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The use of socio-spatial data for sustainable roads planning: a national forest case study

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National forest roads allow access to public lands providing connections to natural and cultural heritage. Planning processes that address potential road closures or conversions can be highly contentious. Public participatory GIS (PPGIS) has been used as a tool to gather information for environmental planning and decision-making. Our PPGIS approach in a national forest in Washington (USA) incorporated workshops and online engagement with 1,810 participants to gather public input for sustainable roads planning. We identified the most important forest destinations and developed an analytical framework for assessing forest roads based on the density and diversity of use. In this paper, we summarize our PPGIS process and identify challenges faced in the application of socio-spatial data. A comparative analysis of road planning in other forests further highlights challenges in incorporating public use data. While the PPGIS process was valued for relationship-building, it is less evident how directly the socio-spatial data informed outcomes.

Keywords: public participation GIS; roads; environmental planning; travel management; national forest

1. Introduction

Effective resource management requires integrated scientific information to support decisions around issues that directly affect people and their use of natural resources (Pierce *et al.* 2005). Social science data can be used in environmental decision-making in several ways: to identify and evaluate tradeoffs associated with management alternatives; to reach decisions that support both human and ecological health; to better understand local socio-ecological conditions; to anticipate variations in social values and landscape uses; and to consider the impact on stakeholders and communities (Charnley *et al.* 2017). However, merely providing social science data to planners is insufficient to trigger its ultimate use in environmental planning or decision-making (Bennett *et al.* 2017). The integration of social science data into institutionalized planning and monitoring processes includes challenges associated with readiness to receive or respond to new information, capacity to adopt new methods, or processes to support integration (Pietilä and Fagerholm 2019).

The past decade has seen a flurry of studies exploring the ways in which public participation geographic information systems (PPGIS) can be used to support

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environmental planning and decision-making (Brown, Sanders, and Reed 2018; Brown 2012; Kahila-Tani, Kyttä, and Geertman 2019; Pietilä and Fagerholm 2019; Morehouse *et al.* 2010; Pocewicz and Nielsen-Pincus 2013; Ramirez-Gomez *et al.* 2016; Sherrouse, Clement, and Semmens 2011, Tyrväinen, Mäkinen, and Schipperijn 2007). Much of this work focuses on collecting spatially explicit data on how people use and value different parts of landscapes (Brown and Kyttä 2018; Brown and Kyttä 2014; Kahila-Tani, Kyttä, and Geertman 2019). An important rationale for collecting PPGIS data is that it is potentially more compatible with biophysical GIS data layers than other forms of social science data, and therefore can more easily be integrated into environmental planning analyses (Brown and Kyttä 2014, Sherrouse, Clement, and Semmens 2011). Reviews of researcher-led projects aimed at integrating PPGIS into environmental planning have found little evidence that the results of such projects are adopted into agency planning processes beyond short-term trials (Brown 2012; Brown and Fagerholm 2015, Brown and Kyttä 2018). However, a review of 203 PPGIS projects that used the user-friendly and customizable Maptionnaire software (Kahila-Tani, Kyttä, and Geertman 2019), suggests that uptake by agencies may be more likely if researchers work closely with planners in designing the research protocol, particularly in the early project phases. In a study of PPGIS use by national park managers in Finland, Pietilä and Fagerholm (2019, 1140) found that managers were most interested in data that were "as concrete as possible and clearly associated with planning site management actions".

Challenges in using PPGIS information in planning stem from a variety of factors. Brown (2012) attributes the lack of interest on the part of government agencies in adopting PPGIS methods to fear of placing too much control over decision-making in the hands of the public, lack of experience conducting public engagement, and regulatory barriers to the collection of data from the public. Environmental planners may not be familiar with social science data analysis techniques or understand the conditions that guide their use (Brown, Reed, and Raymond 2020; Bennett *et al.* 2017). Moreover, there may be uncertainty about how to integrate data stemming from different sources or collected at different spatial or temporal scales (Pietilä and Fagerholm 2019; van Wyk *et al.* 2008). One institutional barrier for incorporating PPGIS is the agency's lack of resources, personnel, or skills to manage and use the data (Kahila-Tani *et al.* 2016). Morehouse *et al.* (2010, 125–126) point out, that although resource planners "have some knowledge of public values and perceptions, it is often unclear how these values might be specifically incorporated into the planning process." van Wyk *et al.* (2008) explain that social science data are not always incorporated into decision-making in recognizable ways even when (a) the data are recognized to be of high quality; (b) direct alignment exists between the data generated and a specific management need; and, (c) the data are prepared with the end user in mind. The lack of a clear understanding of how social science data fits within the analysis frameworks that agencies use constitutes a barrier to using such data in environmental planning.

In this article, we seek to enhance understandings of how PPGIS data can be integrated into natural resource agencies' analytical frameworks to overcome barriers to the use of science in planning. To do so, we discuss how socio-spatial data analysis techniques were adapted to fit with the travel analysis process for roads management implemented by the US Forest Service. First, we seek to understand the role of social science data and its use in travel analysis processes broadly. To do this, we describe the range of analytical approaches and decision criteria used for national forests in

Washington and Oregon to develop their travel analysis reports (TARs). Next, we discuss the travel analysis process in the Mount Baker-Snoqualmie National Forest (MBSNF), where a PPGIS approach was requested by resource managers. We explain the collaborative engagement effort undertaken, the PPGIS approach used, and the generation of a socio-spatial dataset. We then discuss the iterative engagement with the travel management planning team to create an analytical map that prioritized roads based on the density and diversity of public use. We then explain how the maps and data ultimately were used in the national forest's final assessment. Our example sheds light on opportunities and challenges social scientists and applied geographers face in generating relevant, actionable data for immediate use in resource planning.

2. Literature and context

2.1. Use of GIS in roads management analysis

GIS is used to analyze road networks in a variety of ways, including examining route choice (Papinski and Scott 2011), traffic volume (Niemeier and Beard 1993), road capacity (Wang *et al.* 2014), travel costs (Salonen and Toivonen 2013), travel behavior (Zhang *et al.* 2012), and accessibility (Miller and Wu 2000). PPGIS also has been used in transportation planning for eliciting public input on a variety of issues including highway routing choices (Bailey and Grossardt 2010; Tang and Waters 2005), highway transportation goals identification (Griffen 2014), exploring mobility patterns and routes used to accessing recreational areas (Laatikainen *et al.* 2017), and safety and accessibility concerns related to walking and biking in urban and suburban environments (Schlossberg and Brehm 2009). A literature review of PPGIS in transportation decision-making from 1997 to 2020 found that PPGIS participants typically provided data but were generally not directly involved in decision-making processes (Giuffrida *et al.* 2019). One study on public participation processes for road and forestry planning revealed a reticence for planners to be involved in public engagement processes (Blicharska *et al.* 2011). For public lands road networks, GIS-based analyses have examined transportation costs for forest products (Gumus, Acar, and Toksoy 2008), environmental impacts of road networks (Girvetz and Shilling 2003), differences in travel route preferences for motorized and non-motorized recreational users (Albritton and Stein 2011; Shilling, Boggs, and Reed 2012), accessibility for different types of logging equipment (Picchio *et al.* 2018), and unauthorized route creation by border patrol officers on the US-Mexico border (Whitbeck and Fehmi 2016). Drăgoi, Palaghianu, and Miron-Onciul (2015) used an analytical hierarchy process that incorporated social, economic, and ecological variables to develop a benefit-cost-risk analysis for planning a forest road network in Romania.

