Advantages and limitations of using mobile apps for protected area monitoring and management

Lorena Muñoz[1], Vera Helene Hausner[1], Christopher A Monz[2]

[1]Department of Arctic and Marine Biology, UiT The Arctic University of Norway, N-9037 Tromsø, Norway
[2]Department of Environment and Society, Utah State University, 5215 Old Main Hill, Logan, UT 84332-5215, USA

To whom correspondence should be addressed:

Lorena Muñoz, UiT-the Arctic University of Norway, Hansine Hansens veg 18, 9019 Tromsø, Norway. Ph +4777644406, e-mail: lorena.munoz@uit.no

Keywords: visitors to protected area, recreation, mobile application, geotag, value mapping, spatial, ecosystem services

Acknowledgements

The authors thank F.J. Ancin-Murguzur for constructive comments on the design of the survey and manuscript. Further, we want to thank N. Backman from Designråd for developing "Jotunheimen Tracking" mobile app. This study was funded by UiT – The Arctic University of Norway under the PhD project "Nature based tourism in protected areas: tradeoffs and synergies among cultural ecosystem services".

ABSTRACT

Digital technologies, including participatory Internet mapping, social media and smartphones, provide new avenues for research in outdoor recreation and tourism. The potential to reach a greater audience and collect visitation data on a broader scale, with less costs than traditional paper surveys, are key advantages that have increased the use of these novel technologies. Using of mobile apps for data collection is still at the experimental stage. We evaluate previous attempts to use apps for monitoring recreation and tourism in protected areas, as an alternative to other in situ or online methods. We present a pilot study implemented in Jotunheimen National Park (Norway), where we developed a mobile app for visitor monitoring and real-time mapping of values and experiences. We present the lessons learned, give suggestions on how and for what apps can be used, and discuss the advantages and limitations of using smartphones for visitor monitoring in protected areas.

1. Introduction

Protected areas (PA) are the main destination for a growing number of nature-based tourists worldwide (Balmford et al. 2009). Tourism can generate public support and provide revenues for conservation and local development, but it also requires careful planning to avoid issues of crowding and ecological impact in PAs (Manning 2011; Newsome, Moore, and Dowling 2013). Understanding the spatial and temporal distribution of visitors, their values, motivation, experience, and impacts, is therefore critical for managing PAs (Beeco et al. 2013; Hammitt, Cole, and Monz 2015; Hadwen, Hill, and Pickering 2007).

Visitors to PAs engage in a range of activities, each with associated spatial behaviors. For example, they are frequently attracted to specific locations of the park (Hallo et al. 2012), they may walk off trails (D'Antonio et al. 2010), they prefer a diverse set of activities and experiences (Ridding et al. 2018), and have different motives for selecting specific locations in the parks (Gundersen et al. 2015). With increased use and a broader range of people and associated activities in PAs, the shift in spatial distribution of use may challenge park resource management or increase the tensions with other park users.

Traditional methods for monitoring visitors such as self-report travel diaries, interviews and surveys, are time consuming for respondents. It could be difficult to recruit people *in situ* when they have just completed a recreational activity and prefer to have a rest, and the methods require a large number of field staff for recruiting participants and for managing and analyzing data after data collection (Shoval, Isaacson, and Chhetri 2014; J. Wolf 2000). The reporting of the spatial dimension of visitors' use depends on the respondents reporting their travel locations on paper maps usually upon trip completion. This increases the chance of imprecise and erroneous reporting because they are highly dependent on the respondents' memory and willingness to participate (Stopher and Greaves 2007). Moreover, paper maps would need to be digitalized, unlike other platforms which can be directly imported into spatial analysis software (Pocewicz et al. 2012).

Tracking visitors by GPS (Global Positioning System) devices, provides higher spatial quality of the data by recording the accurate time and spatial location of the visitors, departure and arrival time, attractions visited and walking speed (Grinberger, Shoval, and McKercher 2014; Orellana et al. 2012; Shoval, Isaacson, and Chhetri 2014). Visitors that enter a PA could be given a GPS device that they carry during their visit which could be followed by a survey collecting their experiences and satisfaction (Birenboim et al. 2015). Data obtained from the GPS devices are accurate and in real time, and provide data on the spatial and temporal behavior of visitors (Shoval, Isaacson, and Chhetri 2014). This method also allows identifying off-trail use and important visitation hotspots (D'Antonio et al. 2010). Although the accuracy of GPS devices has been shown to be better than other methods (Raun, Ahas, and Tiru 2016), studies carried out using GPS devices have usually been applied in confined and limited areas, as it requires specific devices to be carried by participants and returned so data can be retrieved (Shoval and Ahas 2016).

