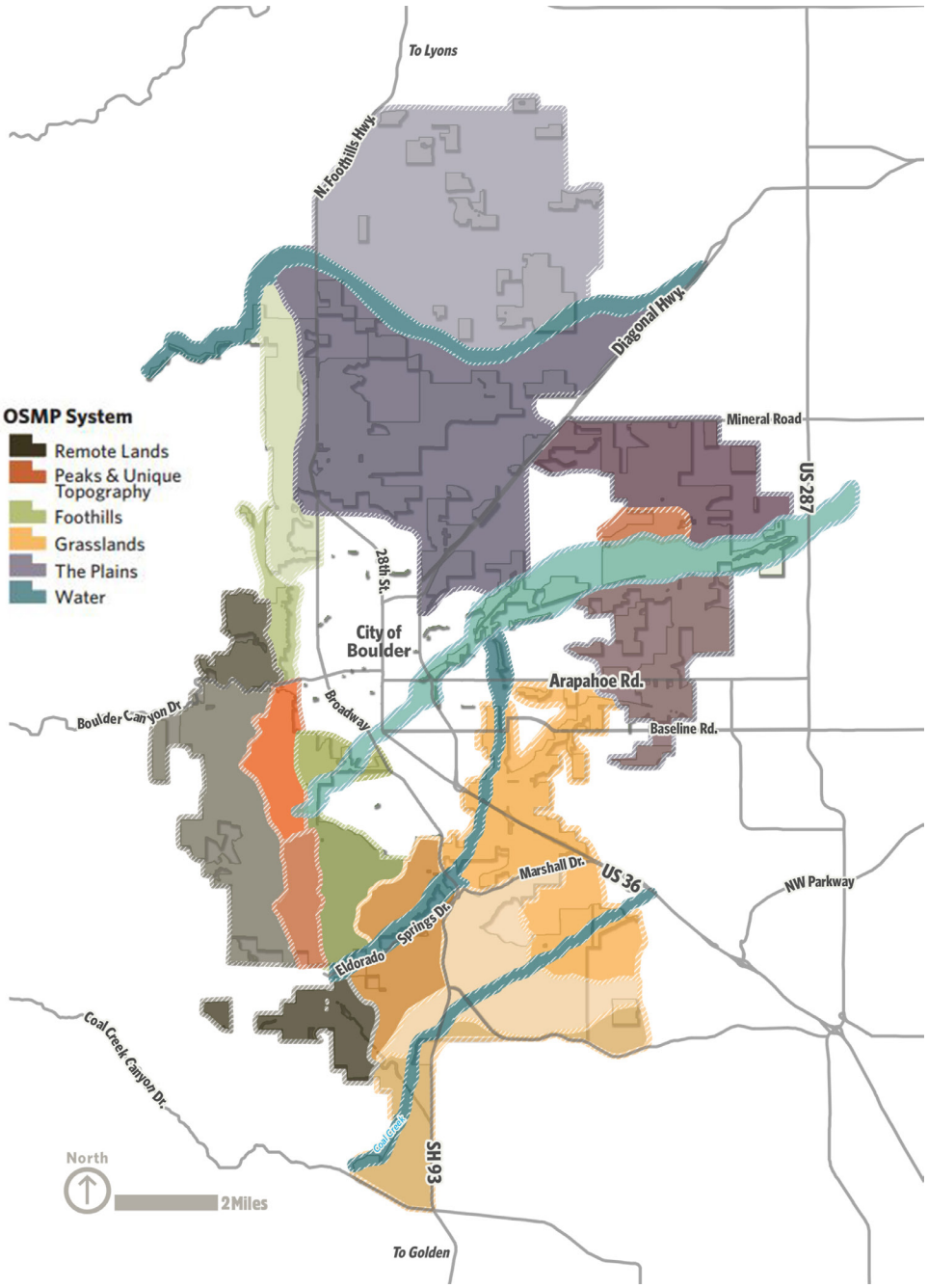

Figure 1. The six distinct Landscape Character Areas of Boulder Open Space and Mountain Parks lands.

The findings detailed in the initial report provide additional context to those reported here, which detail the spatial heterogeneity in preferences for landscape features using photographs posted to social media.

Study Area

Boulder OSMP lands provide valuable cultural ecosystem services to the public, serving as places for recreation, relaxation, and inspiration. Scenic landscapes, like those managed by OSMP, improve overall psychological and emotional well-being and contribute to physical health through opportunities for exercise (e.g., Dorning, van Berkel, & Semmens, 2017; Seresinhe, Preis, & Moat, 2015; Tieskens et al., 2017; van Zanten et al., 2016). Boulder OSMP managers have identified six distinctive landscape character areas (LCAs) within their jurisdiction (Figure 1). These include: 1) Foothills; 2) Peaks and Unique Topography; 3) Grasslands; 4) Plains; 5) Remote Lands; and 6) Water. We use these LCAs to frame our analysis. Doing so allows us to determine if visitors derive different benefits from Boulder OSMP lands, depending upon which type of area they choose to visit.

METHODS

Social Media Photographs

To assess the aesthetic preferences of visitors to OSMP lands, we collected all geotagged photographs uploaded to Flickr (years 2004-2018) and Panoramio (years 2005-2015) for the area. Geotagged photographs from these platforms are publicly available through each platform's application programming interface (API). We were able to mine the coordinates, photograph urls, and captions included in all posts made from Boulder OSMP lands. Platform-specific algorithms were written in Python to obtain 28,969 and 712 photographs from Flickr and Panoramio, respectively. In this report, we solely focus on the Flickr data due to the much larger sample provided by that platform. The densities of photos