Few PPGIS applications have focused on road networks found on public lands, such as parks or forests. One exception is Brown's (2003) assessment for a 'scenic byways' planning project in Alaska where respondents identified qualities associated with particular highway corridors. Brown recommended that hotspot analysis be used to rank highways according to their abundance of scenic byway criteria, with the subsequent rankings being used to prioritize which highways to nominate as scenic byways. In another study, Brown and Reed (2012) completed a values compatibility analysis for proposed off-highway vehicle (OHV) use areas on the Mt. Hood National Forest (Oregon), obtaining spatially explicit data on forest values and special places. They combined PPGIS results with a GIS layer of proposed OHV areas, and used density analysis and diversity analysis to identify locations where OHV use was in conflict or compatible with forest values. The authors do not speak to whether or how these data were used by the national forest.

2.2. US Forest Service travel management planning process

A network of approximately 745,000 km of roads provides access to national forests in the United States, with roughly 621,000 km managed by the US Forest Service (USDA-FS 2001). Most of these roads were originally built to transport lumber and other raw materials out of the forest or provide fire suppression and administrative access (Gucinski *et al.* 2001). However, by the late 20th century, the use of national forest roads for recreation had far surpassed their use for timber-related activities (USDA-FS 2001). Moreover, in the face of declining budgets, the US Forest Service no longer had the capacity to maintain such a large road network (USDA-FS 2001).

In 2005, the US Forest Service adopted a Travel Management Rule (36 CFR 212.5(b) Subpart A) requiring all national forests to conduct science-based travel analyses of their road systems by 2015. The ruling did not require that the planning team gather public input, but some national forests incorporated listening sessions, public meetings, or online feedback into their travel management assessment processes. The planning process relied on use of an interdisciplinary (ID) team comprised of specialists tasked with integrating biophysical, economic, safety, engineering, tribal connections, and public use data (Cerveny *et al.* 2011; Garcia 1989). This planning approach is based on a rational planning model, (Simon 1955), which emphasizes the amassing of data and use of objective analytical criteria to evaluate and prioritize various inputs to the model (Boyne *et al.* 2004). As scholars have noted, rational planning approaches are not always ideal in addressing resource decisions that have a strong policy element or that have implications for public use, often resulting in decisions leading to further conflict, decision paralysis, and public dissatisfaction (Lachapelle, McCool, and Patterson 2003). The travel analysis reports (TARs) produced to comply with the Travel Management Rule were intended to be a first step toward each national forest developing a travel management plan specifying which roads they will continue to maintain, which they will decommission, and which they will convert to other uses.

Roads provide public access to places in the forest that have meaning and use for people. National forests are sources of livelihoods, and provide opportunities for outdoor recreation, subsistence, and nature connection. Roads are especially important for senior citizens, families, and people with disabilities who seek nature connection and solitude that is accessible (Bengston and Fan 1999). An organized road network is critical for sustainable management of forest resources (Gumus, Acar, and Toksoy 2008). The prospect of decommissioning treasured forest roads or downgrading their maintenance levels caught the public's attention throughout the United States, and in some cases, erupted into controversy. For example, when the Wallowa-Whitman National Forest in eastern Oregon announced their travel management decision, county commissioners and residents raised concerns about the lack of public involvement, resulting in a retraction of the plan (Cockle 2010). In California, a legal coalition sued both the Plumas National Forest and the Tahoe National Forest over their motorized travel plans (Wathen 2017). National forest supervisors who had waited to begin the travel management planning process, watched with concern and began to formulate efforts to engage the public early in the planning process.

2.3. Study context and planning process

This study takes place in the US Forest Service's Pacific Northwest Region, which includes 16 national forests and grasslands in Washington and Oregon. Our case study took place in the Mount Baker-Snoqualmie National Forest (MBSNF) located in northwestern Washington (USA) on the western slope of the Cascade Mountain Range (Figure 1). The 6,870 sq km. forest borders Canada on the north and extends south 370 km to Mt. Rainier National Park (USDA-FS 1990). The MBSNF is close to several large urban areas, with parts of the forest located within 100 km of the Seattle (WA) metropolitan area (pop. 3.9 million) (State of Washington 2015) and 70 km of the Vancouver (BC) metropolitan area (pop 2.5 million) (Statistics Canada 2017). Forest officials claim that the MBSNF is the most heavily visited national forest in the United States, with about 2.0 million annual visitors (USDA-FS 2010). Steep topography and dense vegetation make travel through and across the MBSNF and surrounding areas difficult; most major transportation routes closely follow rivers and only three major highways cross the Cascade Mountain Range within the forest's boundaries. The forest includes 3,927 km of roads used for a variety of purposes, including providing access for recreational use, timber harvesting, safety and fire protection, tribal areas preserved in treaty rights, and private inholdings (USDA-FS 2015a). At the time of the project, forest officials claimed to have resources to maintain 35 percent of the existing road system, or 1,344 kilometers of road (USDA-FS 2015a, 14).

Eager to engage the public early in the travel management process, the MBSNF supervisor solicited assistance from social scientists (authors of this paper), to develop a broad-based public engagement process that would allow the general public to have input into the MBSNF travel analysis. The project was highly collaborative in nature, with the social science team working closely with forest officials and an affiliation of partner organizations to design and implement the PPGIS approach and to generate data that could be readily incorporated into the planning process. The intent of the public engagement efforts was to identify which roads on the MBSNF are used by a broad spectrum of forest visitors as well as the types of visitor activities for which road access is needed. The project occurred over the course of two years in three major phases, the planning phase, the public engagement phase, and the analysis phase (Figure 2).

