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Integrating social values with GPS tracks through Denali National Park and Preserve

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ABSTRACT

This study advanced knowledge of the geospatial relationships between social values elicited during a participatory mapping exercise and on-ground travel patterns understood through Global Positioning System (GPS) tracking of backcountry visitors to a protected area in Alaska. As one of the first studies to combine social values and real-time use of a protected area landscape, we showcase how these combined forms of knowledge can be better understood when compared against biophysical conditions. Contrary to previous research, we observed that perceived social value hotspots, defined by an abundance of point data, did not fully align with use patterns, suggesting that visitors value areas that are not experienced first-hand. Specifically, backcountry travel routes in Denali were less dispersed than areas perceived to be important. Use was mostly concentrated in backcountry units close to the middle sections of the park road while highly valued units coincided with major landmarks, such as the peak of Denali. Travel cost induced by terrain conditions (summarized by elevation, slope and landcover), accessibility (measured by proximity to the park road), and long-view visual resources all contributed to how observed travel behavior deviated from perceived social values. These findings help inform policy and management decisions about outdoor recreation, visitor safety, and visual resource stewardship.

1. Introduction

Parks and protected areas are often posited as global solutions to environmental challenges given their potential to preserve ecologically intact environments, generate stewardship to inspire nature conservation across generations, preserve vestiges of human history, and provide opportunities for quietude and night skies that would otherwise be lost in the wake of human development and land-use change (Manning et al., 2022). Rapid growth in the extent and type of designated protected areas is challenged by these competing outcomes and has resulted in calls for innovations and efficacy of management agencies in the protection of natural areas. The International Union for Conservation of Nature (IUCN) has consequently established a goal of preserving 30% of global land and sea area by the year 2030 (Woodley et al., 2019). Such lofty goals are intended to be achieved through the adoption of global policy instruments, including the Convention of Biological Diversity targets and the UN Sustainable Development Goals (Essl et al., 2020), which focus attention on protected area conservation. At a time of widespread biodiversity loss, habitat destruction, and threats to human livelihoods owing to climate change (Díaz et al., 2015; Pascual et al., 2017), resource management has moved from the theoretical to the practical whereby policy instruments recognize tensions among stakeholder groups and respond with reflexivity and the co-creation of management strategies (Raymond et al., 2022). Research that integrates knowledge across the social, natural, and physical sciences within the context of protected areas is thus urgently needed to inform

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evidence-based decisions (D'Antonio et al., 2021; Perry et al., 2020; van Riper et al., 2020).

The ambitious goals around protected area conservation are contested because setting land aside (e.g., establishing a federally designated Wilderness) requires public input and endorsement of policies that rely on negotiation and consideration of diverse values (Tallis & Lubchenco, 2014). Indeed, attention has been directed toward embracing pluralism and engaging stakeholders in an equitable manner (Hill et al., 2021; Matulis & Moyer, 2017; Pascual et al., 2021). An unresolved issue in the conservation sciences is the extent to which inclusion of stakeholders across a diversity of values, especially people at the fringes of collective efforts, is appropriate (Mace et al., 2014). To address this issue, there is a need to consider multiple "social values," defined as individual valuations of ecosystem services aggregated at a group level (Raymond et al., 2014). As expressions for the multiple reasons why places are considered important, social values serve as motivators for generating stewardship that can be incorporated into public land management decisions (van Riper et al., 2012). However, the intangible, non-monetary social values that confer an array of benefits to society, such as aesthetics, soundscapes, and therapeutic experiences, have only recently been given prominence in the study of cultural ecosystem services (Chan et al., 2012; Harmon & Putney, 2003; Himes & Muraca, 2018; Milcu et al., 2013; Raymond et al., 2021). Within this burgeoning albeit small body of literature, there are limited efforts to model the spatio-temporal variation in social values, operationalized here through participatory research (Brown & Kyttä, 2014; Engen et al., 2018) and as real-time assessments (Pettersson & Zillinger, 2011) of visitor experiences in a protected area.

Visitors travel large distances to experience nature-based settings for the vastness and solitude that these places offer, despite the opportunity cost of travel time (Richardson et al., 2017; Smith et al., 1983). Venturing into wilderness-like areas can involve substantial exposure to risk of injury (Harmon & Putney, 2003), particularly from adverse weather, snowpack, and terrain conditions. Backcountry travelers weigh trade-offs when faced with choices such as experiencing a near-view of a glacier versus enjoying more accessible vistas on an easy hike, depending on their safety perception, travel time and monetary travel cost (Gstaettner et al., 2020; Rogers & Leung, 2021). As visitors evaluate current conditions, they may choose to avoid unexpected terrain features (e.g., dense canopy) to reduce threats including entrapment, drowning, and aggressive wildlife encounters. All these potential travel cost incurred by visitors are weighed against social values derived from experiencing special places, which dictate choices about access points and hiking routes (Jones et al., 2010). These tradeoffs determine judgments about safety and where to enter the backcountry (Lawson & Manning, 2002; Silverton et al., 2009), as well as affect valuations of what is (or is not) directly experienced in trailless wilderness areas (van Riper & Kyle, 2014).

Denali National Park and Preserve, AK, USA, is a prime example of a protected area that provides freedom to explore and involves selecting travel routes that are desirable yet dispersed to minimize human impacts on resource conditions (Stamberger et al., 2018). There is limited knowledge of off-trail travel behavior in areas without a pre-determined trail system but potential to build a more comprehensive representation of travel decision making. Indeed, few studies have explained and explicitly linked social values with active tracks of backcountry use (for exception see: Garcia et al., 2020). This is a critical research gap, because GPS tracking technologies are limited to recording visitors' movements, making it generally impossible to solely use GPS data to characterize factors influencing decision-making processes, including subjective valuation of the park experience and objective environmental features (Shoval & Ahas, 2016; Taczanowska et al., 2014). While social values are often framed as having permanence and trait-like qualities, they provide self-reported and individual-specific background information on the factors that motivate visitation (Brown & Kyttä, 2014; Engen et al., 2018; van Riper et al., 2020). The combination of GPS tracking and participatory mapping methods thus makes it possible to better understand the (mis)match between observed travel behaviors and perceived social values.

1.1. Outdoor recreation in protected area contexts

Increasing interest in outdoor recreation alongside the rise of multi-functional landscapes present challenges for public land management agencies that oversee protected areas. The pressures facing public goods and services warrant careful planning and attention to meet the needs of the public while also sustaining natural resources (Manning et al., 2022). According to Lime and Stankey (1971), all lands have a recreational carrying capacity in which there is not a set value of how much the land can be used for recreation, but rather a complex interconnected system of different activities that require assessments of administrative, budgetary, and resource constraints. The potential for land degradation from increasing visitation rates further exacerbates other management challenges in protected areas (Hammitt et al., 2015; Pickering et al., 2018). That is, there are many factors that must be considered when determining how to manage protected areas sustainably. These settings have the legislative ability to preserve a wide array of ecological functions that are intrinsically important but also instrumental for tourism and recreation (DeFries et al., 2007). Knowing the kinds of behaviors performed and perceived social values that outdoor recreationists seek, public land management agencies will be better prepared to meet the needs of stakeholders who care about the future of protected landscapes.