While using GPS devices for visitor tracking offers accurate and precise mapping of visitor use patterns with high-resolution, crowdsourced data could be used to assess a large number of users at a broader scale (Shoval and Ahas 2016; van Zanten et al. 2016). Crowdsourcing involves a large number of people collaborating to solve a problem (Doan, Ramakrishnan, and Halevy 2011), or contributing with ideas or content, particularly by use of internet, social media or smartphone apps (Levin, Lechner, and Brown 2017) . According to Doan, Ramakrishnan, and Halevy (2011), crowdsourced data systems can be developed by explicit or implicit participation of users. For example, crowdsourced data can provide the locations visited in PAs on online platforms (explicit participation) where visitors would manually enter their location. This is defined as Volunteer Geographic Information (VGI), which is based on volunteers registering geospatial information of a certain issue, as for example Wikimapia, which is a platform where users can geolocate places and add descriptions of the place (Goodchild 2007). Crowdsourced data can also be obtained through passive positioning of mobile phones, such as data collected from phone companies which store the location of mobile phones; i.e. (implicit participation (Birenboim and Shoval 2016; Brown and Weber 2013) . Crowdsourced data from georeferenced social media, such as Flickr, Twitter, Panoramio and Instagram, has been used to estimate the number of visitors in PAs (Wood et al. 2013) and to evaluate what attracts tourists to a site by content analysis of the pictures (Walden-Schreiner, Leung, and Tateosian 2018; Gliozzo, Pettorelli, and Haklay 2016;

Martínez-Pastur et al. 2016). In addition, passive positioning of mobile phones has been used to study the geographical distribution of international visitors (Ahas et al. 2008).

Disadvantages of using secondary crowdsourced data such as social media and call activity include the lack of other variables that are not recorded by the platform, such as demographics, satisfaction and travel motives (van Zanten et al. 2016). Moreover, manual geotagging can be imprecise (Walden-Schreiner, Leung, and Tateosian 2018) due to unfamiliarity with the area, or lack of memory due to *a posteriori* tagging. Social media and call activity could also be biased towards certain user groups of the PAs. People cannot be recruited by face-to-face contact or mail to participate, and it is therefore challenging to evaluate which of the user groups are over- or underrepresented in the resulting maps.

Public Participation Geographic Information System (PPGIS) collects primary crowdsourced data on an online participatory platform where visitors can drag and drop markers on a map. Web-PPGIS has been used to map values, management preferences, visitor experience and satisfaction, and can be combined with online surveys to collect data on demographics, travel motives, value-orientations and environmental attitudes (van Riper et al. 2012; Brown and Weber 2013). The web-PPGIS can ease the recruitment of respondents in areas with low density of visitors and increases the time people can devote to answering the survey, by participating *a posteriori* at home. An additional advantage is that the recruitment is not affected by meteorological conditions, as is the case of *in situ* questionnaires and GPS tracking. However, web-PPGIS carries some of the challenges of completing a survey after the event/activity is over, which include imprecision and memory dependency, as in the case of locating the markers on the exact location or remembering past feelings and values. Online mapping may also capture only those respondents that are drawn towards using such technologies, such as those with higher education (Pocewicz et al. 2012; Brown et al. 2015). Until recently web-PPGIS required computational skills which acted as barriers for using online mapping, but recently commercial software have eased the process of setting up such platforms (see International Society for Participatory Mapping (2018) for an overview of software and tools).

Smartphones have been proposed to overcome some of the challenges held by the methodologies listed above (Birenboim and Shoval 2016; Shoval and Ahas 2016). Modern smartphones include a set of sensors and features that allow collecting spatial data in real time, are often carried by visitors during their trips and do not depend on face-to-face recruitment. There are many mobile apps dedicated to tourism, mainly providing information for tourists, giving personalized feedback and allowing tourists to give their feedback so other tourists can receive updated information (Dickinson et al. 2014). These mobile apps are assumed to influence travel decisions (Wang, Park, and Fesenmaier 2011) and may contribute to tourism research by solving many of the shortcomings faced by other tracking methodologies (Shoval and Ahas 2016).