3. Study methods and approaches

3.1. Analysis of travel analysis reports

To understand the role of social science data and use in travel management planning broadly, we conducted a content analysis of sixteen Travel Analysis Reports (TARs) for each national forest in the Pacific Northwest Region (USDA-FS 2019). The national forests used three broad categories of factors (economic/administrative, ecological, and social) in their travel analyses. To systematically assess the reports, we established criteria for exploring (a) the types of economic, social, and ecological factors included in the decision criteria; (b) incorporation of public use data; (c) method for public engagement.

3.2. Participatory GIS in the Mount Baker-Snoqualmie National Forest

In 2013, the Sustainable Roads project team was formed, consisting of MBSNF forest leaders, members of the MBSNF interdisciplinary (ID) planning team, social scientists from US Forest Service Research and Development, geo-spatial researchers from a nearby university, and representatives of an emerging group of 44 partner organizations, known as the Sustainable Roads Cadre. The core project team worked closely for several weeks to engage in co-learning and to identify appropriate information outputs that would be most useful to the MBSNF ID team. While MBSNF forest officials and public affairs specialists led the team, MBSNF ID team members, including the hydrologist and engineer engaged closely with the project team. The

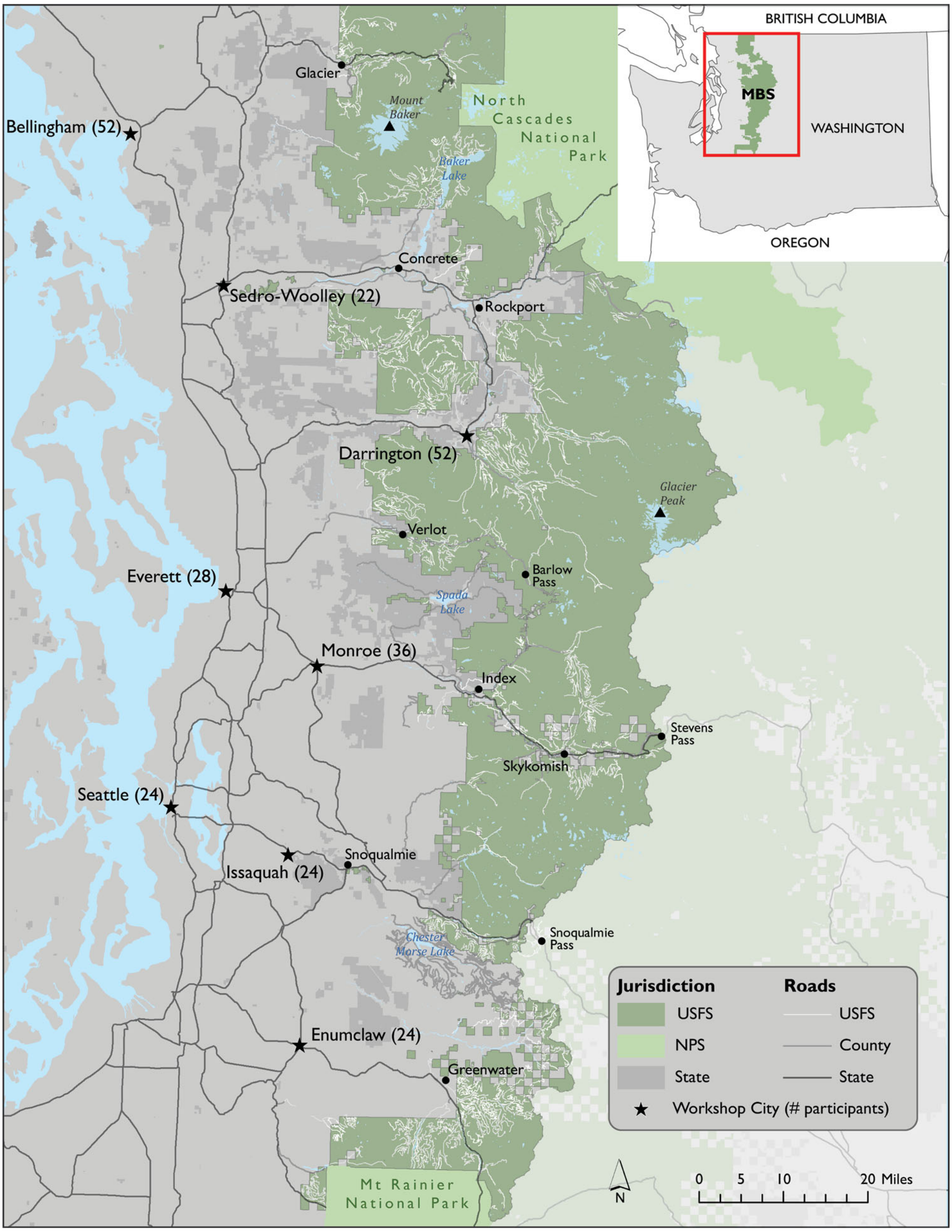

Figure 1. Mount Baker-Snoqualmie National Forest road system.

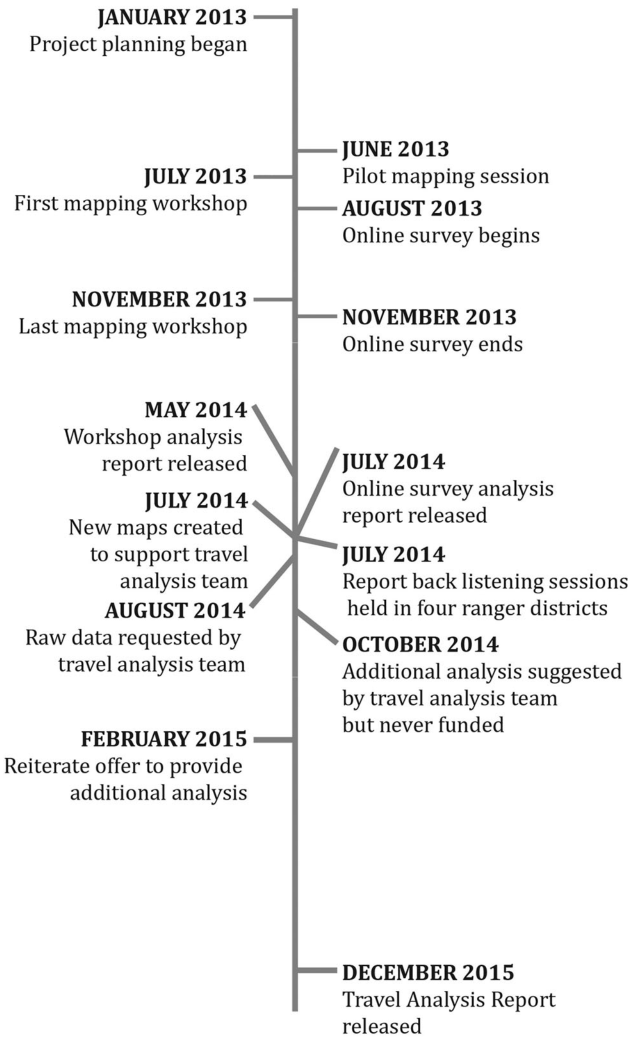

Figure 2. Mount Baker Snoqualmie Sustainable Roads planning process.

team used a co-development approach, with all members actively shaping the study design, protocols, and implementation. The intent was to generate a socio-spatial data layer of ‘public use data’ that identified user preferences of forest roads that the ID team could integrate with biophysical and infrastructural data layers to inform their assessment.