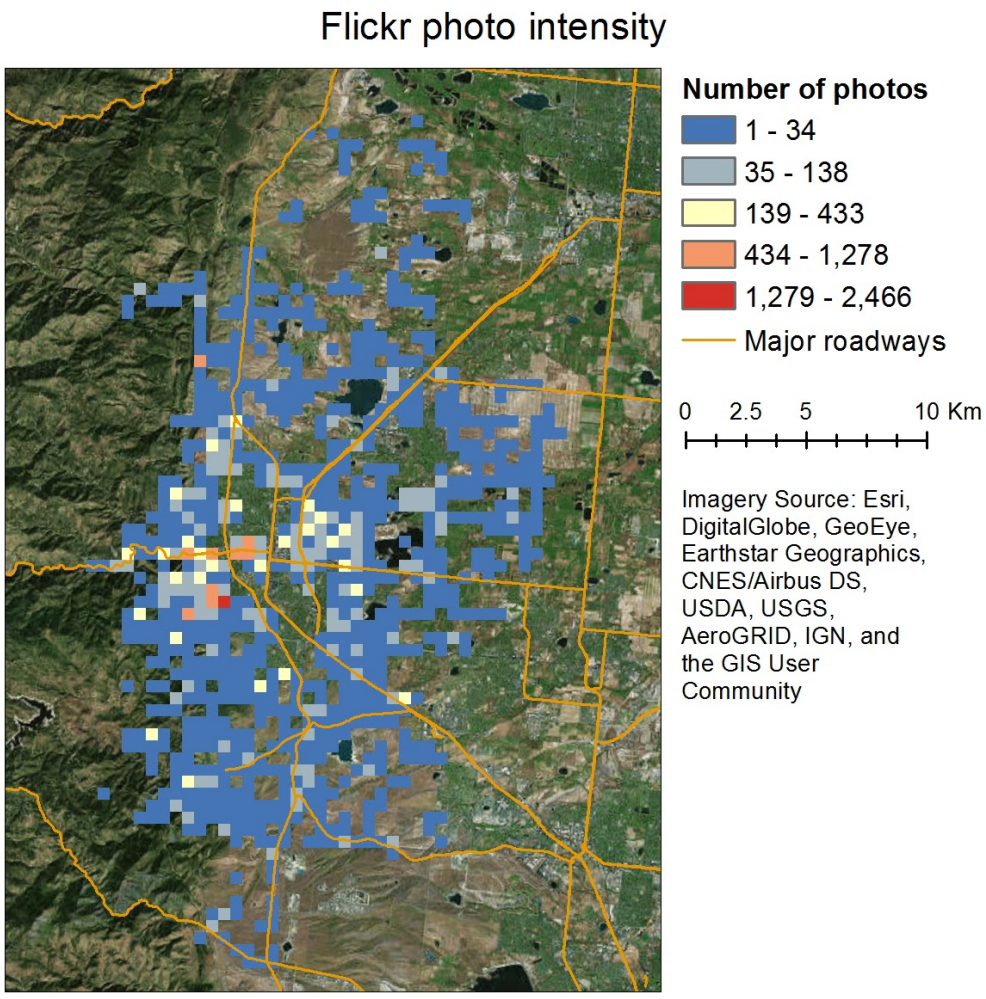

Figure 2. Density of photos posted to the Flickr platform.

taken at different locations provide a good indication of popular areas for landscape photography, outdoor recreation, and accessible iconic features on OSMP lands (Van Berkel et al., 2018). The densities of photos taken across OSMP lands are shown in Figure 2. Further analysis of the viewsheds visible from the location where each photograph was taken, as well as the photographic content of each photograph, can provide additional information about the features users value.

Viewed Landscapes

To identify the landscape features visible from locations that are being used by visitors to OSMP lands, we constructed individual viewsheds for each photo location using the coordinates of the social media photographs and a digital surface model (DSM). A viewshed is the 360° area that is visible from a discrete location (Figure 3). It includes all the surrounding area within the line-of-sight of an assumed viewer's location and excludes points that are obstructed by the terrain and other features. We were able to identify only the landscape features visible to the individual or group taking the photograph by using the DSM, which accurately represents the landscape elements that obscure visibility (e.g., buildings, trees and mountains for calculating viewsheds). Viewshed calculations were based on an assumed human height of 1.6 m (5 ft 3 in). For this stage of the analysis, we chose a max viewing range of 5 km to represent the visible environment. All mapping and LiDAR calculations were completed using GrassGIS (Neteler & Mitasova, 2008). Viewshed calculations were automated using a Python script. While the photograph itself may not capture the full 360° view, the viewshed area provides a depiction of the landscape visible to the photographer when they are taking a photograph.

To identify the most aesthetically pleasing locations within and adjacent to OSMP Lands, we aggregated all individual viewsheds of Flickr photographs (Figure 4). These aggregated maps represent the number of times a specific point on the landscape was viewed from all photographed locations; we refer to this measure as viewshed intensity. The viewshed intensity measure is an indicator of visitors' preferences for that point (i.e., its scenic value). In addition to identifying the most aesthetically pleasing locations (viewshed intensity) visible from OSMP lands, we also identified the most aesthetically pleasing locations visible just to OSMP trail users. We did this by restricting our analysis of viewshed intensity to photographs taken on OSMP trails. We defined these areas as official OSMP trails plus a 30 m buffer on either side. The most aesthetically pleasing locations visible just to users of OSMP trails are shown in Figure 4.

To statistically compare the viewshed intensities of each LCA, we sampled 100,000 random points within the area visible from OSMP trails. We collected the viewshed intensity value for each randomly sampled point and classified these points by their LCA. We then compared the viewshed intensities of each LCA, allowing us to determine if there are statistically significant and meaningful differences in viewshed

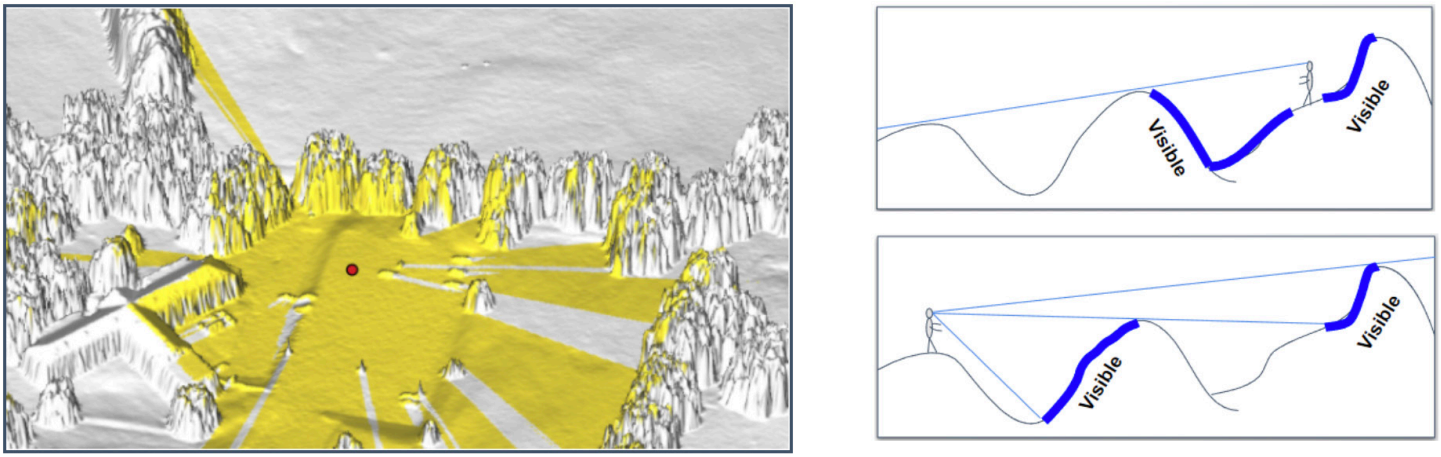

Figure 3. Viewsheds depict all visible locations from a discrete location.