Outdoor recreationists comprise a constituency that supports local economies through visitation to public lands like protected areas but also contributes to environmental disturbances that require oversight and management (Peterson et al., 2020; Smith et al., 2019). The activities pursued in protected areas are highly variable, but all have the same general idea: to engage with the land and create opportunities for building environmental stewardship and human well-being. The intensification and expansion of use in protected areas underscores the importance of understanding the transactional relationships between the effects people have on the land and how those physical spaces are being interpreted (Brown et al., 2014; Zube, 1987). Innovations in technology have enabled previous research to illustrate the spatial dynamics of human-environment interactions through outdoor recreation (Rice & Park, 2021; Riungu et al., 2018; Zhang et al., 2021). A focus on participatory mapping of social values shows particular promise as a strategy to integrate a diversity of stakeholder voices alongside consideration of their environments to inform decision-making.

1.2. Understanding social values through participatory mapping techniques

Participatory mapping techniques are increasingly applied in research to define and spatially locate the social values of places. Previous studies have relied on a range of techniques to assess social values across spatial scales, particularly Public Participation in Geographic Information Systems (PPGIS) (Sieber, 2006). Much of this work has relied on typologies to characterize the range of tangible and intangible values of places (Rolston & Coufal, 1991). Bengston and Xu (1995) developed a typology to illustrate how stakeholders valued changes to a forested landscape over an eleven-year period. Brown and Reed (2000) then adapted this work and identified thirteen social values to inform forest management practices. Previous research has continued to adapt the typology from Brown and Reed (2000), including work by Sherrouse et al. (2011) and van Riper et al. (2017) to illustrate how social values relate to landscapes in U.S. public land management contexts. This body of work has indicated that a wide array of social values is associated with landscapes and can be physically mapped by survey respondents as a form of participatory engagement in discussions about changes in social-ecological conditions (Brown et al., 2020; D'Antonio et al., 2021).

Previous research has relied on PPGIS to understand how people interact with and develop connections to nature, particularly protected areas. For example, Johnson et al. (2019) compared the social values and landscape qualities of two island protected areas in the U.S. and Australia. The authors found places on both islands carried Aesthetic, Biological Diversity, and Recreation values. Similarly, Brown and Weber (2011) utilized a Geoweb PPGIS approach to gauge residents' preferences for tourism development. These authors posited that PPGIS was a useful tool for determining where development would be viewed as most appropriate, with special consideration given to landscape values. This technique can also be used to map conflicts and human well-being (Brown & Raymond, 2014; Fagerholm et al., 2016; Wolf et al., 2018), thus providing evidence of its suitability as an application for understanding different user groups within protected areas.

1.3. GPS tracking

Advanced spatial technologies, such as Global Positioning Systems (GPS), have become a practical and successful means for unobtrusively observing sampled visitor spatial behavior in parks and protected areas (Beeco & Brown, 2013; D'Antonio et al., 2010; Hallo et al., 2012; Peterson & Zillinger, 2011). GPS tracking data illustrate the actual decision footprints of recreationists and provide insight into the densities, flows, and distributions of human movements (Sykes et al., 2020). Past works have geographically tracked the variety of ways people move through natural landscapes (e.g., hiking, biking, driving) (Beeco et al., 2013; Kidd et al., 2015, 2018), recorded the amount of time people spend at a single site (D'Antonio et al., 2010; Abkarian et al., 2022), and pinpointed hotspots for visitor use of natural spaces (Beeco et al., 2013; Stamberger et al., 2018). Given the potential to inform agency choices relating to resource conservation and human use, several scholars have begun to apply GPS-based research to public land management contexts (D'Antonio et al., 2013; Taczanowska et al., 2014). Specifically, GPS tracking methods have been utilized to understand off-trail travel (Kidd et al., 2015; Wimpey & Marion, 2011) as well as other ecologically harmful behaviors that are tied to visitor use (e.g., camping location, backcountry travel patterns) (D'Antonio et al., 2013; Stamberger et al., 2018). Despite the rapid advancement and implementation of GPS-based research in recreational contexts, there is a need for deeper knowledge of the linkages among GPS tracks, important decision-making factors such as social values, and terrain conditions that have a direct and major influence on travelers' decisions to choose a specific route.

1.4. Study objectives

This study compared real-time use of a protected area landscape documented with GPS tracking data to the perceived importance of places elicited from a PPGIS exercise. Specifically, three objectives guided this study: 1) compare backpackers' paths used for travel with their social values, 2) examine the relationship between travel paths and social values across backcountry units designated by the National Park Service (NPS); and 3) identify terrain conditions that could explain where social value points do and do not overlap with GPS tracking data. Our goal was to show how combining multiple forms of knowledge about visitor experiences could reflect sustainable behavior to advance stewardship and enhance resource management practices to achieve conservation objectives in Denali National Park and Preserve.

2. Methods

2.1. Study context

This research was conducted within Denali National Park and Preserve located in southcentral Alaska, U.S.A. This protected area covers a 250-million-hectare subarctic landscape in the Alaskan Interior that supports an array of wildlife, including charismatic megafauna such as grizzly bears (*Ursus arctos horribilis*), wolves (*Canis lupis*), and ungulates (e.g., moose, caribou, Dall sheep), as well as a diversity of alpine flora and fauna (Abbe & Burrows, 2014). The Alaskan Range transects the park's landscape, including wide valleys, braided river systems, and panoramic mountain views. The symbolic and nearly geographical center of this protected area is Denali, which is the highest peak in North America, reaching 6190 m (National Park Service, 2017). The NPS manages the nearly 2.4 million hectares protected area, which is also classified as a UNESCO Biosphere Reserve. When Denali expanded its boundaries to its current size through the 1980 Alaska National Interest Land Conservation Act (ANILCA), federal Wilderness designation was overlaid on the original park boundary (National Park Service, 2006). Within this area that covers approximately 81,000 ha, the park is mandated to preserve specifically defined characteristics of Wilderness, in accordance with the Wilderness Act of 1964. Wilderness characteristics include: pristine and intact landscapes, untrammeled and undeveloped land, solitude and quietude (ability to be surrounded by natural sounds), and no motorized land access (National Park Service, 2006).

Although backcountry travelers have the freedom to travel in Denali's nearly trail-less landscape, their travel patterns are influenced by park staff and restricted by a backcountry unit quota system. The entirety of Denali National Park and Preserve is segmented into 87 separate backcountry parcels (see Fig. 1), which serve as units of management for monitoring visitor use (Stamberger et al., 2018). Among them, 41 units have a quota on the number of individual backcountry users staying overnight in each unit, usually ranging from two to 12 users per night. The quota system guarantees dispersed visitor use to avoid environmental degradation and allow visitors to have high-quality opportunities to experience solitude physically separated from other user groups. Backpackers also utilize this array of backcountry units to plan their trips and identify available campsites in consultation with the NPS. For example, video-based training is provided that teaches visitors about the risks of backcountry travel and encourages experiences that respond to levels of experience. In the peak seasons, backcountry users often need to reserve permits ahead of time, with no more than 14 days prior to the beginning of their trip (see Fig. 2).

2.2. Data collection

We collected GPS tracks from overnight backcountry visitors during the 2016 high use season (June–August). During the sampling periods, survey days were stratified by time of the day and day of the week. All backcountry groups that passed through the Backcountry Information Center and received backcountry permits were asked to participate in the study. These groups were limited by restrictions on overnight use within each backcountry unit. We asked one person in each group to carry a Canmore GT-740 FL GPS unit and that person was responsible for returning the unit at the end of the visit. The major advantages of using Canmore GT-740 FL units are their extended battery life and high spatial and temporal accuracy. These units are able to record a three-day trip, which was common within our sample. For groups that planned to be on an extended multi-day trip, they were given multiple GPS units in order to capture the entire trip (Keller & Foelske, 2021). The manufacturer-specified accuracy for our GPS units under ideal conditions (e.g., open terrain, clear sky) was 2.5 meters. The GPS units were set to document waypoints at 15-second intervals to optimize for high-frequency GPS point data collection. On a weekly basis, the on-ground GPS data were extracted and converted into.gpx files using Canway software.