Two concurrent public engagement methods were designed to promote dialogue and gather public input about road use in the MBSNF. Community workshops engaged local stakeholders in constructive dialogue and built trust in the process while gathering important data about forest road use. An online survey that mirrored the workshop questions allowed local and non-local participation. Details of the methodological approach used are provided elsewhere (McLain *et al.* 2017; USDA-FS 2015b; Wilderness Society 2015) and are summarized below for continuity.

The authors acknowledge the importance of protecting human subjects and adhered to policies and protections outlined by the US Department of Health and Human

Services (Office for Human Research Protections 1991). Each participant was informed at the time of registration that by signing in, they were providing consent to participate in a research study. Registration forms were stored separately from data gathered in worksheets and were never linked to actual data. Workshop participants were informed verbally by the research team that their data would be treated in a confidential manner, that responses to all questions were voluntary, and that they could skip questions or feel free to leave at any time. They were informed that no data would be attributed to them or described in a way that they could be identified. These instructions also were repeated by table facilitators. Similarly, survey participants were also informed that the data being gathered would be used for research purposes. They checked a box confirming agreement to participate and were informed that their participation was voluntary, that they could skip questions, or discontinue the survey at any time, and that their data would not be used in a way that they could be identified. The Institutional Review Board of Portland State University waived the need for review in 2013 because the GIS data analyzed by the university team were considered secondary data gathered by MBSNF officials and partners. The GIS dataset did not come with personal identifiers. All steps were taken to protect the confidentiality of research participants in the processing of data and rendering of study results.

3.2.1. Use of a PPGIS approach for identifying priority forest destinations and roads

Eight workshops were held in both urban and rural communities resulting in 262 participants. Workshop recruitment was a coordinated effort by MBSNF officials, which relied on traditional media outlets, and the Sustainable Roads Cadre, which used social media. The focus of the workshops was a mapping exercise where participants marked priority forest destinations and roads used to access those destinations. Participants gathered around tables with two facilitators (members of the Sustainable Roads Cadre). Two large maps (160×102 cm) on each table featured the northern and southern segments of the MBSNF. Maps featured prominent landmarks, roads, and trailheads and were at the scale of 1:72,000. Facilitators asked workshop participants to identify up to eight locations in the MBSNF of importance to them and assisted participants in wayfinding on the maps and navigating the protocol. Selected sites were identified with colored sticker dots and participants used a color-coordinated pen to trace the route traveled to access that destination from the nearest major roadway. Follow-up questions were asked on accompanying worksheets for each location (e.g. activities, frequency of visitation, etc.). On average, workshop participants identified seven sites and routes (Figure 3).

In tandem with the community-based workshops, the Sustainable Roads Cadre sponsored an online survey resulting in 1,548 respondents. The survey questions largely mirrored the workshop protocol; however, the condensed project timeline did not allow development of an interactive mapping application. Rather, participants were asked to name destinations and describe their locations, using a pdf version of the MBSNF road system map for reference. They were also asked to provide forest road numbers or road names to indicate routes. Roughly half (727) of the participants noted at least one mappable destination. On average, online participants mapped 3 destinations. Notably, there was a drop-off in the number of participants identifying multiple destinations, with 290 providing four destinations and only 10 noting eight destinations.

Figure 3. Mount Baker Snoqualmie Sustainable Roads mapping workshop, 2013.

3.2.2. Socio-spatial analysis to identify high-priority roads

GIS data were created in ArcGIS 10.2.2 from the workshop map markings using a comprehensive dataset of roads obtained from the US Forest Service as a baseline. The mapping process was fraught with challenges. For the workshops, some participants did not clearly mark a particular road but used a straight line to approximate the route. This was especially common in areas with a high density of roads. Our team attempted to discern the most logical route to the marked destination. Destination points were digitized as placed on the map, with a few exceptions. Destinations points placed away from the road system were moved to the end of the route traveled, where they likely parked their cars. The road data from the online survey had numerous errors and inconsistencies; there were mismatches between road names and road numbers and between roads and presumed destinations reachable on those roads. Given these inconsistencies, we did not analyze the roads data for the online survey, although the online survey provided reliable data on priority forest destinations.

3.2.3. Analytical products to inform travel management planning

The ID team lead for the roads planning process indicated that two measures they could use in developing the travel analysis would be road density (frequency of use) and diversity (the range of activities a road would provide access to). To create a map of road densities, the digitized routes from the workshop data were first intersected and then dissolved to obtain a count of overlapping road segments. Certain roads varied in their density values along their length, the result of using road segments rather than entire roads as the unit of analysis. The MBSNF ID team also requested destination and road density maps and maps indicating top forest destinations.

To create a map of the diversity of uses associated with forest roads, we used the Inverted Simpson index (Simpson 1949), a measure of species diversity that emphasizes common species rather than rare species. We were interested in a view of diversity that focuses on common rather than rare activities, which made the Inverted Simpson index appropriate for our use. We calculated diversity using an R package by compiling the counts for each of eight activity classes for each road segment. The activity classes included: hiking, winter recreation, motorized recreation, strenuous recreation, observation, collecting/harvesting, relaxation/camping, and cultural. (See USDA-FS 2015b for a description of activity classes). Participants mentioned as many as six different activities for a given road. We weighted each activity equally since there was no way to tell which one was done more frequently.

Subsequently, the MBSNF ID team requested that we re-analyze road density and diversity using entire roads so that each road, rather than each road segment, was assigned a rating. The planners also requested that we use three categories (high, medium, and low) instead of five categories to rate each road. To address these requests, we merged the road segments by road number and then averaged the results over the total road length. To account for the different ways in which we had analyzed the data (i.e. density, diversity, and top destinations), we used multi-criteria analysis to assign each road a single social value based on whether it had a high value for density, a high value for diversity, or was a route to a top destination. Roads meeting all the criteria were rated as 3 (i.e. high); if two criteria were met, we rated them as 2 (moderate), and if one criterion was met, we rated them as 1 (low). Roads that met none of the criteria were assigned a zero.