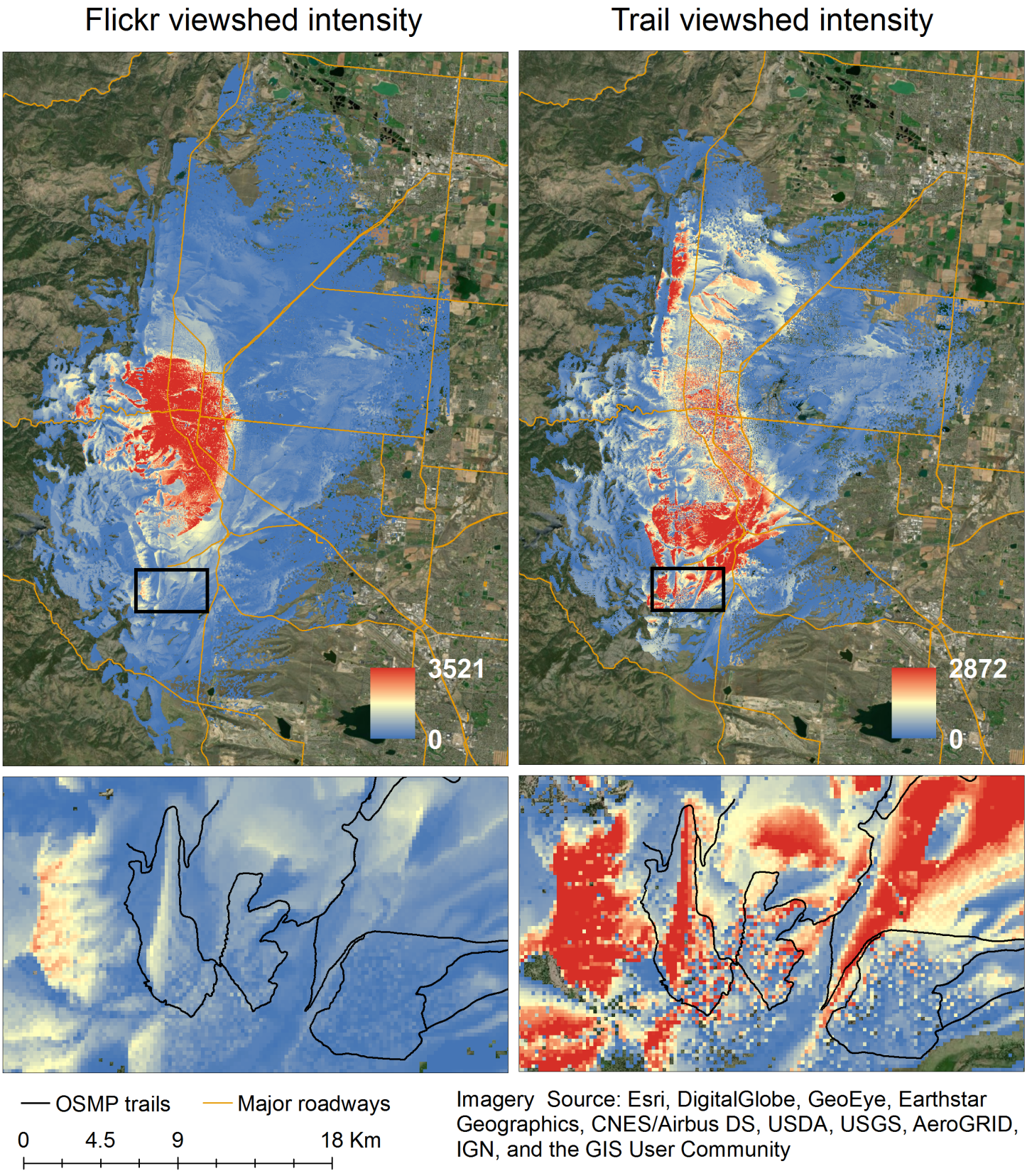

Figure 4. The aggregated viewsheds of Flickr photos (left), with the viewsheds from OSMP trails (right) shown for comparison, and inset windows identified. Insets (below) focus on the region surrounding the Spring Brook Loop trail. Viewshed intensity values represent the number of photo locations (or points on the trail) from which a location could be viewed.

intensity across the LCAs. Since some locations are visible from more locations in the landscape than others we conducted the same analysis using a normalized viewshed intensity value. Normalized viewshed intensity was calculated by dividing the viewshed intensity generated by social media photographs taken across all Boulder OSMP lands by the viewshed intensity generated by photographs just taken on OSMP trails. The normalization controls for landscapes that are photographed more due to their greater ability to be seen from OSMP trails.

We used the same 100,000 randomly sampled points to compare the land cover types that are most commonly viewed across each LCA. We overlaid the randomly sampled points with land cover data from the National Land Cover Database (NLCD), classifying each point according to its land cover type. We then compared the proportions of each land cover classification within each LCA. We similarly analyzed detailed vegetation data (OSMP vegetation) as a measure of the importance of these unique flora to OSMP visitors. This analysis gives us an indication of the importance of these unique flora for OSMP visitors (Appendix A). For this analysis, NLCD data were used to fill in areas where detailed vegetation data (i.e., the OSMP vegetation layer) were unavailable.

Photographic Content Analysis

To give an indication of photographic subject matter favored by visitors to OSMP lands, we analyze the content of each photograph using a machine learning algorithm. The algorithm provides textual descriptions of the features, activities, and landscape characteristicswithin each photograph. We analyzed these descriptions for each LCA, using them to create statistics which characterize the photographic content.

Trail Prominence

Finally, we measured the visual prominence of each OSMP trail by calculating the average viewshed intensity for all trails on OSMP lands. Again, we defined trail areas as official OSMP trails plus a 30 m buffer on either side. For each trail, we calculated the average viewshed intensity, normalizing this value by the total length of the trail. This corrects for biases toward longer trails which may be more likely to be visible from different locations across OSMP lands.

FINDINGS

Viewed Landscapes

There were statistically significant differences in viewshed intensity (Kruskal-Wallis chi-squared = 14,258, df = 5, p-value < 0.001) and normalized viewshed intensity (Kruskal-Wallis chi-squared = 8989.1, df = 5, p-value < 0.001) across the LCAs,

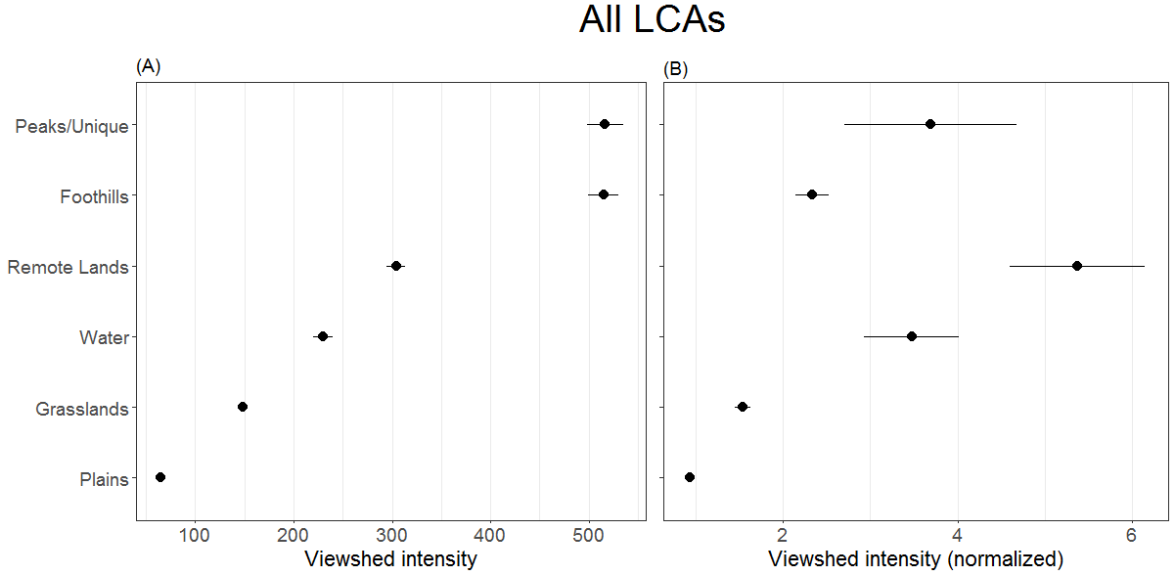

Figure 5. (A) Viewshed intensity for each LCA. (B) Normalized viewshed intensity (viewshed intensity / trail viewshed intensity) which controls for landscapes that are photographed more due to greater ability to view those landscapes from OSMP trails. Points represent the mean viewshed intensity for each LCA and lines show 95% confidence intervals based on 100,000 randomly sampled viewshed locations.

indicating some LCAs were more popular than others as the subject of photographs. The mean viewshed intensity was greatest within the Peaks and Unique Topography and Foothills LCAs (Figure 5A), indicating these landscapes were the most viewed by Flickr users on Boulder OSMP lands. However, landscapes in the Remote Lands LCA are distinctive, having the most views when controlling for visibility from OSMP trails (Figure 5B). After controlling for visibility from OSMP trails, landscapes in the Water LCA were viewed more frequently, and landscapes in the Foothills had fewer views. The Grasslands and Plains LCAs were the least frequently viewed LCAs overall. Based on these results, views of Remote Lands, Peaks and Unique Topography, Water, and Forested LCAs appear to be most popular among OSMP visitors.