The use of dedicated mobile apps for tourism tracking and monitoring is an emerging field (Pickering et al. 2018), and most pioneer studies have made use of already existing platforms to collect spatial data on visitors. Norman & Pickering (2017) compared three tracking apps to collect data on visitors' spatial distribution and to assess the usefulness of such tools for three areas of varying degree of remoteness. They found these apps to be useful for visitor distribution monitoring and off-trail use, but number of visitors on formal trails was more accurately measured by automated counters. Montini, Prost, Schrammel, Rieser-Schüssler, & Axhausen (2015) developed the PEACOX journey travel mobile app as an alternative to traditional paper based travel diaries. They concluded that data collected by dedicated GPS devices have a higher accuracy and gather a greater amount of trips than smartphones, but both tools could replace traditional paper diaries in terms of mapping travel behavior. Kangas, Rasinmäki, Eyvindson, & Chambers (2015) developed a mobile app called Tienoo as a tool for participatory forest planning. The app has three functions, which are i) practical information for visitors (e.g. trails, ecology, history), ii) georeferenced opinions of visitors at any time and place, and iii) a geocaching game that directs visitors to certain locations in the forest and asks them about those particular areas. They argued that mobile apps can increase the accuracy of georeferenced feedback and provide real-time data. The main advantage of using mobile apps compared to other methods, is that a set of different data collection methods can be combined in a single interface, both spatial and non-spatial, thanks to built-in smartphone functionalities. Also, participants can be asked to consent to using their data for a research study or monitoring program unlike e.g. passive data gathering methods. There are, however, several challenges to solve before smartphone-based visitor monitoring becomes a standard method for protected area management.

The purpose of this paper is to explore the potential of using a dedicated smartphone application to combine GPS tracking (real-time data on travel routes and time spent on location in the park), participatory mapping of visitor experiences and values (real-time mapping of what visitor like and dislike, a.k.a. real-time PPGIS) and short surveys (including sociodemographic data, travel motives and satisfaction). We first present the lessons learned from our pilot study in Jotunheimen National Park and Utladalen Protected Landscape and thereafter we discuss how mobile apps can be implemented for visitor monitoring and research in PAs.

2. Jotunheimen Tracking mobile app: A pilot study

We developed a dedicated mobile app (called *Jotunheimen Tracking*) for visitor monitoring as a proof of concept to show the utility of using such a technology for visitor monitoring in protected areas and social spatial data gathering in an integrated interface. While mobile apps have been developed previously for location-specific preferences in forest management (Kangas et al. 2015), we are not aware of any mobile apps monitoring visitors to PAs using questionnaires and real-time PPGIS mapping of landscape values in a single interface. The goal of the app was to identify the spatial distribution of visitors, locate value hotspots and the type of activity conducted during the trip to a PA. In addition to questionnaires, the app included a functionality to tag places of interest *in situ* while visitors were on tour. This functionality resembles real-time PPGIS and can emulate trail use.

2.1. Study area

We tested the app in two PAs in southern Norway: Jotunheimen National Park and Utladalen Protected Landscape. They were designated in 1980 for the purpose of protecting wilderness and cultural landscapes in alpine environments. These are among the most visited PAs in Norway as Jotunheimen National Park contains the highest peaks in Scandinavia, several lakes and glaciers that attract many visitors. There is about 300 km of trails offering cabin-to-cabin hikes that run across the national park. In Scandinavia, PA management is challenging as visitors do not necessarily enter through major gateways in the parks. The Right of Open Access ("allemannsretten") allows visitors access to non-intrusive outdoor recreation, including hiking and camping almost anywhere in PAs, unless special restrictions have been set (Kaltenborn et al. 2017; Tolvanen et al. 2005). The reason behind using a mobile app instead of other methods for visitor monitoring, is the challenges of recruiting participants due to low density of visitors, dispersed hiking off trails, and undefined entrances to protected areas (Kuba et al. 2018). We reasoned that a mobile app would be appropriate for our study because it requires the least face-to-face contact, whilst actively involving visitors to provide data on spatial information on values and experiences from the locations they visited in the park.

2.2. App description

The mobile app can be downloaded at jotunheimen-tracking.no, where we also include instructions for its use. The app was designed in collaboration with users to enhange usability and clarity for the users. The interface was divided in four individual screens (screen 2,3 and 4 were developed with input from park managers and accommodation venues). First, the study aim and the instructions were presented to the participants. Informing the participant about the study is crucial for motivating visitors to participate, to provide clear instructions for how to use the app, and to inform about confidentiality, free consent and their rights to withdraw from the study. At this stage, a confidentiality consent was signed by the participant following the Norwegian Personal Data Act 2000. In the second stage participants were asked to provide demographic variables (Table 1), which were answered only once, independently of the amount of times the mobile app was used for tracking activities. Demographic variables have been shown to influence travel behavior, and they are therefore important to include in the app (Gundersen et al. 2015; Korpilo et al. 2018).

(Table 2 about here)

Third, visitors were encouraged to map their values in real-time inside the study area (also referred to as real-time PPGIS). The GPS functionality was activated by clicking on “Start” to activate the tracking. During the trip, visitors could push the buttons “I like this area” or “I dislike this area”, each of which opened a list of reasons for why they liked/disliked the area (Figure 1). The list aimed at capturing the values that people ascribe to nature and was inspired by The Common International Classification of Ecosystem Services (European Environmental Agency 2018) and studies on disservices emphasizing negative values that people may assign to nature and impacts caused by other humans (hereafter refer to as disservices) (Plieninger et al. 2013; Hammitt, Cole, and Monz 2015; Mackay and Campbell 2004). The time, day and location was recorded for these values at the moment the like/dislike button was pressed. When the activity was finalized, the visitor pushed the finish button which directed respondents to the next survey. Thus, the variables registered were: start and end locations of the trip, and the location of landscape values and disservices. We assessed the possibility of including a tracking functionality to the mobile application in order to track the route of participants, but this was eliminated to avoid battery drainage.