3.2.4. Science delivery, public feedback, and analytical revisions

The social science team provided the MBSNF ID team with four products derived from the density and diversity analyses: (a) a geospatial database, including all codes used and a user manual; (b) a 60-page final report, which provided an overview of the approach, analytical framework, methodology, and findings in the form of multi-color maps, with narrative explanations to accompany each map (USDA-FS 2015b); (c) an executive summary report of research highlights, geared toward general audiences (The Wilderness Society 2015); and (d) priority destination maps created by integrating the online and workshop destination data (Supplemental materials, Figures 1–3).

In 2014, four community feedback workshops (48 participants total) were co-organized by MBSNF officials and the Sustainable Roads Cadre to provide another opportunity for public comment and to demonstrate that the public views were being captured. Poster-sized maps were displayed showing the density of high-priority forest destinations and roads as well as spatial patterns of recreation activities and community use trends. Participants were asked to study the maps and then engage in guided dialogue about observed patterns, surprises, and omissions. Feedback sessions provided validation to both participants and the project team that the maps had effectively captured public priorities. The sessions were important for building trust and showing that the workshop data were generating products relevant to the roads planning process.

3.2.5. Document analysis and project evaluation of the public engagement process

Once the sustainable roads strategy report was published, our study team conducted a systematic document analysis to understand how public use data gathered by the study team was used in the analysis. In addition, the authors reached out by email to four members of the MBSNF ID team to ask for feedback about the usefulness of the PPGIS data used in the planning process. These comments helped to identify successes in the process as well as roadblocks in data use.

4. Results

4.1. The role of social science in shaping travel analysis reports for Pacific Northwest forests

In comparing the 16 Travel Analysis Reports (TARs) across national forests in the Pacific Northwest Region, we found that the types of economic/administrative and social factors included in the decision criteria varied widely (USDA-FS 2019). Economic/administrative factors typically taken into consideration included whether a road was important for providing access to special use areas, such as grazing leases or mining in-holdings, forest product extraction sites, and access for fire management, as well as maintenance costs. Ecological factors included vegetation, hydrology, aquatic habitat, wildlife, and wildlife habitat, especially for threatened and endangered species. Social factors included items such as whether roads provided access to developed recreation sites, highly frequented dispersed recreation sites, trailheads, OHV areas, or heritage and cultural sites. The national forests differed in the type and number of variables they included within each of the broad categories, as well as in their analysis procedures.

Most of the forest planning teams began their travel analysis with a risks/access needs assessment (also referred to as a risks/benefits assessment). The risks/access needs assessments rated the social, ecological, and economic/administrative factors for each road segment according to how likely they were to be negatively affected by the continued presence of the road or the extent to which that road segment was considered important for providing access to different types of sites or resources. Road segments were rated either using a multi-point scale (e.g. high/medium/low) or binary (presence/absence) designation. The initial rating for each variable was transformed into a quantitative value, which was then manipulated to create a summary rating. The factors were summed using a GIS overlay technique to construct a risks/access needs matrix. In one national forest (Umpqua), planners used more sophisticated GIS analyses that involved normalizing the risks and access needs factors so that their value was between zero and one, and then weighting the scores according to the planning team's assessment of the relative importance of each factor. In three forests (Olympic, Deschutes and Rogue River), planners used an analytical hierarchy process combining qualitative and quantitative factors for ranking and evaluating alternative scenarios. Ultimately, planning teams in all 16 forests produced maps depicting road segments that would likely be needed or not needed for future use. The percentage of the road networks the forests identified as "likely not needed" ranged from one to 33 percent.

The number of social factors incorporated into the travel analyses relative to other factors varied greatly across the forests and typically they were outnumbered by economic and ecological factors (Figure 4). Few normalized their risk and access needs scores and most gave all factors equal weight. For forest planning teams using the equal weights approach, the social factors inevitably carried less weight than economic or biological factors since fewer factors were assigned to the social category. Recreation was the social factor most likely to be represented by more than one variable. In most of the TARs, the recreation analyses were based on the presence and absence of recreational facilities rather than on spatially explicit and systematically

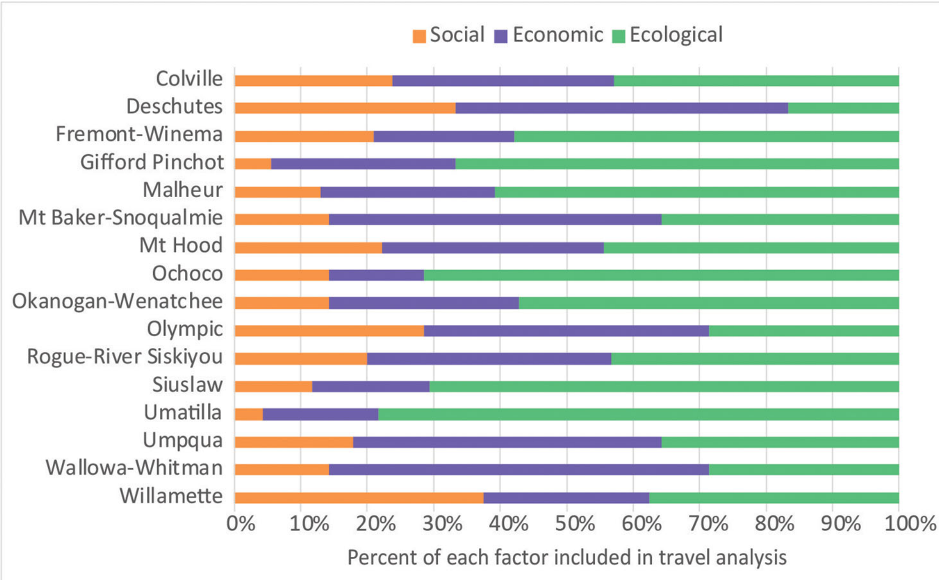

Figure 4. Decision criteria used in travel analysis reports for national forests in Washington and Oregon.

documented input from forest users about where they go to recreate, how often they go there, or what they do there.

There was little consistency across the forest planning teams in their incorporation of public use data or the public engagement practices. Ten of the travel analysis reports described using a current public involvement process to gather input for their analyses (Table 1). Public involvement generally focused on eliciting information about whether roads or road segments were used or not used, rather than systematically identifying what they were used for or how often they were used. The MBSNF public engagement process, which involved 1,810 individuals, was the most extensive.