There were statistically significant differences in viewshed intensity (Kruskal-Wallis chi-squared = 8,432.2, df = 7, p-value < 0.001) and normalized viewshed intensity (Kruskal-Wallis chi-squared = 6419.8, df = 7, p-value < 0.001) of different land cover classes visible across all Boulder OSMP lands; this indicates some land cover types were more popular than others as the subject of photographs. The overall mean viewshed intensity across all LCAs was greatest for forested landscapes (Figure 6A), indicating these landscapes were the most photographed by Flickr users visiting Boulder OSMP lands. Barren, shrubland, and developed landscapes were also popular. However, by controlling for the viewshed intensity from users of OSMP trails, it appears barren and shrubland landscapes may be more photographed due to their visibility (i.e., their spatial location on the landscape) rather than solely due to their aesthetic appeal (Figure 6B). Agriculture, herbaceous, and water land cover types were least frequently viewed overall. Based on these results, views of forested and developed landscapes appear to be particularly appealing to OSMP visitors, although viewshed intensity also varied depending on the LCA being photographed (Appendix X).

Photographic Content Analysis

Our analysis of photographic subject matter indicated there is high correspondence between image content and the characteristics that typify the different LCAs (Figure 7). For example, the Plains and Grassland LCAs had a high proportion of “grassland”, “prairie”, and “field” subject matter, while individuals took photographs of “waterways” and “water” in the Water LCA. Similarly, the subject matter of photos in the Remote Lands LCA was dominated by photographs depicting “mountains”, “rocks”, “hill stations,” and wilderness. This result lends support for the argument that social media photographs can be used as a valid indicator of landscape character.

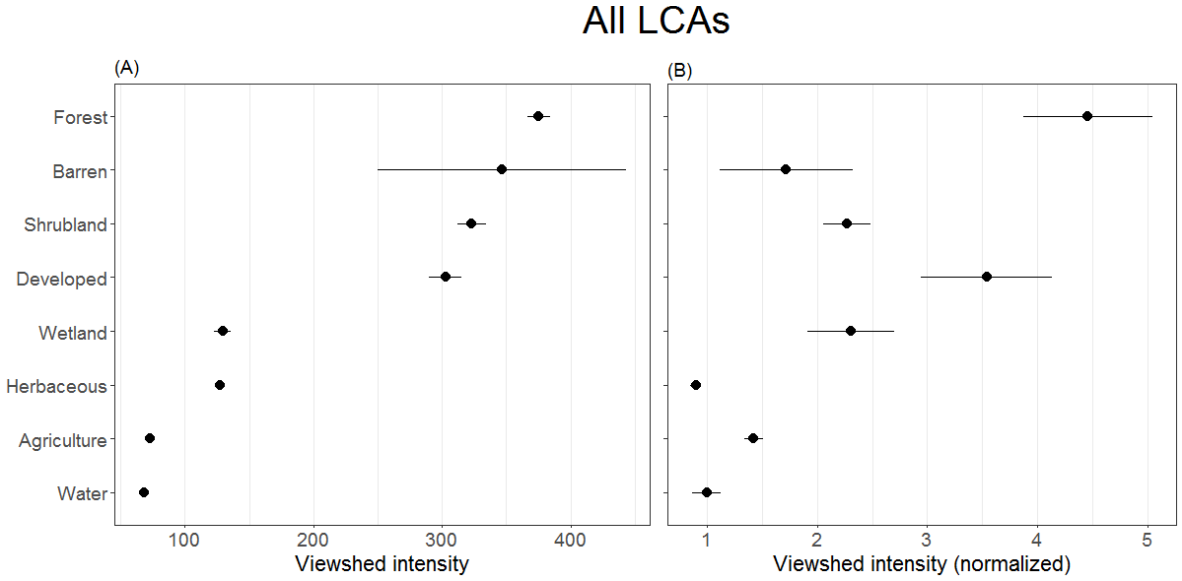

Figure 6. (A) Viewshed intensity for land cover types across all LCAs. (B) Normalized viewshed intensity (viewshed intensity / trail viewshed intensity) which controls for landscapes that are photographed more due to greater ability to view those landscapes from OSMP trails. Points represent the mean viewshed intensity for each class and lines show 95% confidence intervals based on 100,000 randomly sampled viewshed locations.

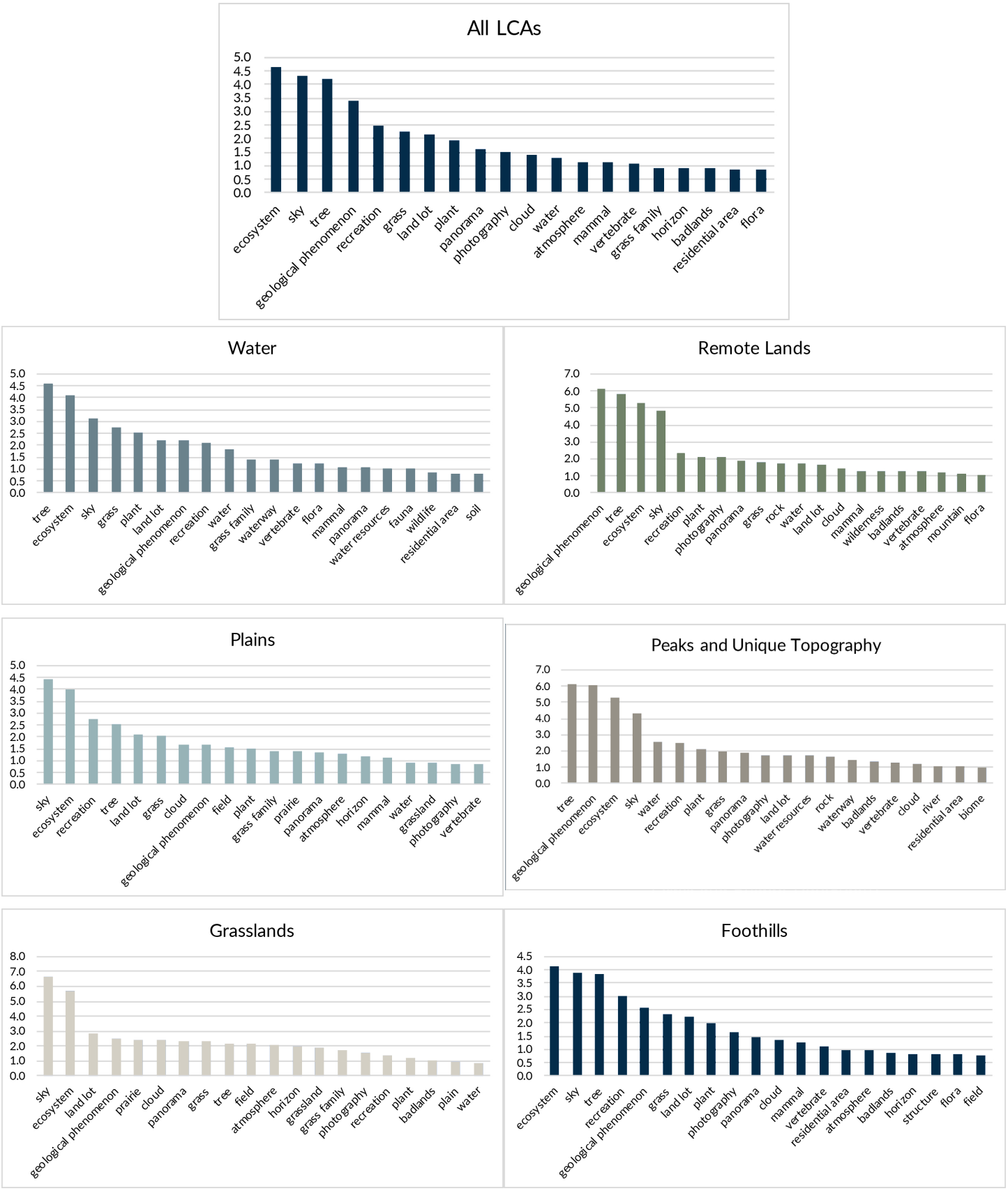

Figure 7. Comparison of the most frequent subject matter captured (content) in social media photographs between each landscape character area (LCA). This is normalized as total percentage of all photographic content depicted within each LCA (or across all LCAs for the first image).