Figure 1. Buttons displaying reasons for liking/disliking a location (Values). The list on the left corresponds to the buttons that appear when "I like this area" is pressed. The list on the right corresponds to the buttons that appear when «I dislike this area is pressed.

(Figure 1 about here)

Fourth, once the activity was finished, the respondents were directed to a final questionnaire about the trip just tracked. Respondents could select all the activities conducted during their last trip from a list. We allowed respondents to select multiple activities since one trip in nature often combines activities (Manning 2011), such as hiking, photography and camping. In order to classify how visitors travel, we asked whether the respondents were accompanied by others during the trip, such as family, friends, partners, were participating on an organized trip, or whether the respondents were traveling alone. We asked three questions regarding the recreational experience of the trip which included values that were difficult to assign to a particular location but that could influence the experience of the trip (rated on a likert scale from 1 to 5), impacts encountered during the trip which could affect visitors' experiences, and the overall experience (Table 2). A description of the recruitment campaign and the results from our pilot study can be found in the Supplementary material.

(Table 2 about here)

3. Results

Here we summarize some of the results obtained from our pilot study (see also supplementary material). While 123 visitors completed the first survey, only 25 completed the last step. This could be due to a variety of reasons, including past visitors answering the first survey, difficulties to understand the mapping exercise, or lack of time or interest to complete all the steps. The average age of respondents was 41.7 years, the majority were males and had colleague or university education. Almost half of the participants were Norwegians, and the same proportion was first time visitors. Most frequently conducted activities were hiking and photography, most commonly together with their partners or family members. "Undisturbed nature" and "aesthetic/scenic" were the most frequently mapped values. Spending time with family and/or friends and contributing to physical and/or mental health were valued highest in the questionnaire addressing non-spatial values. The overall experiences was rated as good by the respondents.

The spatial analyses of place values demonstrated that the mapping functionality was not properly understood, nor used for long trips, as 90 % of the values were placed within 1 km from roads and the median distance between start/end locations and values was 13.8 m. Most of the participants only used less than 15 minutes for a tracked trip, which could be explained by the functionality, battery capacity or a lack of motivation for the mapping exercise. Few left their email address for further evaluation of the app, so we were not able to get feedback directly from the users.

4. Lessons learned from using mobile apps for visitor monitoring in protected areas

A primary goal of this pilot study was to understand the challenges and opportunities of using a mobile app-based approach for visitor monitoring. The principal question researchers (and practitioners) need to ask before embarking on a monitoring program using crowdsourced data is whether it is the right tool to undertake a mobile app study for visitor monitoring (Why use mobile apps for visitor monitoring?). It is also important to consider the feasibility of visitor monitoring using mobile apps by asking: what population of visitors are we targeting? How, when and where do we recruit people? What kind of data can be collected? What kind of technical support is needed? We also discuss some of the challenges of implementing the mobile app.

4.1. Why monitor visitors using mobile apps.

Most protected areas lack the spatial and temporal data of visitor use necessary for managing the increasing number and diversity of nature-based tourists (Newsome, Moore, and Dowling 2013; Hammitt, Cole, and Monz 2015; Schägner et al. 2017). Visitor monitoring is limited by the costs and logistical constraints for collecting data on the park level, and lack of data with sufficient accuracy for site-specific management within park boundaries. Previous studies have shown that crowdsourced data could provide the “volume, velocity and variety” for monitoring visitor numbers on park level (Wood et al. 2013; Levin, Lechner, and Brown 2017), and for early detection of new activities and trends in visitors' uses of the parks (Heikinheimo et al. 2017). PPGIS has the potential to account for the wider spectrum of values appreciated by visitors to PAs which can be defined by the researcher, whereas other VGI methods are limited with regard to mapping indirect-use and non-use values (Levin, Lechner, and Brown 2017). The mobile app approach could therefore be used when there is a need for site-specific information about values, preferences or experiences associated with different user groups. The "Jotunheimen tracking" app was specifically designed for capturing spatial explicit information about visitors' values and experiences in PAs for evaluating spatial behavior, crowding and ecological impact on PAs. Mobile apps are unique compared to other methods in terms of its ability to couple broad scale data on sociodemographic profiles, with the spatial and temporal pattern of visitor use to site-specific preferences, values, and experiences mapped in real-time.