4.2. Summary of public use data for the Mount Baker-Snoqualmie National Forest

4.2.1. Respondent characteristics of public engagement effort

We summarize demographic characteristics here, which also have been described in previous articles (McLain *et al.* 2017; USDA-FS 2015b; Wilderness Society 2015). In total, 1,810 people contributed to the workshops and online survey. There were 262 participants in the eight community workshops. Workshop participants were predominantly male (74%), who have lived in Washington for an average of 36 years. The average age of participants was 55 (Washington State average is 36 years). Nearly half (45%) participated in the workshops as official agency representatives. Participants reflected a broad range of education and income levels. There were 1,548 actual respondents to the online survey, although 1,776 initially logged on. Respondents were predominantly male (71%), with an average age of 51 years and had spent 32 years living in the area. Just 4% of respondents officially represented an organization or agency. Participants represented a broad range of education and income levels.

Table 1. Summary of public involvement for travel analysis for national forests in Washington and Oregon.

National Forest	Format of public engagement *	Information collected	Number of meetings	Number of participants	How information was used
Gifford Pinchot	- Held public meetings - Online survey - Gifford Pinchot Task Force survey	Spatial data Survey data	6 4 report back	- 128 meeting attendees - 220 accessed online survey - 228 responses to GPTF survey	Any roads marked are considered public interest
Malheur	- Held road-related meetings with public - Met with tribes and county - Co-opted previous public engagement	Not stated	Not stated	Not stated	Not stated
Mt Baker-Snoqualmie	- Held public meetings - Online survey	Spatial data Survey data	8 4 report back	- 275 meeting attendees - 1775 accessed online survey	Not stated
Mt Hood	- Held open house meetings - Solicited comments online	Not stated	4	Not stated	Not stated
Olympic	- Held open house meetings (with survey) - Online mapping survey - Solicited comments from tribes and timber industry	Spatial data Survey data	8	- 842 comments addressing road segments	10+ comments on a road considered high interest 1-9 comments considered medium interest
Rogue River-Siskiyou	- Held public meetings (directed to website to comment) - Co-opted previous public engagement	Not stated	Not stated	No appendix available	Not stated
Umatilla	- Held public meetings - Solicited comments at FS offices - Solicited comments from resource advisory committee and collaborative groups - Met with tribes	Not stated	6	Not stated	Not stated

(*Continued*)

Table 1. (*Continued*).

National Forest	Format of public engagement *	Information collected	Number of meetings	Number of participants	How information was used
Umpqua	- Held public meetings - Co-opted previous public engagement	Maps used at meetings	Not stated	Not stated	Not stated
Wallowa- Whitman	- Maps available to mark by public - Co-opted previous public engagement	Marked maps	N/A	Not stated	Not stated
Willamette	- Met with transportation stakeholder team - Held constituent group meetings - Held public meetings - Online mapping survey	Spatial data	24 groups 6 public	- 450 attended constituent group meetings - 100 attended public meetings - 1000 accessed on-line survey with 107 online comments	Not stated

* The following forests co-opted previous public engagement information: Colville, Deschutes, Fremont-Winema, Ochoco, Okanogan-Wenatchee, Siuslaw.

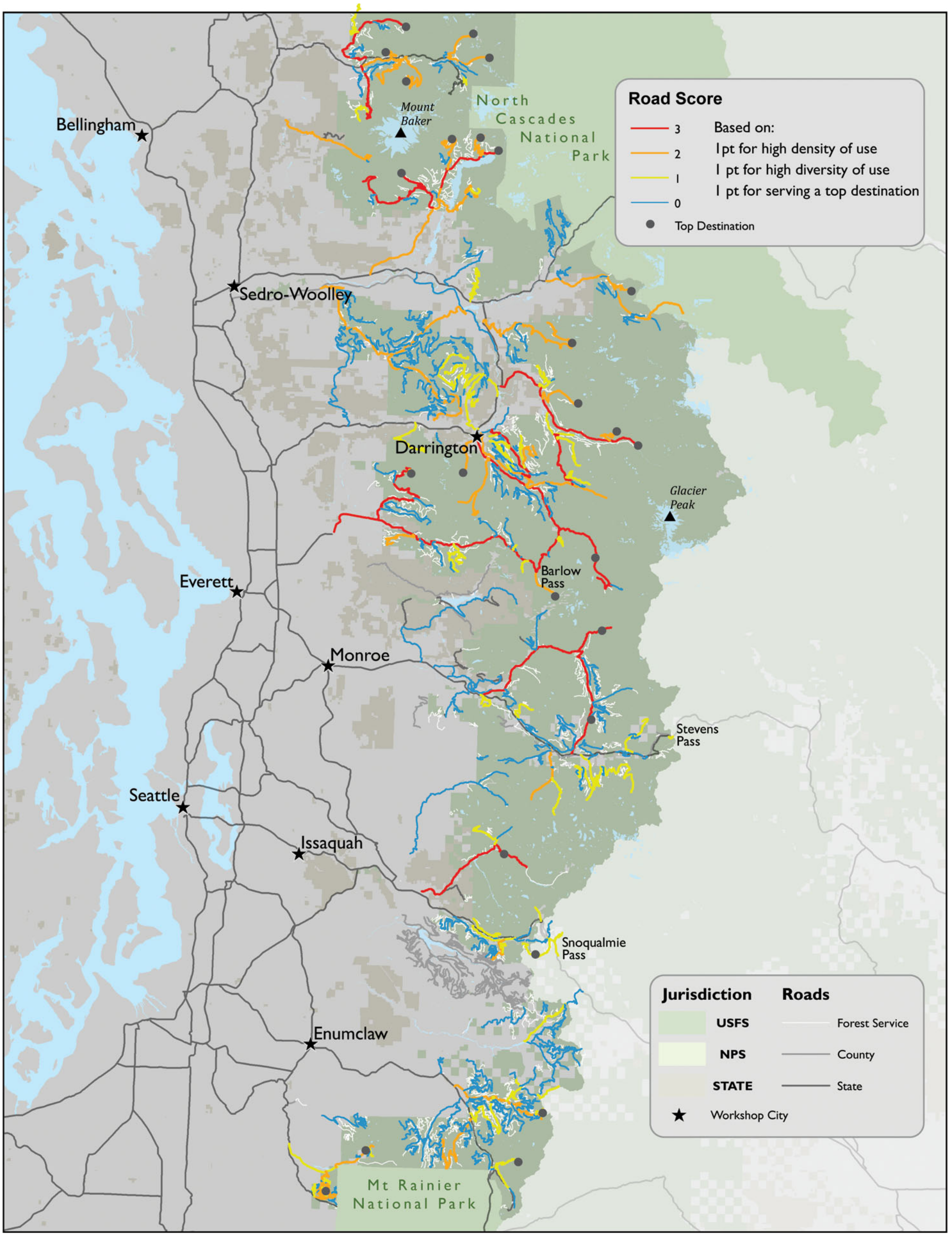

Figure 5. Overall ranking of roads marked during public engagement workshops for Mt. Baker-Snoqualmie National Forest using measures of density of use, diversity of use, and top destinations identified by the public.