When the overnight groups returned from the backcountry, we administered a follow-up survey that included a participatory mapping exercise. First, respondents assigned 100 hypothetical "preference points" across 13 value types (see Table 1). Second, we asked respondents to identify up to 10 locations on a 86 cm by 33 cm map of the park that they felt embodied the social values selected in the first step. Additionally, respondents provided information on socio-demographic

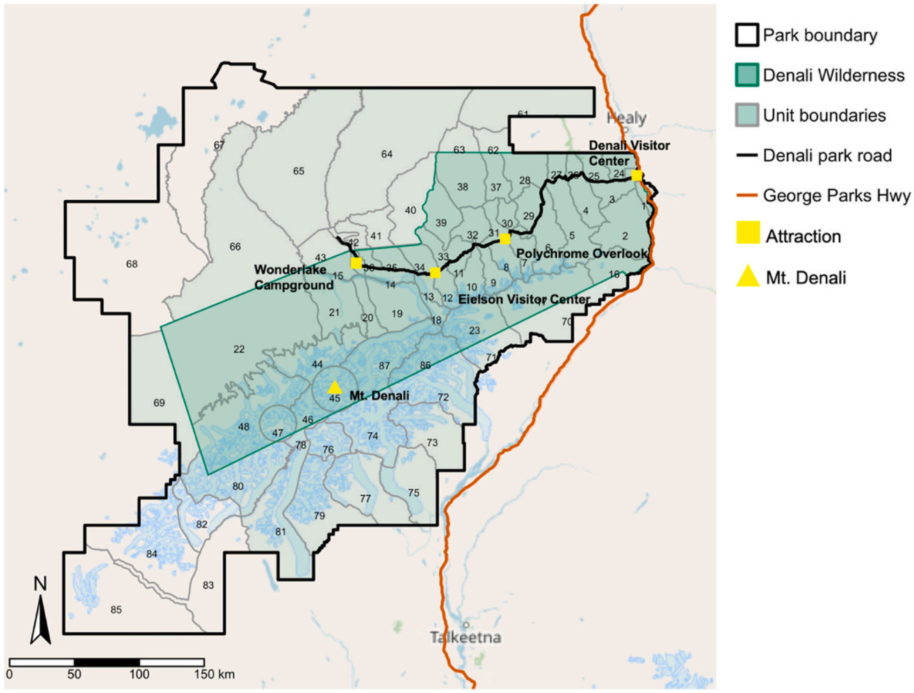

Fig. 1. Designated backcountry units in Denali National Park
Notes: Basemap layer was sourced from OpenStreetMap.

information (e.g., gender, education, income). To collect information from unguided backcountry recreationists, the trained survey administrators distributed the same survey to visitors across five designated high-traffic sampling sites in the park. The on-site survey was administered both in the morning and afternoons of 28 weekdays and 14 weekends using Insignia tablets and Qualtrics software. A total of 734 visitors were asked to participate in the survey, 667 of whom agreed, yielding a response rate of 90.6%.

2.3. Visually mapping social values with PPGIS and SolVES

We generated spatially explicit information about how locations were valued using PPGIS in combination with the Social Values for Ecosystem Services (SolVES) mapping application developed by the U.S. Geological Survey. Sherrouse et al. (2011) developed SolVES to analyze social values in relation to a series of landscape metrics using Maximum Entropy (MaxEnt) modeling (Phillips & Dudík, 2008). The SolVES program builds a logistic surface layer using both social and ecological data to predict the locations that embody social values within a study area (van Riper et al., 2017). The resulting spatial projection identifies high and low priority locations on a cell-by-cell basis, which is shown on a rasterized map that includes a standardized Value Index score. The Value Index falls on a 10-point scale that includes a non-monetary metric derived from survey data to quantify social values (Sherrouse et al., 2011). This allows for a visual illustration of social values that land managers can utilize to identify key areas of valuation from respondents within a specified area.

2.4. Data processing

Social value and GPS tracking data were uploaded to R 4.0.1 for data cleaning. The raw social value data included a total 577 survey respondents with 3602 geolocated social value points. After matching the survey data with the GPS tracking data, 454 survey respondents were excluded from the final database because these respondents did not participate in the GPS visitor tracking aspect of the study. As a result, we obtained a final dataset containing 123 respondents (final number of respondents = 577–454). For these respondents, we matched their social value and GPS tracking data. There were 830 geolocated social value data points from 13 categories of social values obtained from these 123 respondents. To examine the difference between unmatched data whereby social value points were analyzed for only respondents who carried a GPS tracker and matched survey data from the comprehensive sample of respondents who completed the PPGIS mapping exercise, an unpaired-samples *t*-test was performed. The test suggested that removing the unmatched sample did not significantly change the frequency distribution of social value types (t-value = −1.873, p-value = 0.061). As such, 123 GPS tracks[1] represented 123 different user groups, and the matched sample was deemed both representative of backcountry recreationists included in our original sample and adequate for our analysis.

Four spatial layers representing on-ground environmental conditions were loaded into the R environment for analysis. The backcountry unit and land cover (30-m cell size) layers were collected from the NPS IRMA Data Store. Elevation and slope angle layers were derived from a U.S. Geological Survey digital elevation model (DEM) with 2 arc second resolution (~60 m). All spatial point data and layers were stored in a North American Datum (NAD) 1983 Alaska Albers coordinate system.

2.5. Analysis of GPS and social value data

We performed statistical and spatial analysis using R with packages 'sf' (Pebesma, 2018), 'spatstat' (Baddeley et al., 2015), 'sparr' (Davies et al., 2018), 'raster' (Hijmans & van Etten, 2012), and 'geosphere' (Hijmans et al., 2017). To address the first objective of this research, the

[1] In the process of cleaning GPS points, we made a decision not to remove stationary points from overnight locations. Our reasoning behind this is that these stationary points contain valuable information regarding the terrain choices made by backcountry travelers for overnight stays. Excluding them would adversely affect the accuracy and comprehensiveness of our analysis. It is important to note that this choice may introduce bias into the results of distance calculation and the relationship of GPS tracks to various terrain conditions.