4.2. Who is the mobile app targeting

Protected areas are often large with a low number of staff which makes recruitment by face-to-face contact at park gateways time consuming. In our pilot, and in many remote PAs, visitors could enter PAs from different trailheads, walk off trail and disperse over large areas, which makes indirect recruitment necessary. Traditional media (such as TV, newspapers, radio, posters), social media (blogs, webpages, Facebook, Twitter and Instagram among others), and tourism information and accommodation venues close to PAs are more appropriate means for collecting data from a large number of visitors reducing the need for field assistance during the sampling campaign. Venturelli, Kieran, and Christian (2016) found recruitment (and retention) to be among the main barriers for using apps to monitoring recreational fishing. According to them, apps need to be easy-to-use, have appealing interfaces, be fun to use, and/or provide some incentives to increase participation. Logging your trips, sharing information with other users and location specific information about destinations in the app are functionalities that can increase the use of mobile apps. Collaboration with the tourist offices, restaurants and accommodation venues surrounding the PAs tourist could provide small rewards (e.g. beverages), and the use of gaming or geocaching functions as in the Tienoo mobile app are more advanced functions which could increase the motivation to participate (Kangas et al. 2015). Finally, informing about how data will be used and reporting of end-results for those who are interested are also considered best practices in research. Brovelli et al. (2016) also concluded from three mobile app studies that the users' awareness of their contribution, the use of the data by decision makers, and monetary or non-monetary incentives are key factors for increasing response rates.

In our pilot study we used direct and indirect contact through traditional media, social media, posters and leaflets at accommodation venues and tourism offices (for details see Supplementary material). An article published in the local newspaper and direct contact through social media increased downloads of the mobile application and visits to our website. However, the lack of collaboration from the main tourist cabin network limited the spread of the application. The use of other methods than face-to-face contact require a prior-to-study campaign where social media content is created and bonds with local media and accommodation venues are established. We adopted the recommendations by Brovelli, Minghini, and Zamboni (2016) to make our mobile application code publicly available in order to ease future studies, and to conduct a short recruitment campaign focusing on groups of interest (see supplementary material for more details on the recruitment strategy), but our pilot study did not include incentives, which could potentially have increased participation.

4.3. What type of data could be collected from mobile apps

Managers often lack spatial data for effective planning of tourism in protected areas. The potential of Web-PPGIS to provide spatial explicit data on visitor values, experiences and preferences for different user groups have previously been demonstrated (Brown and Weber 2013; I. D. Wolf et al. 2015; Levin, Lechner, and Brown 2017; Muñoz et al. 2018). The "Jotunheimen tracking" app was designed to provide the same kind of data, but with higher spatial accuracy compared with *a posteriori* mapping. However, some visitors might be reluctant to use mobiles for real-time PPGIS mapping as it would impact their enjoyment of the recreation activity. Some authors have raised questions regarding the battery capacity when implementing such a mobile application (Montini et al. 2015; Shoval, Isaacson, and Chhetri 2014). For studies that only require a tracking a route, smartwatches with built-in-GPS functionality can overcome this limitation. Also, in our pilot people mapped values and experiences close to cabins and roads, which may indicate a biased mapping. Further improvements of our mobile app should include a clear instruction on how to use the app and provide participants with a summary of the maps they create to increase their motivation to participate.

An additional potential of mobile apps is to collect data on spatial behavior by use of GPS tracking such as time spent in different locations, travel speed, tracks and destination chosen, and off-trail hiking (Viswanath, Yuen, Ku, & Liu 2015), data commonly gathered in studies using dedicated GPS devices (D'Antonio et al. 2010). Several mobility studies have shown the applicability of mobile apps for transport mode and travel behavior analyses based on travel distance and speed (Jariyasunant et al. 2011; Nitsche et al. 2014). The advantage of using smartphone built-in GPS functionalities over passive positioning is that it allows continuous tracking, also in remote areas where phone coverage is poor or non-existent. Built-in GPS functionality can be combined with other smartphone features so mobile apps could be used to record unique data that could explain spatial visitor use. Thus behavioral data could be directly combined with how visitors perceive the quality of their destination (i.e. real-time mapping of values, experiences and satisfaction), and the motivation of different user groups to select the different destinations (i.e. brief survey recording motivation and sociodemographic data).

Another functionality which could be incorporated includes geotagged photos or voice recordings. These can illustrate the real-time experience the visitor have during the trip. For example, Birenboim et al. (2015) used a GPS device to track visitors in a zoo and phone messages to report real-time experiences, which could be integrated in a mobile app for visitor monitoring. Regarding the use of geotagged photos, the advantage of mobile apps over other crowdsourcing methods (such as social media) is the possibility to sign a consent for data usage and collect other data than the picture or its metadata. Also, participatory mapping could capture visitor impacts or disservices to a larger extent than geotagged photos in social media would do, as social media posts are generally more positive although negative posts show a higher impact (Stieglitz and Dang-Xuan 2013).