4.2.2. Mapping road density and diversity on the national Forest

Using the multi-criteria social values data, we were able to assign ratings to all of the roads in the road network, thereby allowing us to readily identify spatially the portions of the road system that the public perceived as most important (Figure 5). Red roads were category 3 for high density and diversity. Orange roads were category 2 (moderate), yellow roads were category 1 (low) and blue roads were not marked by anyone in the study sample. Interestingly, approximately 30 percent of road miles in the entire MBSNF were not marked by any study participants, although they may be important to forest officials for administrative purposes or to users not represented.

4.3. *From knowledge to action: development of the sustainable roads strategy report*

In December 2015, the MBSNF supervisor released its forest-wide Sustainable Roads report (USDA FS 2015a), which describes the interdisciplinary planning process, decision criteria and recommended actions. Our careful document analysis revealed that the report followed a standard protocol often found in environmental assessments, which assess biophysical and social conditions. When it came to discussions of access, which is most germane to the public, the report summarized components in a standardized manner that reflects US Forest Service management categories, including vegetation management, recreation, cultural heritage, special uses, administrative needs, landowner considerations, and others. The report did not deviate from this standard organization to acknowledge the public use data generated by the PPGIS-driven public involvement process, even though the socio-spatial data were germane to recreation, heritage and special uses. Instead, these report sections relied on secondary data sources.

Despite significant investment by MBSNF leaders in the public engagement process in terms of staff time, resources, and expenditure, there was no documented evidence that the public use data our team had gathered had been systematically incorporated in the assessment. It also is notable that the authors worked closely with forest officials and the ID team to cater the data to their planning needs, resulting in a product that was of high relevance to travel analysis planning. The report contains no maps or GIS data we had provided. The first mention of our public engagement effort and the subsequent GIS analysis appears in a section on 'economic impact to communities' (USDA FS 2015a, 23), where the engagement process is described. The report our team produced through that process is referenced in an appendix (USDA FS 2015b). However, nowhere in the report is the data from the Sustainable Roads public engagement effort explicitly incorporated in the decision process.

This realization caused us to reflect on what we could have done differently to ensure that our results would be directly used in the ID team's analytical process. Post-project evaluation interviews with the MBSNF planning team indicated that the public engagement process had been highly valued, but acknowledged that the data use was not maximized. The ID team had faced capacity challenges, time constraints, and staff turnover during that inhibited their ability to work with and integrate the spatial data using their GIS platform.

5. Discussion

5.1. *Examining travel analysis reports across Pacific Northwest forests*

The Travel Management Rule of 2005 required that a science-based travel analysis be conducted in each national forest to assess the status of its road system (35 CFR 212.5 (b) Subpart A). It is well-understood that resource managers rely on scientific information to support decisions that have repercussions for public use of and access to natural resources (Pierce *et al.* 2005). Use of PPGIS data and analysis is increasingly recognized as useful in planning decisions and is particularly effective when done using a collaborative or co-development approach with resource planners and scientists engaging at multiple phases throughout the process (Fagerholm *et al.* 2021). Data from the TARs analysis and the MBSNF case study suggest that there has been limited use of social values data in these planning efforts.

A review of TARs completed for 16 national forests in the Pacific Northwest Region showed that in most of the TARs, the social values associated with forest roads were treated in a simplistic, binary manner (i.e. road used/road not used) rather than taking into account other criteria, such as the intensity or frequency of road use or the importance that forest users place on sites accessed along a particular road. Furthermore, the TARs collectively demonstrated a strong leaning toward ecological and economic data over social factors. And, social factors were heavily dominated by recreation use, particularly uses associated with developed recreation infrastructure.

Several additional features stand out about the travel analyses as revealed by the TARS report. First, for the national forests where substantive public involvement had been offered, (including the MBSNF), it is unclear whether or how such data were used. Second, the social data used in the TARs are heavily biased toward facility locations and do not incorporate systematically collected data about roads people use or the range of activities these roads support. Third, for every forest described in the TARS report, only a small percentage of the road network was categorized as likely not needed for future use. Given that nearly all roads were determined to be needed for future use, it is unclear how the travel analyses for these national forests will inform decisions when determinations about road closures or conversions are made. These findings suggest that there are inconsistencies in the integration of social science data and socio-spatial data across the region as well as varying degrees of engagement with the public around the roads question. In cases where forest officials had engaged the public or incorporate social data, it is unclear how the data shaped the travel analysis outcomes.

5.2. Incorporation of the density/diversity map in the road planning process

PPGIS scholars have pointed out the importance of researchers circling back to the planning teams and adapting analytical methods at different phases of the project to suit the needs of planners (Kahila-Tani, Kyttä, and Geertman 2019). This was a priority for the MBSNF sustainable roads project team. Yet, despite iterative engagement and agreed-upon adjustments to the density/diversity map, the analytic output created was not directly used. Our analysis of the MBSNF Sustainable Road Report found that the intensive public engagement effort that resulted in 60 pages of socio-spatial data appeared to have a very minimal role in shaping the analytical process. The MBSNF officials requested and received a map of the national forest indicating the priority roads based on a density/diversity index. These ratings could easily have been factored into the travel analysis, as could the 30 percent of roads that were not marked at all. However, instead of using the Sustainable Roads PPGIS data for the social component of the travel analysis, the planners used data from a recreation facilities analysis that provided data for only 1,460 km of roads, or only slightly more than one-third of the road system (USDA-FS 2015a). When we subsequently inquired whether and how the Sustainable Roads public involvement data was used, we were told, "The mapping data was discussed during the ID team meetings, but in the end it was primarily used as validation of the ID team analysis results." Meanwhile, the report demonstrated several examples where biophysical data had been incorporated. Having a variety of disciplinary specialists on the ID team does not guarantee that there will be a balance scientific information used; in fact, research on ID teams has shown that there is considerable discretion in the interdisciplinary process depending on team leadership, composition, and focus (Trusty and Cerveny 2012). Similarly, a study of the role of science in bioregional assessments for four national forest plans demonstrated the predominance of terrestrial and aquatic ecosystem data and the minimal use of social science, recreation or heritage data (Ryan *et al.* 2018). An ongoing challenge for PPGIS projects is encouraging planners to treat the social data layers in a manner equivalent to their use of biophysical data layers (Brown and Reed 2009; Brown 2012).