The Water LCA had a high proportion of photography depicting "wildlife" and "flowers" compared to the others. The photography on the Grasslands LCA usually included "sky" (over 50% of all identified content) and depicted "clouds" and the "atmosphere" much more than other LCAs. "Outdoor recreation" was captured in higher numbers within the Remote Lands and the Peaks and Unique Topography LCAs, likely reflecting opportunities for mountain biking and rock climbing respectively. Still, the total number of photographs depicting outdoor recreation activities was small for all LCAs (1.2 - 4.1 % of all photographs). "Vertebrates" and "mammals" were captured in a high proportion of all photographs (4.5 - 9.7% and 6.1 - 10.1% respectively), with slightly fewer in the Grasslands LCA compared to all other LCAs.

Viewshed Prominence of Individual Trails

Our analysis indicated trails near the city of Boulder and around the Flatirons are frequently photographed by visitors to OSMP lands (Figure 8). Within the LCAs, specific trails were visited and photographed more than others (Figures 8 and 9). For example, within the Foothills LCA, Shadow Canyon and the Shanahan trails are visually prominent, while Fern Canyon and Bear Peak were more prominent in the Peaks and Unique Topography LCA. Within the Remote Lands LCA, the Goshawk Ridge and Spring Brook Loop North trails were the most prominent. Visually prominent trails on the Plains and Grassland LCAs included Prairie Vista, Flatirons Vista South, and East Boulder near the Spur and Teller area. Visually prominent areas in the Water LCA were along the South Mesa Sur trail.

DISCUSSION AND CONCLUSIONS

Through these analyses, we were able to: (1) identify points in the landscape where users are often inspired to take photographs; (2) map the landscapes most often viewed by visitors; (3) summarize the types of landscape features viewed from OSMP lands; and (4) determine how these landscape features vary across LCAs.

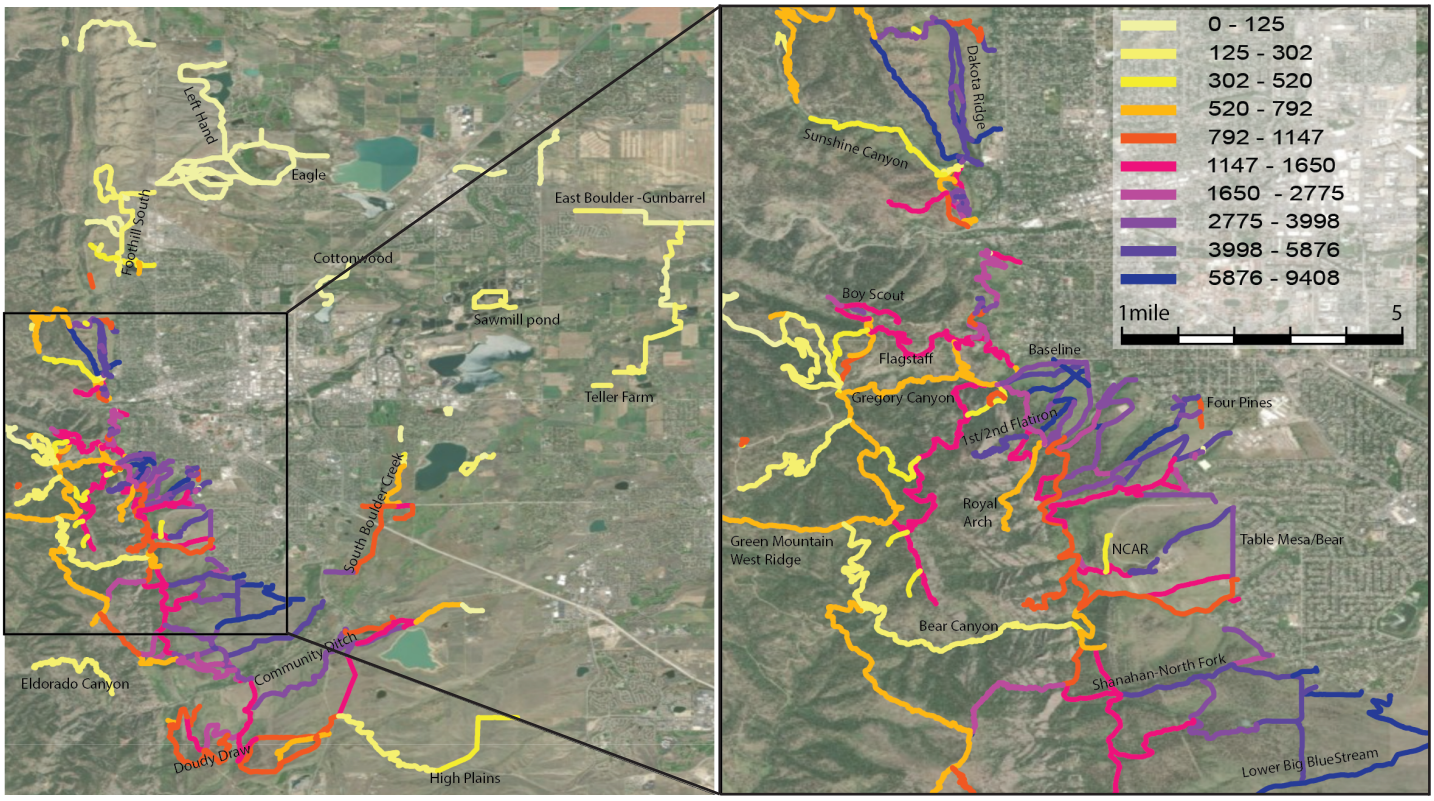

Figure 8. Map of the most frequently photographed trails on OSMP lands depicted as trail viewshed intensity. Imagery Source: ESRI, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN and the GIS User Community.