4.4. Challenges

There are several limitations of using mobile applications for visitor monitoring in protected areas. The use of novel technologies for participatory mapping may be limited to certain groups of respondents which are more familiar with the technologies used. Using digital technologies for collecting data on values, preferences and experiences are likely to be biased towards specific user groups. Brovelli, Minghini, & Zamboni (2016) found that the majority of the participants in a mobile app mapping studies were under 30 years old. Web-PPGIS studies with random household sampling have shown a tendency for overrepresentation mid-aged men with higher education (Brown and Kyttä 2014). Due to lack of knowledge on actual visitor statistics in our study area, we are unable to assess the representativeness of the sample. In general our pilot corresponded to previous visitor surveys showing that the majority visiting Jotunheimen are Norwegians, first time visitors, and people in their mid-ages, but there was most likely a large overrepresentation of males (2/3) and highly educated respondents (70.3%). Shoval et al. (2014) found that tourists are more willing to participate in GPS tracking than other groups, but we had no possibilities to evaluate whether international or domestic visitors were more willing to participate than others.

Unlike a GPS device, people are generally used to carrying their smartphones (Birenboim and Shoval 2016), but activating and using the mobile app during a trip is easy to forget (Montini et al. 2015). This poses a challenge in real-time PPGIS, which required active mapping during the whole trip. *A posteriori* mapping could overcome this limitation; however, the precision of mapped values would be dependent on the respondent's memory, which is the main reason to implement a real-time PPGIS rather than *a posteriori* PPGIS.

The accuracy of smartphone built-in GPS varies from device to device which can be corrected and averaged depending on the question at hand (Korpilo, Virtanen, and Lehvävirta 2017) . This can be challenging for studies that require a given accuracy of coordinates, which may favor the use of dedicated GPS devices.

Developing and implementing mobile apps for visitor monitoring carry a set of technical challenges similar to those often encountered in other mobile apps. Mobile applications designed with relevance and needs of the end user in mind, with clear and easy navigation are more successful and are able to recruit more users (Luna et al. 2018; Sturm et al. 2018). Furthermore, allowing direct feedback and making data publicly available are important principles when involving citizens in data collection (European Citizen Science Association 2015; Ahmad, Rextin, and Kulsoom 2018). Open source,code increases the usability and reuse of such a technology thereby reducing the costs of designing and developing a new app (Sturm et al. 2018; Luna et al. 2018). This allows more investment in time and resources for improving the design and functionality of the new mobile app.

5. Conclusion: advantages and limitation of using mobile apps for visitor monitoring

The advantage of using mobile apps for PA monitoring is the potential of simultaneously collecting different types of data: visitor behavior through GPS tracking, spatial information of values and experiences mapped by visitors themselves, and questionnaire responses. Similar to other crowdsourced data (VGI and PPGIS) a large number of visitors can be recruited using indirect contact methods, which increases the chance to capture those visitors that enter PAs from other entrances than major gateways. However, contrary to *a posteriori* mapping by web-PPGIS, real-time mapping of values and experiences reduces accuracy problems and dependency of memory and knowledge about the location visited. In addition, the use of smartphones with built-in GPS functionality reduces logistic challenges of delivering and collecting GPS devices in visitor tracking studies. Compared to passive positioning methods in PAs, which depend on phone coverage, GPS tracking through smartphones could also provide data on spatial behavior in remote areas (although depending on battery capacity for long-distance trips). Unlike passive positioning and social media, real-time PPGIS can better capture negative experiences. Also, the mobile app allows implementing an adaptive monitoring strategy by adapting the app to collect new information as needed in the monitoring program. This could be done by either adjusting survey questions or using other built-in functionalities.

Despite the advantages, mobile apps also carry some shortcomings. First, the use of novel technologies, such as mobile apps, can bias the data to visitors that are more accustomed to digital tools. Shoval et al. (2014) found that tourists are more willing to participate in GPS tracking studies, and mobile apps are perhaps most appropriate for monitoring the emerging trends in tourism and new user groups in the PAs. However, it is not necessarily the right tool for capturing the use of visitors living in the vicinity of the parks. Second, visitors' behavior could change when they know that they are tracked. There are no published studies that evaluate behavioral change as a result of tracking (Shoval and Ahas 2016), which is a limitation for understanding the efficiency of mobile apps for monitoring. Third, the high battery capacity needed to track an activity for several hours or days on the smartphone is a limitation for collecting visitor use patterns and time spent at different sites. It is possible to use an external power bank, or as we did, limiting the functionalities of the app by prioritizing real-time PPGIS instead of continuous GPS tracking. Finally, collecting data about users through mobile apps involves privacy concerns, albeit mobile applications allow to ask for consent to use data in research, unlike passive tracking technologies. As for all online surveys, and particularly for those including the location of individuals, tracking visitors' behavior through mobile apps carries the responsibility of a careful data treatment and a comprehensive ethical review before implementation (Fisher and Dobson 2003; Shoval and Ahas 2016),