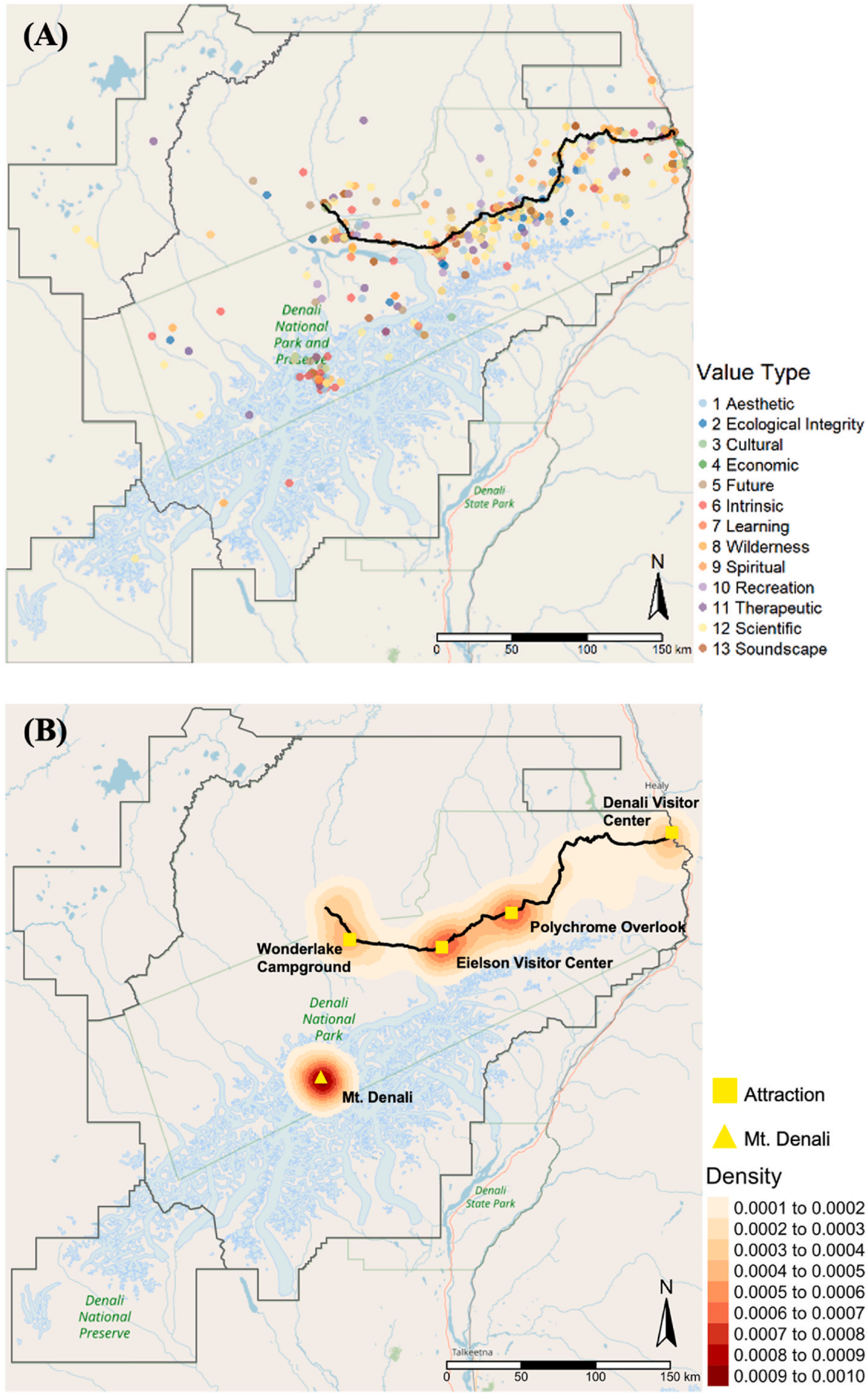

Fig. 2. Raw data of social value points mapped by survey respondents (A) and results from a kernel density analysis of social value points (B)
Notes: Visitor group sample size n = 123. Densities are measured as a unit of social value point per square kilometer. Basemap layer was sourced from OpenStreetMap.

spatial dynamics of social values and GPS tracks were examined, including an assessment of the raw data pattern and point density maps. We performed Kernel Density Estimation (Bailey & Gatrell, 1995) to produce a smoothly tapered surface of digitized social value points and GPS points to visually display the "hotspots." To be able to compare spatial patterns across two datasets, the smoothing bandwidth of all kernel density estimations was set to be 5 km with output cells of 0.25 km^2. A 5-km bandwidth was selected according to Silverman's rule of thumb (Silverman, 2018). Guided by the second objective, the relationship between social value points and GPS tracks was compared across backcountry units designated by the NPS. The frequency and percentage of spatial points for each backcountry unit were calculated and mapped. A measure of the accessibility of backcountry units was determined as the shortest straight-line distance from a backcountry unit to the park road. In response to the third study objective, three layers of biophysical conditions were compared to social value points and GPS

Table 1
Definitions of 13 social value types assigned to places by survey respondents in Denali National Park and Preserve.

Assigned value	Description
Aesthetic	I value Denali National Park for the attractive scenery, sights, sounds, or smells.
Ecological Integrity	I value Denali National Park for its intact ecosystem where predators (e.g., wolves) and prey (e.g., dall sheep) are in balance.
Cultural	I value Denali National Park because it preserves historic places and archaeological sites that reflect human history of the island.
Economic	I value Denali National Park because it provides economic benefits from recreation and tourism opportunities.
Future	I value Denali National Park because it allows future generations to experience this place.
Intrinsic	I value Denali National Park in and of itself for its existence.
Learning	I value Denali National Park because I can learn about natural and cultural resources.
Wilderness	I value Denali National Park because it represents minimal human impact and/or intrusion into natural environment.
Spiritual	I value Denali National Park because it is spiritually significant to me.
Recreation	I value Denali National Park because it provides a place for my favorite outdoor recreation activities.
Therapeutic	I value Denali National Park because it makes me feel better, physically and/or mentally.
Scientific	I value Denali National Park because it provides an opportunity for scientific observation or experimentation.
Soundscape	I value Denali National Park because I can hear natural sounds.

tracks, including landcover, elevation, and slope angle. Each layer was spatially joined to the value and GPS points, respectively, to retrieve raster values for each data location point. In addition, zonal statistics were extracted to examine the distributions of elevation and slope for each land cover type. Descriptive statistics were used to demonstrate the terrain conditions and accessibilities associated with the two datasets under the assumption that the elevation/slope of an area was higher, and travel cost incurred by visitors was higher. We also compared the shortest distances to the road for social value and GPS points by visually comparing cumulative distribution functions (CDFs) of distances and conducting a Mann-Whitney U Test of difference.

3. Results

The result section has been divided into three subsections. We start with a brief summary of the socio-demographic characteristics of our visitor group sample, which established the background for subsequent analysis. Then, we summarize the spatial distributions of both social values and GPS tracks by displaying the point density maps of the social value and travelers' actual visitation patterns. Results from comparing density maps between social value and GPS tracks indicated both the overlap and difference between perceived social value and observed travel patterns. The last subsection focuses on factors that influence route selections and explain such differences.

3.1. Socio-demographic characteristics

We received responses from 156 backcountry travelers after their trips, which accounted for 62.2% of the total surveys distributed. Among the respondents, 64.7% were male, and the average age was about 32 years. Close to 54% of respondents were between 20 and 29 years of age. The education level of respondents was above the U.S. average, with over 80% holding a four-year college degree or higher. We observed that annual income was evenly spread across the income brackets. The majority claimed to be primary residents in the U.S.A. Travelers from Western European countries composed the second largest group in the sample. Additionally, the race of respondents was predominantly White or Caucasian (93.1% identified as White and 3% as Hispanic or Latino). The socio-demographic composition of the sample was consistent with previous research conducted in the same region (Alessa et al., 2008; Hallo et al., 2012).