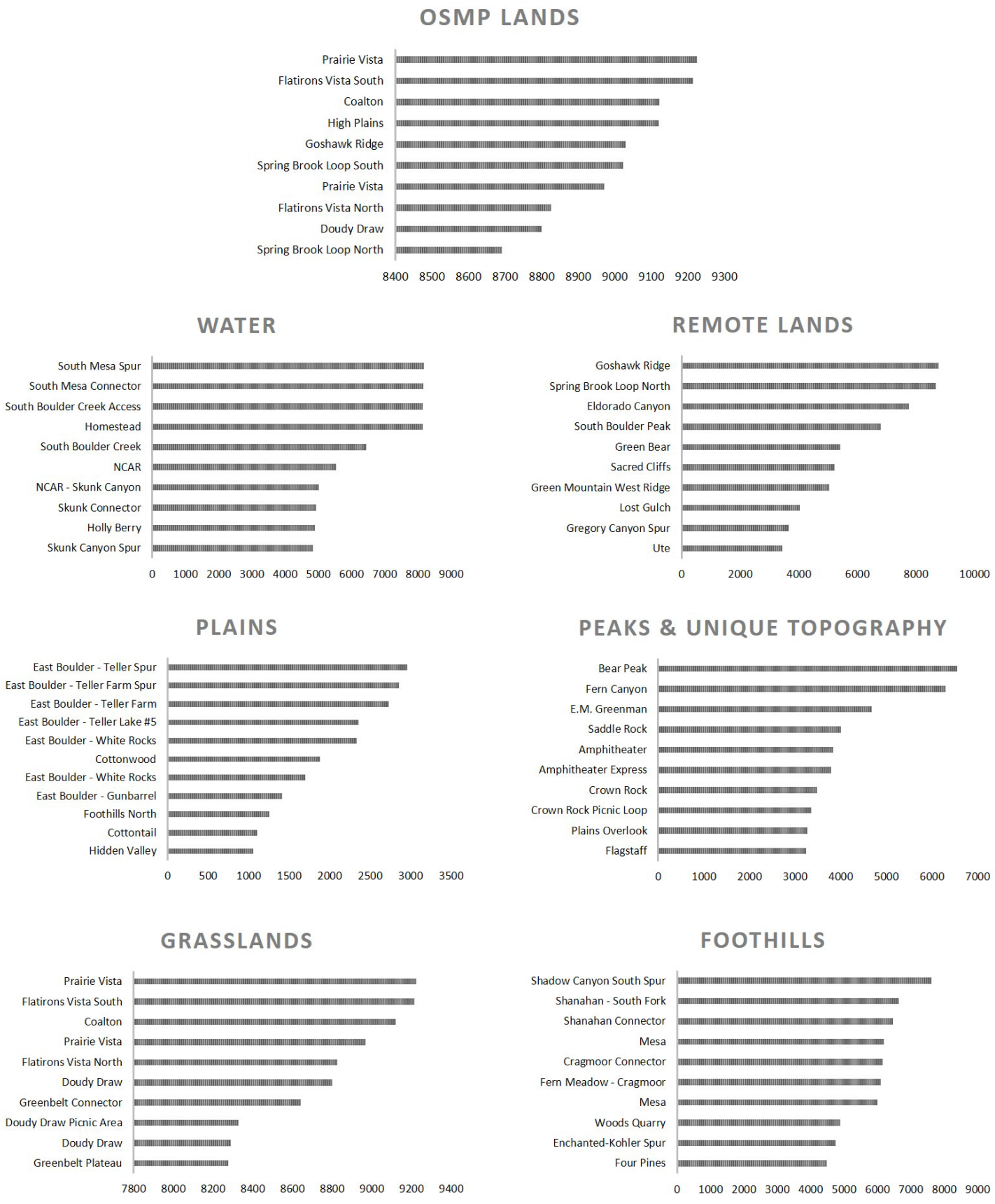

Figure 9. The top 10 photographed trails within OSMP lands for each landscape character area based on Flickr viewshed intensities (mean intensity for each trail).

Mapping the landscapes most often viewed by visitors provides Boulder OSMP managers with spatially-explicit information about how their management actions might impact the aesthetic quality of OSMP lands. We suggest managers utilize the viewshed intensity maps (Figure 4) when considering management actions that may have an impact on the aesthetic quality of OSMP lands. For example, clearing vegetation for the construction or maintenance of utilities infrastructure will have a greater aesthetic impact in locations with a high viewshed intensity. Similarly, intensive vegetation management such as mechanical thinning to reduce wildfire risk will have a larger visual impact if those actions are taken in areas with higher viewshed intensities. Managers should consider the aesthetic impact of their decisions, and the viewshed intensity maps provide a useful, and scientifically defensible tool, to do that.

Our analysis of the types of land uses viewed most frequently by OSMP visitors suggest visitors' spatial behavior (i.e., where they are choosing to go on the landscape) reflects their reported values for biodiversity and aesthetically pleasing landscapes. Results from our survey of Boulder OSMP visitors revealed viewsheds that contain natural vegetation, rocky outcrops, and water features have a positive influence on visitor experience (Wilkins et al., 2018). These findings were echoed in our analysis of social media photographs as we found forested landscapes were the most photographed by Flickr users visiting Boulder OSMP lands. One important point of distinction resulting from the analysis reported here is that developed landscapes were a commonly visible land cover type, this is despite development having a predominantly negative effect on visitors' experiences (Wilkins et al., 2018). We suspect these landscapes may often be captured by default when visitors take photographs due to their prevalence and proximity to heavily used trailheads.

Our analysis of the photographic subject matter revealed a high correspondence between image content and the characteristics that typify the different LCAs. More explicitly, the content of pictures taken from within each LCA reflects the name and characteristics of that LCA. These findings lend support for the use of LCAs as discrete landscape types within the Boulder OSMP system.

Finally, our analysis of the visual prominence of individual trails can inform managers about where to prioritize trail maintenance and vegetation management...if their goal is to improve the aesthetic experience of visitors to OSMP lands. Specifically, managers should prioritize trail management actions to trails that have a relatively high viewshed intensity; these trails are more likely to be visible by visitors using Boulder OSMP lands. Generally, the visual prominence of individual trails is highest immediately adjacent to the city and declines as you move further up into the surrounding foothills and mountains.

Future work is needed to refine the methodology we have developed here. For example, it would be useful to examine viewsheds based on multiple viewing distances. The topography of mountainous landscapes makes identifying a maximum viewing distance challenging. Peaks may not be within a typical viewing distance but could greatly influence the decision of where outdoor recreationists take photographs. Future work that builds predictive models relating photograph locations to viewshed features is also needed. This would allow for the creation of maps depicting where valued outdoor recreation opportunities may be provided if access were available. Future work that compares photo and viewshed content to the values and landscape features found to be important to visitors could also be useful; it would provide a better understanding of the depth of information which can be gained from social media photographs when detailed survey data are unavailable.

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APPENDIX A

Viewshed intensity of land cover types varied by LCA, indicating varying preferences depending on the type of landscape being photographed. In the Foothills LCA, the most commonly photographed land cover types included developed landscapes and wetlands, though forested landscapes are also common when accounting for visibility from trails. In the Grasslands LCA, shrublands were most photographed, though developed, wetland, and agricultural landscapes were more popular when accounting for visibility from trails. Developed landscapes were most commonly photographed in the Water LCA regardless of visibility. In the Remote Lands LCA, barren, herbaceous, shrubland, and forests were most photographed. There were few differences in viewshed intensity across land cover types in the Peaks and Unique Topography and Plains LCAs.