References

Ahas, Rein, Anto Aasa, Antti Roose, Ülar Mark, and Siiri Silm. 2008. “Evaluating Passive Mobile Positioning Data for Tourism Surveys: An Estonian Case Study.” *Tourism Management* 29 (3):469–86. https://doi.org/10.1016/j.tourman.2007.05.014.

Ahmad, Naveed, Aimal Rextin, and Um E Kulsoom. 2018. “Perspectives on Usability Guidelines for Smartphone Applications: An Empirical Investigation and Systematic Literature Review.” *Information and Software Technology* 94:130–49. https://doi.org/https://doi.org/10.1016/j.infsof.2017.10.005.

Balmford, Andrew, James Beresford, Jonathan Green, Robin Naidoo, Matt Walpole, and Andrea Manica. 2009. “A Global Perspective on Trends in Nature-Based Tourism.” *PLOS Biology* 7 (6). Public Library of Science:1–6. https://doi.org/10.1371/journal.pbio.1000144.

Beeco, J. Adam, Jeffrey C Hallo, William Rockie English, and Gary W Giumetti. 2013. “The Importance of Spatial Nested Data in Understanding the Relationship between Visitor Use and Landscape Impacts.” *Applied Geography* 45. Elsevier Ltd:147–57. https://doi.org/10.1016/j.apgeog.2013.09.001.

Birenboim, Amit, Kristian Hegner Reinau, Noam Shoval, and Henrik Harder. 2015. “High-Resolution Measurement and Analysis of Visitor Experiences in Time and Space: The Case of Aalborg Zoo in Denmark.” *Professional Geographer* 67 (4):620–29. https://doi.org/10.1080/00330124.2015.1032874.

Birenboim, Amit, and Noam Shoval. 2016. “Mobility Research in the Age of the Smartphone.” *Annals of the American Association of Geographers* 106 (2):283–91. https://doi.org/10.1080/00045608.2015.1100058.

Brovelli, Maria Antonia, Marco Minghini, and Giorgio Zamboni. 2016. “Public Participation in GIS via Mobile Applications.” *ISPRS Journal of Photogrammetry and Remote Sensing* 114. International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS):306–15. https://doi.org/10.1016/j.isprsjprs.2015.04.002.

Brown, Greg, Vera Helene Hausner, Małgorzata Grodzińska-Jurczak, Agata Pietrzyk-Kaszyńska, Agnieszka Olszańska, Barbara Peek, Marcin Rechciński, and Eiliv Lægreid. 2015. “Cross-Cultural Values and Management Preferences in Protected Areas of Norway and Poland.” *Journal for Nature Conservation* 28:89–104. https://doi.org/10.1016/j.jnc.2015.09.006.

Brown, Greg, and Marketta Kyttä. 2014. “Key Issues and Research Priorities for Public Participation GIS (PPGIS): A Synthesis Based on Empirical Research.” *Applied Geography* 46. Elsevier Ltd:122–36. https://doi.org/10.1016/j.apgeog.2013.11.004.

Brown, Greg, and Delene Weber. 2013. “Using Public Participation GIS (PPGIS) on the Geoweb to Monitor Tourism Development Preferences.” *Journal of Sustainable Tourism* 21 (2):192–211. https://doi.org/10.1080/09669582.2012.693501.

D’Antonio, Ashley, Christopher A Monz, Steve Lawson, Peter Newman, Dave Pettebone, and Alyson Courtemanch. 2010. “GPS-Based Measurements of Backcountry Visitors in Parks and Protected Areas : Examples of Methods and Applications from Three ... GPS-Based Measurements of Backcountry Visitors in Parks and Protected Areas : Examples of Methods and Applications from Three.” *Journal of Park and Outdoor Recreation* 28 (November).

Dickinson, Janet E., Karen Ghali, Thomas Cherrett, Chris Speed, Nigel Davies, and Sarah Norgate. 2014. “Tourism and the Smartphone App: Capabilities, Emerging Practice and Scope in the Travel Domain.” *Current Issues in Tourism* 17 (1):84–101.

https://doi.org/10.1080/13683500.2012.718323.

Doan, Anhai, Raghu Ramakrishnan, and Alon Y. Halevy. 2011. “Crowdsourcing Systems on the World-Wide Web.” *Communications of the ACM* 54 (4):86. https://doi.org/10.1145/1924421.1924442.