3.2. Spatial dynamics of social values and GPS tracks

The first objective of this study was to examine the spatial location and intensity of assigned socal values and backcountry use. Results showed dispersion of value points across the Denali landscape based on the distribution of 13 social values mapped by backcountry recreationists (see Fig. 3a). Four hotspots were identified around landmarks such as the peak of Denali, Polychrome Overlook, Eielson Visitor Center, and the Denali Visitor Center, as illustrated by heat maps from a kernel density analysis (see Fig. 3b). Among those landmarks, the intensity of social value assignments was the highest on Denali, as indicated by the darkest colored hotspots. Overall, value clustering coincided with major landmarks in the park. GPS points recorded by all GPS tracks showed that use patterns radiated out from the "park road," which runs for 149 km from the entrance station to the center of the protected area (Fig. 3a and b). Such result supports the assumption that the single park road is used as the only access point to backcountry areas sampled, which will bias the distribution of GPS points. Kernel density analysis of GPS tracks showed travel patterns concentrated toward the middle of the park road, particularly within two predominant hotspots near the Eielson Visitor Center and Polychrome pass (Fig. 3c and d). In general, social values tended to be allocated to a greater portion of the Denali landscape than people actually "tracked," despite an overlap in social value allocation and GPS tracks along and near the park road.

3.3. Relationships of social values and GPS tracks across backcountry units

To address the second objective of this research, the relationship between social value points and GPS tracks was examined across backcountry units designated by the NPS. Both social value points and GPS tracks were spread across the landscape, though social value points were more broadly distributed to places regardless of whether those areas were experienced first-hand. Out of 87 backcountry units, GPS points were located in 33 of the units whereas social value points were located in 57 units. On one hand, the backcountry units entitled Mount McKinley, Polychrome Mountains, and Polychrome Glaciers received the highest density of social value points (see Table 2). These backcountry units were perceived to be important and were adjacent to the middle section of the park road except for the Mount McKinley Unit, which is a region that reflected the symbolic value of the park (see Fig. 4a) and was a long ways (35 km) from the nearest access point along the park road. On the other hand, the most popular destinations for backcountry users were Mount Eielson, Upper Teklanika, East Branch Upper Toklat, and Polychrome Glaciers. Use was mostly concentrated in the units of popular "destination stops" where excellent views of Denali and peaks of the Alaska Range were possible (see Fig. 4b). Although the most popular backcountry units were easily accessible and within walking distance from the park road (40-170 meters), the units that carried important social values were geographically remote (>1 km). Apart from the differences found in our comparison between the two datasets, results suggest that five units in the western portion of the park road corridor are both intensely valued and heavily visited.

3.4. Social values and GPS tracks related to environmental conditions

In response to the final study objective, we assessed the locations of social value points and GPS tracks in relation to three biophysical conditions including land-cover, elevation, and slope layers. Results from the land-cover analysis showed that the landcover types most frequented were not fully matched with the landcover types most valued by survey respondents (see Table 3). As one of the most common types of landcover types in Denali (Boggs et al., 2001), low shrub birch-ericaceous willow was most valued and traveled; however, snow and ice were

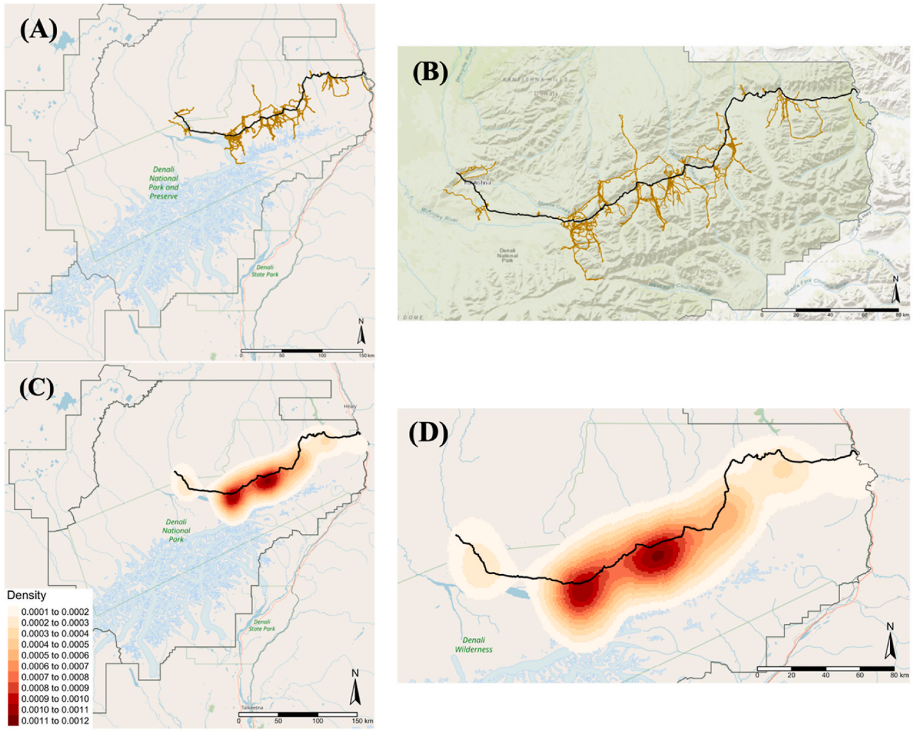

Fig. 3. Raw data of GPS tracks showing travel patterns across the protected area (A) and a zoomed-in version of these results centered on the Denali Park Road (B), as well as results from a kernel density analysis of GPS tracks showing travel patterns across the protected area (C) and a zoomed-in version of these results (D) Notes: Visitor group sample size n = 123. Densities are measured in a unit of GPS point per square kilometer. Basemap layer was sourced from OpenStreetMap.

second most valued by survey respondents but not frequented by backcountry travelers. Bare ground was second most traveled by travelers but not highly valued. Sparse vegetation and low shrub-sedge land covers were similarly ranked.

Similar results emerged in the comparison between social value points and GPS tracks against a histogram of elevation, particularly given similar average elevation values for GPS tracks (1038.71 m) and social value points (1087.59 m). The frequency distribution of elevation extracted from these two point-based datasets greatly overlapped (see Fig. 5a). However, there was a wider range in elevation underlying the social value points, particularly larger volitivity and a longer right tail. Both highland and lowland landscapes could be intensely valued, and a quarter of places considered as important were in relatively higher elevations (>1500 m) (see Fig. 5b). By comparison, backcountry travel patterns were generally greater in lower elevations, by 700–1300 m.

Striking differences were observed between the slope angle of valued places and frequented areas. In general, survey respondents valued places with steeper slopes whereas they tended to avoid such places on the ground, with an average slope of 13.2° for social value data and 6.3° for GPS tracks. Fig. 5b suggests the frequency distribution of the slope angles associated with social value points was more leaning to the right than that of GPS points. Specifically, visitors were likely to value areas with a steeper slope, but such places challenged most hikers, and consequently, very few users visited these locales. In addition, the slopes of social value points were more volatile than that of GPS points. However, because slope angles could only take on a value from 0 to 90°, the heavy right tail from the slope distribution was less prominent as compared to elevation.

Zonal statistics were examined to verify the distribution of elevation and slope angles for each land-cover type. Results from sorting the average elevation and slope suggest that certain places with symbolic values located on rugged terrain will incur significant travel cost to most backcountry hikers who wish to physically reach those places. First, the behavior of most recreationists avoided direct passage through landscapes of snow and ice, yet it was a highly valued land-cover type. Table 4 shows that snow and ice were the landcover type with the highest elevation and fourth steepest slope. Second, travelers had a high propensity to hike on bare ground, which was a land-cover type considered less important (i.e., ranked 10th). Table 3 further suggests that bare ground was associated with less steep slopes. If we assume a positive correlation between the required body fitness and preparation level and rough terrain conditions measured by high elevation and/or steep slope, the travel cost incurred and difficulty to access this area are also higher. Thus, land-cover types with higher elevation and steeper slopes are less likely to be frequented. Backcountry recreationists also avoided open-woodland spruce environments because spruce woodland predominantly grow in lower elevation and could potentially limit visibility.