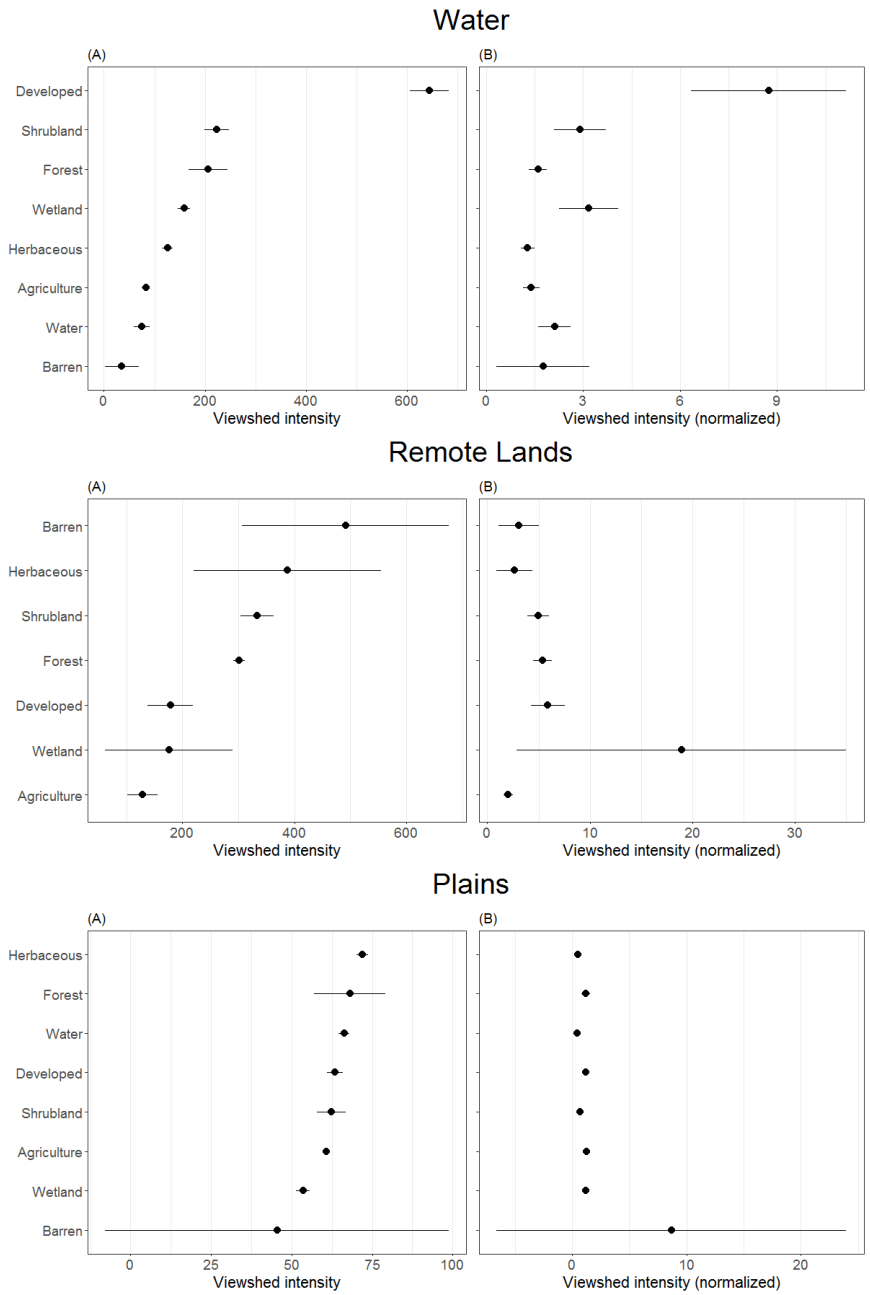

Figure A1. (A) Viewshed intensity for land cover types within each LCA. (B) Normalized viewshed intensity (viewshed intensity / trail viewshed intensity) which controls for landscapes that are photographed more due to greater ability to view those landscapes from OSMP trails. Points represent the mean viewshed intensity for each class and lines show 95% confidence intervals based on 100,000 randomly sampled viewshed locations.

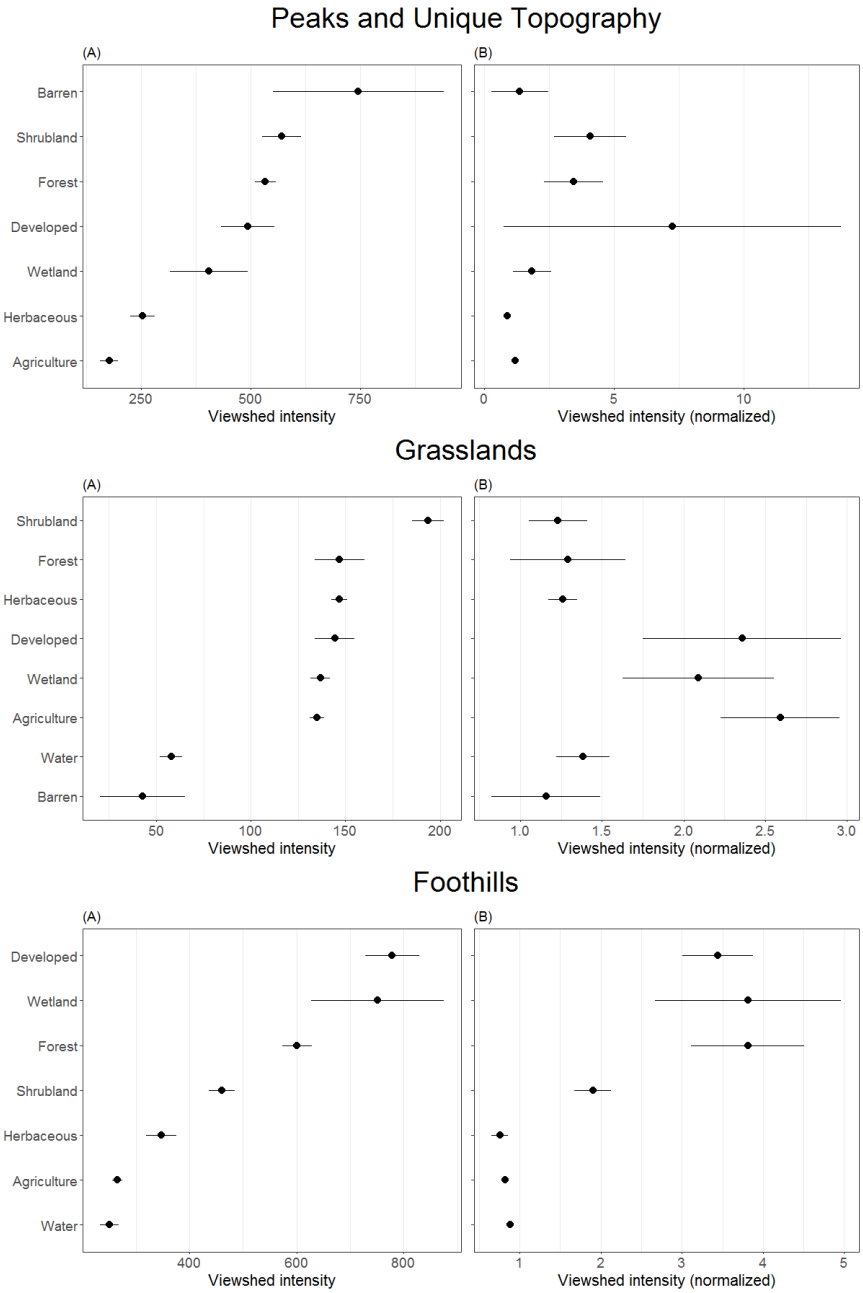

Figure A1 cont. (A) Viewshed intensity for land cover types within each LCA. (B) Normalized viewshed intensity (viewshed intensity / trail viewshed intensity) which controls for landscapes that are photographed more due to greater ability to view those landscapes from OSMP trails. Points represent the mean viewshed intensity for each class and lines show 95% confidence intervals based on 100,000 randomly sampled viewshed locations.

APPENDIX B

In the Foothills LCA, floodplain forest vegetation, grasslands, and rocky landscapes were commonly viewed, as well as some mixed ponderosa pine and urban landscapes. Grassland LCA views included floodplain forests and urban areas, in addition to grassland, sedge, and other herbaceous vegetation. Grassland and herbaceous vegetation were also commonly viewed in the Plains LCA, along with shrubland. Views in the Peaks and Unique Topography and Remote Lands LCAs frequently included shrubby landscapes and mixes of ponderosa pine, with rocky and sparsely vegetated landscapes also commonly viewed in Remote Lands. Views in the Water LCA covered a wide range of landscape types, including shrubs and forbs, urban landscapes, pine and fir forests, and floodplain forests and other wet landscapes.