5.3. Critical importance of timing in the planning process

As others have noted, environmental planning process can occur over prolonged periods with times of dormancy interrupted by frenetic activity amidst shifting priorities (van Wyk *et al.* 2008). Alignment of planning with science providers is not always easy. Moreover, environmental planners are not always explicit about the integrated analytic models they will be using or how tradeoffs will be evaluated (van Wyk *et al.* 2008). Collaboration between planners and researchers during the early project phases builds trust and allows the development of shared understanding about how the data should be collected and analyzed, increasing the likelihood of integration (Kahila-Tani, Kyttä, and Geertman 2019).

Anticipating that the MBSNF planners might be unsure about how to use the Sustainable Roads PPGIS data, we approached the lead planners at the beginning of the project to find out what types of data and data formats would be compatible with the spatial analyses. Initially the MBSNF planners were unable to provide guidance since they had not yet developed an analytical framework. By the time they finalized the travel analysis framework, we had already collected and analyzed the PPGIS data. In response to requests from the planners, we adjusted our analysis and associated data layers to make them compatible with the ID team's analysis plan. ID team staff turnover may have inhibited data integration. Several ID team members transitioned to new positions after the public engagement process had been completed. Their successors were not familiar with the socio-spatial dataset and had not participated in the public engagement process, and thus were not as vested in the data outcomes generated by that process. Despite our efforts to work closely with the forest GIS team to ensure data compatibility, the ID team chose not to integrate the socio-spatial data we provided with other spatial data layers, which was how we had intended it to be used. Turnover has been identified as a barrier to effective outcomes in interdisciplinary processes (Stern and Predmore 2012).

5.4. Long-standing planning approaches and regulatory processes make it difficult to incorporate new forms of knowledge

Others have pointed to the pervasive practices (or planning habits) in bureaucratic agencies that rely on diffusion of planning approaches among employees (Rogers 2010; Sabatier, Loomis, and McCarthy 1995). One courageous national forest ID team will forge ahead to develop a planning process, data sources, analytical rubric, or report structure that is deemed successful (or acceptable), and this approach becomes standardized as others adopt the model. Over time, these approaches become institutionalized and embedded in agency practice as standard operating procedure (Pietilä and Fagerholm 2019). When faced with new sources of data, concepts, or processual approaches that might be extremely relevant, it may be difficult to incorporate these innovations or insights without changing the process, particularly when "what is tried and true often does the trick." Pressure to conform to existing processes is greater when the stakes are higher, the timetable is shorter, or there is external pressure (Sabatier, Loomis, and McCarthy 1995).

5.5. *Enhanced trust among forest agencies and partners is a positive outcome*

Even though the socio-spatial data that was customized for the MBSNF travel planning process was not integrated with other spatial datasets used to develop the travel analysis, the project was still deemed successful by all parties involved. Trust between stakeholders and agencies can grow when participants have trust in the process as well as enhanced interpersonal trust based on relationships (Stern and Baird 2015; McGee 2011). Increased trust through public interaction and citizen engagement can yield a tendency to future participation in planning (Vosick 2016) and public support for management decisions (McGee 2011). The MBSNF leaders emphasized the importance of the project as a means for building trust and increasing mutual understanding about what matters to people about forest access and their use of roads.

The project embraced a collaborative approach allowing the formation of strong ties among stakeholders. The public engagement process generated a favorable response among stakeholders and partners, many of whom forged new ties and continued to collaborate beyond the project on issues of forest access, travel, and recreation. The project also expanded stakeholder capacity for PPGIS approaches, which were subsequently replicated throughout the region. The PPGIS-based engagement approach employed for the MBSNF has been disseminated widely and regional officials refer to it as an exemplary model for broad-based public engagement. The ability of workshop PPGIS approaches to build relationships among actors within a planning process is significant. As Lauer *et al.* (2018) note, stakeholder satisfaction is not only about opportunities for involvement, but depends on knowing that planners considered and incorporated public input. What would be even more valuable is if the empirical output of these efforts could be incorporated into plans, reports, and assessments to the same degree as ecological, economic, and administrative sources.

5.6. *Still considered a success*

Although the forest planners opted not to use the PPGIS data, there is evidence that in some respects they valued the Sustainable Roads public engagement process and some of the resulting data. The workshop data analysis is included as an appendix to the MBSNF TAR (USDA-FS 2015b) and a summary report of the workshop and online survey results is posted as a standalone document alongside the TAR (Wilderness Society 2015). Moreover, subsequent conversations with MBSNF planners indicated that they used data from the MSBNF TAR Sustainable Roads appendix and summary report to inform the development of regional sustainable tourism strategies, a monitoring strategy and stewardship plan for climbers, and a regional sustainable recreation strategy. A recreation facility planning project initiated in 2020 adopted the same public engagement model in cooperation with one of our coauthors and many Sustainable Roads Cadre partners have since initiated their own PPGIS public engagement efforts.

6. Conclusion

Our investigation of travel analysis planning reports for national forests across the Pacific Northwest region revealed inconsistent reliance on social data in the planning process. Working in one national forest addressing travel management, we developed a robust public engagement process that involved PPGIS to generate socio-spatial data about priority forest destinations and roads. We also pioneered analytical techniques that combined user density and diversity indices to distill public use of forest roads into a four-tier framework that was easy to integrate with other spatial data. Despite the extensive level of public input reflected in the data, national forest planners ultimately chose not to incorporate the data directly into their risks/benefits assessment, relying instead on data layers constructed from indirect and less comprehensive measures of road-related social values. The socio-spatial layers were used to confirm professional assessments by the ID team. Our case study suggests that more work is needed to understand the factors and conditions that result in data that are more likely to be used in the ways that had been intended.

Social scientists wrestle with how to present information to resource managers and planners in a way that is useful and that yields more informed outcomes (Charnley *et al.* 2017). The presence of quality social science data does not guarantee its ultimate use (Bennett *et al.* 2017; van Wyk *et al.* 2008). Challenges in using scientific information in planning often stem from cultural differences between the world of scientists who produce the information and managers who use the information to make or implement decisions (van Wyk *et al.* 2008). Barriers also exist in integrating new data into institutionalized planning processes (Pietilä and Fagerholm 2019) and lack of experience incorporating PPGIS data into planning (Brown, Reed, and Raymond 2020). The differences result in frustration or mutual misunderstandings, where scientists are criticized for not understanding the information needs of planners and planners are criticized for not responding to the environmental information they have been provided.

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Supplemental data

Supplemental data for this article can be accessed here.

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