Comparing shortest distances to the park road from the social value and GPS points, we found there was a significant difference in distances to the park road for two datasets according to a Mann-Whitney U Test (p-value = 0.002). The median distance was 3157 m for the valued places compared to 2834 m for the places that are most frequented. Empirical CDFs in Fig. 6 suggest closer proximity to the park road for GPS points versus the social value points. Around 25% of the social value assignments were 30–60 km away from the park road and outliers of longer distance (>60 km) were evident through the long end tail of the CDF curve for the social value data.

4. Discussion

The purpose of this study was to link real-time use of backcountry recreationists documented by GPS tracking data with the perceived importance of places elicited from a PPGIS exercise to better understand how factors that influence high use areas by backcountry travelers deviate from valued places. Our study provides a focused sample of off-trail backpacking footprints that best represent travel decision making in a nearly trail-less landscape. We found a significant difference in the spatial density and distributions across backcountry units characterized by social value points and on-ground travel patterns. Geographically,

Table 2
Backcountry units ranked by social value points and GPS points.

Backcountry units	Distance to park road (km)	Social value frequency[a]	Social value percent[b] (%)
Unit 45 - Mount McKinley	35.714	135	21.565
Unit 31 - Polychrome Mountain	0.044	40	6.390
Unit 8 - Polychrome Glaciers	0.043	39	6.230
Unit 11 - Stony Dome	0.042	28	4.473
Unit 10 - West Branch Upper Toklat	0.044	28	4.473
Unit 5 - Upper Sanctuary	0.044	25	3.994
Unit 12 - Sunset/ Sunrise Glaciers	0.044	23	3.674
Unit 7 - Upper East Fork	0.169	22	3.514
Unit 42 - Eureka Creek	0.92	20	3.195
Unit 19 - Pirate Creek	3.161	19	3.035
Backcountry units	**Distance to park road (km)**	**GPS points frequency[c]**	**GPS points percent[d] (%)**
Unit 13 - Mount Eielson	0.044	38416	11.297
Unit 6 - Upper Teklanika	0.043	34249	10.072
Unit 9 - East Branch Upper Toklat	0.041	32563	9.576
Unit 8 - Polychrome Glaciers	0.043	30613	9.002
Unit 10 - West Branch Upper Toklat	0.044	25616	7.533
Unit 12 - Sunset/ Sunrise Glaciers	0.044	21283	6.259
Unit 33 - Stony Hill	0.043	16858	4.957
Unit 7 - Upper East Fork	0.169	16067	4.725
Unit 4 - Upper Savage	0.043	15984	4.700
Unit 31 - Polychrome Mountain	0.044	12576	3.698

Notes: Visitor group sample size N = 123.
[a] Number of geolocated social value points intersected with each backcountry unit.
[b] Percentage of geolocated social value points intersected with each backcountry unit among the social value data sample (n = 830).
[c] Number of GPS points intersected with each backcountry unit.
[d] Percentage of GPS points intersected with each backcountry unit among the GPS tracking data sample (n = 370033).

the backcountry travel routes in Denali were less dispersed than areas perceived to be important. In line with previous research (van Riper & Kyle, 2014), respondents valued but did not travel to less accessible areas of the park. Overlap between GPS and PPGIS data was observed near access points within the protected area, particularly the park road and units that were popular destination stops for visitors. The deviation of observed travel behavior from perceived social values could be attributed to the differences in terrain conditions summarized by elevation, slope, and land cover types and proximity to the park road. Our results thus suggest that high travel cost was one important consideration when backcountry travelers weighed better scenic views against increasing difficulty to reach viewpoints.

Areas that were not places for direct onsite travel for backcountry users were remote backcountry units far away from the park road and/or places with steeper slopes, extremely high/low elevation, and a land-cover type of snow-ice, indicating steep, elevated, and snowy terrain were key indicators of high travel cost. These factors were instrumental in shaping the decisions being made about trips before outdoor recreationists saw the protected area (Gstaettner et al., 2020). Previous research indicates that visitors prefer hiking routes that offer the best longview visual experiences; however, the benefits of these experiences must outweigh the cost (Mannberg et al., 2018). If visitors are to travel in these contexts, the costs incurred by rough terrain are likely shaped by at least three factors: (1) Physical fitness: High altitude travel requires above-average physical conditioning (Leggat, Shaw, & Milne, 2002). Lack of fitness may result in major health problems or exacerbate some pre-existing medical illnesses when traveling in particular terrain conditions (Luks & Hackett, 2022). (2) Skills and preparation: traveling in an area with steep slopes requires proper climbing skills and sufficient preparation to be familiar with local weather conditions and to handle emergency situations. One must practice for a long period of time to develop the required skills. In most cases, the preparation work is also time-consuming (Hadley, 2014). (3) Financial costs: The proper gear is required for safe travel in rough terrain. This gear is often expensive to purchase or rent, which directly increases the costs for potential travelers (Smart et al., 2021). As a result, a route that requires strenuous climbing up hills may pass through snow-ice or a dense canopy of trees that result in prohibitive travel costs to most backpackers. Such a route may be less attractive to average backcountry users and therefore reserved for more experienced recreationists. This result provides evidence that recreationists adjust their plans about hiking routes and travel behavior based on an assessment that integrates the perceived importance of places and incurred travel costs. In contrast, travel costs are less likely to affect social value assignments, especially intrinsic social values, possibly because high "risky" terrain can still be seen from a distance along with panoramic views of Denali (e.g., Savage Loop Trail, Eielson Visitor Center) and areas near the entry of the park (National Park Service, 2022).

Longview visual resources are key factors that influence visitors' experiences of valued places (Gobster & Smardon, 2018; Liu & Nijhuis, 2020). The fulfillment of social values can occur through multiple pathways that respond to place-based conditions. In the context of Denali, traveling through a landscape in which people can see the snow-capped peak from a distance may fulfill their desired social values for Denali and maximize enjoyment from their trip (Drabelle, 2021). That is, visitors do not need to physically camp or climb Denali's slopes as a mountaineer to enjoy the namesake of the protected area. Given that an unobscured view of the peak is a major draw for tourists, weather conditions, particularly recent increases in wildland fire smoke events and degraded air quality (Buxton et al., 2017, 2020; Zajchowski et al., 2018) add a layer of uncertainty that carries potential to impact the quality of visitor experiences. Visual resource stewardship in designated wilderness thus provides another explanation for the misalignment between observed travel patterns and the perceived social values of visitors. Despite the fact that ravel costs and long-view visual resources are considered primary factors for explaining why travelers' observed behaviors deviate from perceived social values, many other factors affect route selection, such as prior knowledge and advice from others.

Although Denali's backcountry management plan limits visitation to 44 backcountry units to reduce environmental degradation (Stamberger et al., 2018), this study suggests that visitor use is still concentrated in units close to the middle sections of the park road. Only 41 backcountry units have visitor quotas, though we found visitors tended to visit only 33 units. These points highlight the importance of educating backcountry recreationists on multiple ways to minimize their impacts (Kidd et al., 2015). For example, although visitors are advised to avoid informal "social trails," future efforts should continue to emphasize this point and inventory these trail systems. Additionally, the protected area delivers important safety messages and training for backcountry travel in Denali's wilderness due to the risks associated with wildlife behavior. As a corollary, we provide backcountry staff with insight on how to focus their patrol efforts and educational training, especially for new visitors embarking on their first trips into the Alaska's wild lands.