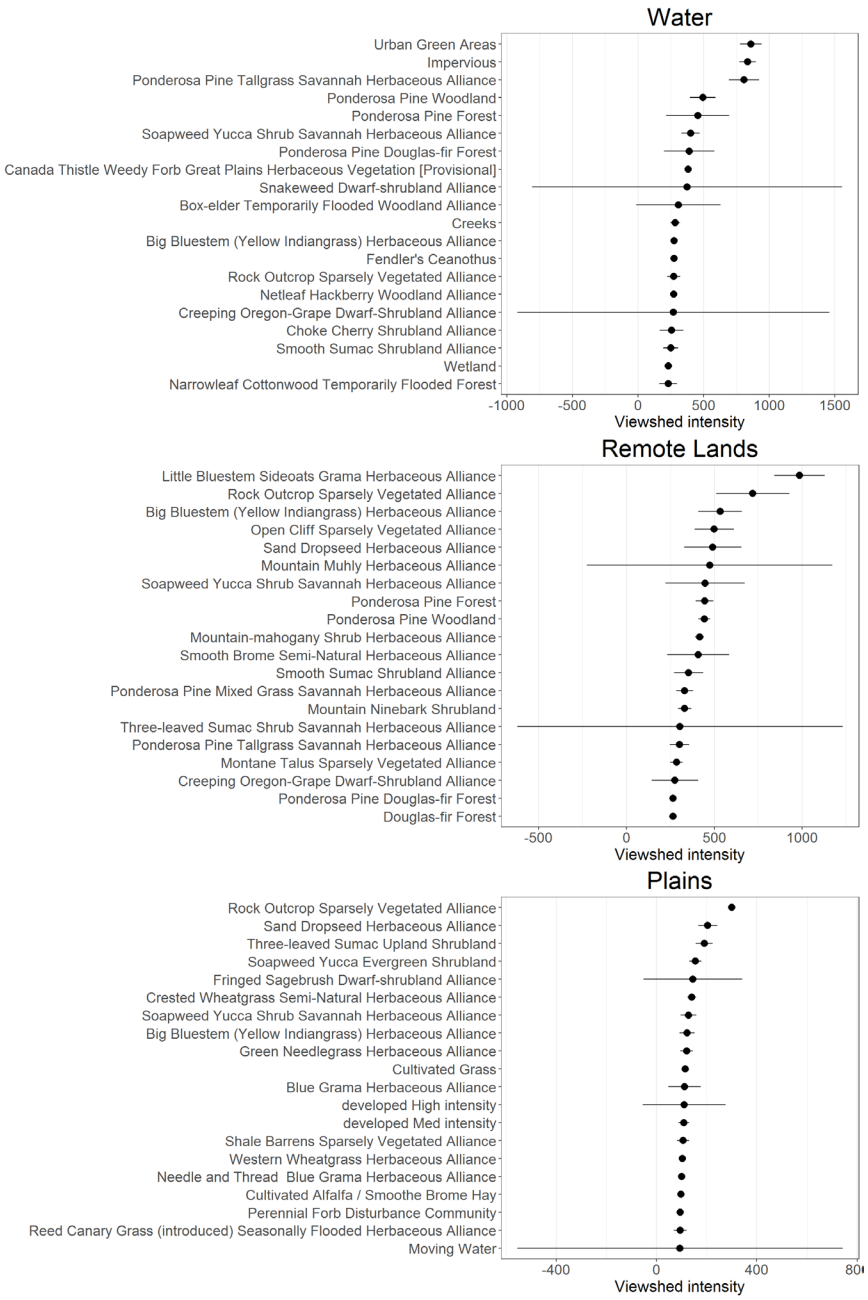

Figure B1. The top 20 most viewed vegetation and land cover classes within each landscape character area based on Flickr viewsheds. Points represent the mean viewshed intensity for each class and lines show 95% confidence intervals based on 100,000 randomly sampled viewshed locations.

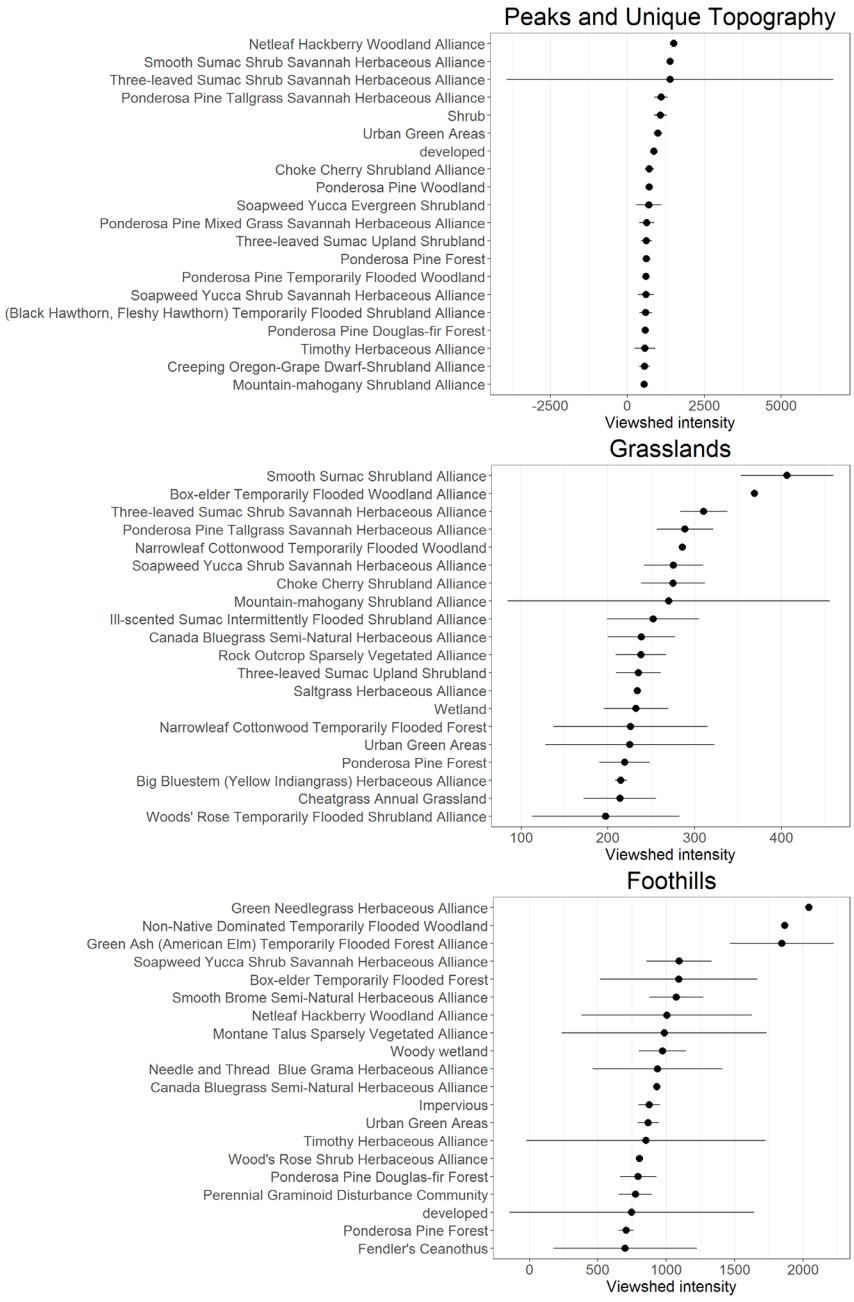

Figure B1 cont. The top 20 most viewed vegetation and land cover classes within each landscape character area based on Flickr viewsheds. Points represent the mean viewshed intensity for each class and lines show 95% confidence intervals based on 100,000 randomly sampled viewshed locations.

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