Future research should continue exploring high resolution spatial and temporal information about weather conditions (Verbos & Brownlee, 2017), accessibility (Dudek, 2017), and terrain features (Brown & Weber, 2011) to gain a more complete understanding of how travel costs are factored into the decisions being made by outdoor recreationists. To

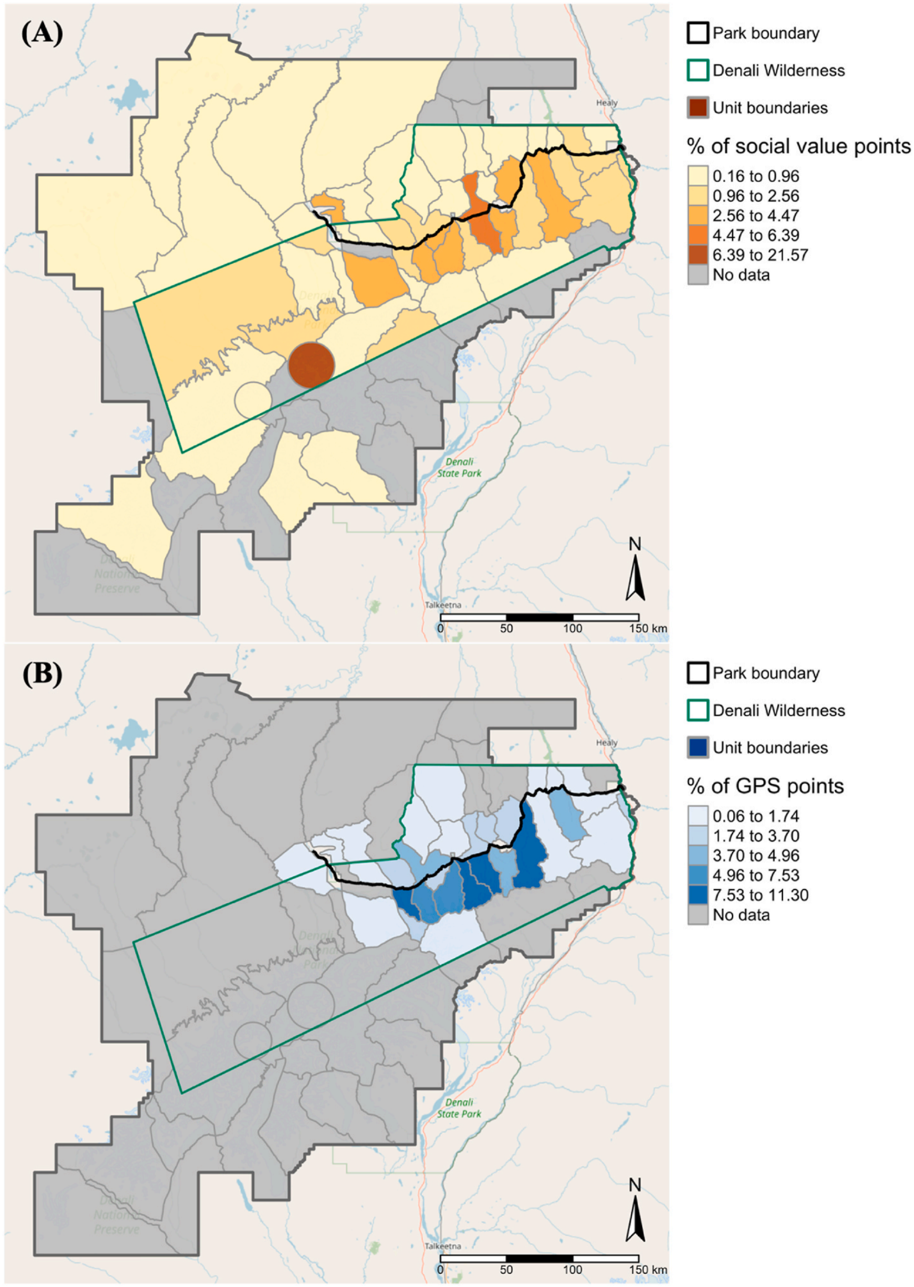

Fig. 4. Backcountry unit map showing density of social value points mapped by survey respondents (A) and GPS tracks (B)
Notes: Visitor group sample size n = 123. Basemap layer was sourced from OpenStreetMap.

fully understand the relationship between observed behavior through GPS tracking and perceived social values, an accurate and robust metric of travel costs is needed to structure appropriately the relationship between use patterns and travel costs in conjunction with other determinants of travel decision making (Freeman et al., 2014). Another important consideration for future work is to carry out a viewshed analysis on GPS tracking data to explicitly understand the importance of longview visual access (Barendse et al., 2016). In addition, many of the interpretations provided in this paper warrant careful consideration to guide future resource management decisions about how best to balance the quality of visitor experiences with potential forms of environmental degradation (Rice & Park, 2021). Because our treatment of social values assumed they were static and trait-like qualities, future work should aim to develop a deeper representation of social values using longitudinal or experimental research (e.g., Andrade et al., 2023) that will help to capture temporal variation in value assignments (Raymond et al., 2021). One final limiting factor of this study was that the backcountry travelers we engaged were specialized and not representative of all park visitors in Denali. The sample generated for this study is also not directly applicable to parks or protected areas with primarily developed frontcountry areas. Future research might consider extending our analysis to include day users or other stakeholder groups that are commonly found around protected areas.

4.1. *Implications for Protected Area Managers*

Multiple implications for resource management agencies can be gleaned from the study findings. First, decision-makers should distinguish between what is valued versus what is experienced. Building on previous research that has emphasized the intrinsic values of protected areas (Harmon & Putney, 2003), we provide empirical evidence that reaffirms these settings are important regardless of their use values.

Table 3
Social value points and GPS tracks in relation to different land-cover types.

Land-cover classifications	Social value frequency[a]	Social value percent[b] (%)
Low Shrub Birch-Ericaceous-Willow	186	22.410
Snow-Ice	160	19.277
Dwarf Shrub	103	12.410
Open-Woodland Spruce	72	8.675
Sparse Vegetation	59	7.108
Stunted Spruce	44	5.301
Alder	37	4.458
Shadow-Indeterminate	34	4.096
Low Shrub-Sedge	33	3.976
Bare Ground	32	3.855
Land-cover classifications	**GPS points frequency[c]**	**GPS points percent[d] (%)**
Low Shrub Birch-Ericaceous-Willow	75013	20.272
Bare Ground	70177	18.965
Dwarf Shrub	68587	18.535
Sparse Vegetation	54014	14.597
Low Shrub-Sedge	21255	5.744
Dwarf Shrub-Rock	16325	4.412
Stunted Spruce	14067	3.802
Open-Woodland Spruce	13222	3.573
Alder	6287	1.699
Shadow-Indeterminate	5769	1.559

Notes: Visitor group sample size N = 123.
[a] Number of geolocated social value points intersected with each land-cover type.
[b] Percentage of geolocated social value points intersected with each land-cover type among the social value data sample (n = 830).
[c] Number of GPS points intersected with each land-cover type.
[d] Percentage of GPS points intersected with each land-cover type among the GPS tracking data sample (n = 370033).

Second, we aim to shed light on management decisions that are regularly made around providing access versus restricting use. Some of the valued places we identified were too dangerous or too costly to be visited by the average traveler; for example, the peak of Mt. Denali was a site that respondents often valued and admired from a distance but without first-hand experience. In this case, it would not be appropriate or feasible to suggest that all highly valued places, such as Mt. Denali, be made more accessible to visitors. That is, decisions about how to distribute use patterns should be informed by place-based knowledge (Manning et al., 2022). Finally, our findings can help to direct managerial attention to high and low priority locations according to current travel patterns, alongside what is valued by park visitors. Following previous investigations of "hotspots" and "coldspots" in protected areas (Alessa et al., 2008; Johnson et al., 2019), management agencies might

Table 4
Land-cover types in relation to average elevation and slope angle in ranked order.

Land-cover classifications	Average elevation (m)
Snow-Ice	1894.873
Shadow-Indeterminate	1444.149
Sparse Vegetation	1251.757
Dwarf Shrub-Rock	1176.966
Bare Ground	1166.421
Dwarf Shrub	1075.559
Dry-Mesic Herbaceous	1027.439
Cloud	962.084
Herbaceous-Shrub	841.170
Low Shrub Birch-Ericaceous-Willow	782.149
Willow	690.044
Low Shrub-Sedge	647.088
Land-cover classifications	**Average slope (degree)**
Shadow-Indeterminate	27.740
Sparse Vegetation	20.836
Dwarf Shrub-Rock	19.450
Snow-Ice	18.595
Dry-Mesic Herbaceous	17.687
Bare Ground	17.506
Dwarf Shrub	15.857
Cloud	15.745
Herbaceous-Shrub	12.731
Alder	12.590
Willow	8.086
Low Shrub Birch-Ericaceous-Willow	6.494

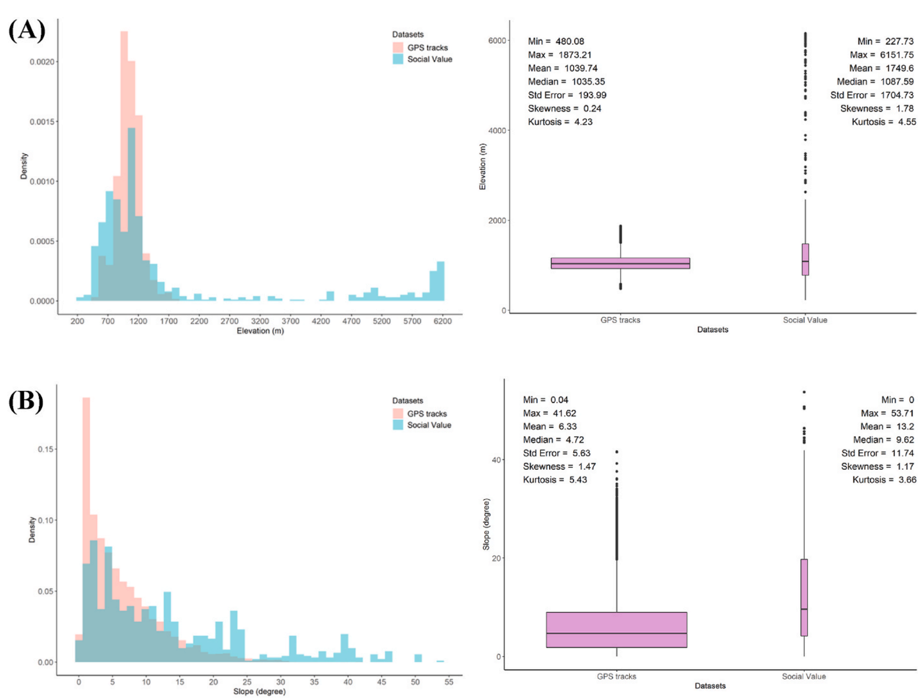

Fig. 5. Histogram (left panel) and boxplot of elevation (A) and slope angle (B) for GPS tracks and social value points.

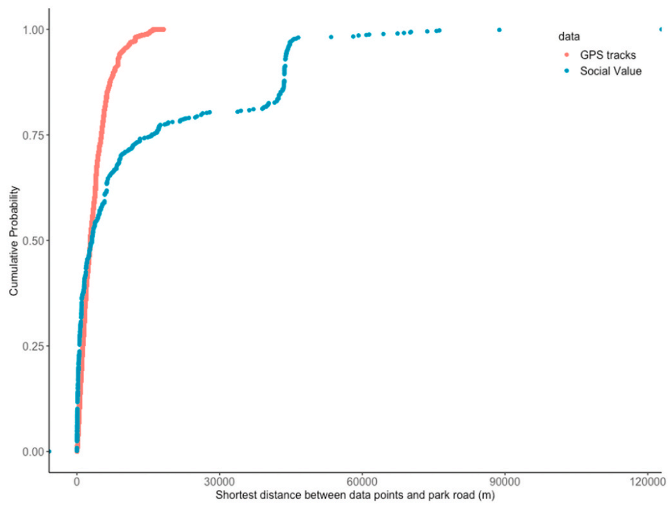

Fig. 6. Comparative cumulative distribution functions for shortest distances to the park road for social value point versus GPS points.

identify the most highly valued places that visitors want to experience within a short distance, and then carefully evaluate existing use patterns, travel safety and environmental vulnerability before drawing attention to this area. Accessibility to underappreciated or rarely used locales could also be improved in response to our study findings by constructing access roads or pullouts that signal a point of interest. Recommendations on how to safely travel in these contexts could also be offered to minimize environmental degradation.

5. Conclusion

Protected area conservation requires understanding the ways in which visitor use and behavior connect with environmental conditions. Eliciting insights on both the tangible and intangible values of nature through participatory research is particularly important – albeit a contested process – to encourage broad engagement and stewardship among stakeholders in ways that fairly represent diverse interest groups (Goodson et al., 2022; Tallis & Lubchenco, 2014). In outdoor recreation contexts specifically, there is a strong need for research to be rooted in the transactional and dynamic relationships between people and the physical spaces they occupy (D'Antonio et al., 2021; Zube, 1987). This research approach will not only incorporate public perspectives into resource management decisions but do so in ways that integrate spatial and temporal scales and thus represent the complexities of visitor use (Perry et al., 2020). Our results indicate that backcountry travel routes in Denali were less dispersed than areas that were ascribed social values. Use was mostly concentrated in backcountry units close to the middle sections of the park road while highly valued units coincided with major landmarks, such as Denali. We further suggest that travel costs induced by terrain conditions (summarized by elevation, slope and landcover) and accessibility (measured by proximity to the park road) contributed to observed travel behavior deviating from perceived social values. Our results have important implications for longview visual resources as a reason for why people assign value to but do not visit remote settings in protected areas. We also aim to inform policy and management decision on dispersed use, visitor safety and visual resource stewardship.

Author statement

Chang Cai: Writing – original draft preparation, formal analysis; Carena van Riper: conceptualization, writing – original draft preparation, supervision; project administration; funding acquisition. Dana Johnson: writing - review & editing, formal analysis, data curation; William Stewart: writing - review & editing, funding acquisition; Christopher Raymond: writing - review & editing; funding acquisition; Riley Andrade: writing - review & editing, supervision; Devin Goodson: writing - review & editing; Rose Keller: writing - review & editing, funding acquisition.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apgeog.2023.102958.

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