European Citizen Science Association. 2015. “Ten Principles of Citizen Science.” London. https://ecsa.citizen-science.net/sites/default/files/ecsa_ten_principles_of_citizen_science.pdf.

European Environmental Agency, . 2018. “CICES Towards a Common Classification of Ecosystem Services.” 2018. https://cices.eu/.

Fisher, Peter, and Jerome Dobson. 2003. “Who Knows Where You Are, and Who Should, in the Era of Mobile Geography.” *Geography* 88 (4):331–37. https://doi.org/10.2307/40573887.

Gliozzo, G, N Pettorelli, and M Haklay. 2016. “Using Crowdsourced Imagery to Detect Cultural Ecosystem Services: A Case Study in South Wales, UK.” *Ecology and Society* 21 (3). https://doi.org/10.5751/es-08436-210306.

Goodchild, Michael. 2007. *Citizens as Sensors: The World of Volunteered Geography*. *GeoJournal*. Vol. 69. https://doi.org/10.1007/s10708-007-9111-y.

Grinberger, A. Yair, Noam Shoval, and Bob McKercher. 2014. “Typologies of Tourists’ Time-Space Consumption: A New Approach Using GPS Data and GIS Tools.” *Tourism Geographies* 16 (1). Taylor & Francis:105–23. https://doi.org/10.1080/14616688.2013.869249.

Gundersen, Vegard, Mehmet Mehmetoglu, Odd Inge Vistad, and Oddgeir Andersen. 2015. “Linking Visitor Motivation with Attitude towards Management Restrictions on Use in a National Park.” *Journal of Outdoor Recreation and Tourism* 9. Elsevier:77–86.

https://doi.org/10.1016/j.jort.2015.04.004.

Hadwen, Wade L., Wendy Hill, and Catherine Marina Pickering. 2007. “Icons under Threat: Why Monitoring Visitors and Their Ecological Impacts in Protected Areas Matters.” *Ecological Management and Restoration* 8 (3):177–81. https://doi.org/10.1111/j.1442-8903.2007.00364.x.

Hallo, Jeffrey C, J. Adam Beeco, Cari Goetcheus, John McGee, Nancy Gard McGehee, and William C Norman. 2012. “GPS as a Method for Assessing Spatial and Temporal Use Distributions of Nature-Based Tourists.” *Journal of Travel Research* 51 (5):591–606. https://doi.org/10.1177/0047287511431325.

Hammitt, William E, David N Cole, and Christopher A Monz. 2015. *Wildland Recreation: Ecology and Management*. John Wiley & Sons.

Heikinheimo, Vuokko, Enrico Di Minin, Henrikki Tenkanen, Anna Hausmann, Joel Erkkonen, and Tuuli Toivonen. 2017. “User-Generated Geographic Information for Visitor Monitoring in a National Park : A Comparison of Social Media Data and Visitor Survey.” *International Journal of Geo-Information* 6 (85). https://doi.org/10.3390/ijgi6030085.

International Society for Participatory Mapping. 2018. “International Society for Participatory Mapping (ISPM).” 2018. http://landscapevalues.org/ispm/software-tools/.

Jariyasunant, Jerald, Andre Carrel, Venkatesan Ekambaram, DJ Gaker, Thejovardhana Kote, Raja Sengupta, and Joan L. Walker. 2011. “The Quantified Traveler: Using Personal Travel Data to Promote Sustainable Transport Behavior.” *UC Berkeley: University of California Transportation Center*. https://escholarship.org/uc/item/678537sx.

Kaltenborn, Bjørn P, Hanne Haaland, Klas Sandell, Bjørn P Kaltenborn, and Hanne Haaland. 2017. “The Public Right of Access – Some Challenges to Sustainable Tourism Development in Scandinavia The Public Right of Access – Some Challenges to Sustainable

Tourism” 9582 (November). https://doi.org/10.1080/09669580108667412.

Kangas, Annika, Jussi Rasinmäki, Kyle Eyvindson, and Philip Chambers. 2015. “A Mobile Phone Application for the Collection of Opinion Data for Forest Planning Purposes.” *Environmental Management* 55 (4):961–71. https://doi.org/10.1007/s00267-014-0438-0.

Korpilo, Silviya, Tarmo Virtanen, and Susanna Lehvävirta. 2017. “Smartphone GPS Tracking—Inexpensive and Efficient Data Collection on Recreational Movement.” *Landscape and Urban Planning* 157. Elsevier B.V.:608–17. https://doi.org/10.1016/j.landurbplan.2016.08.005.

Korpilo, Silviya, Tarmo Virtanen, Tiina Saukkonen, and Susanna Lehvävirta. 2018. “More than A to B: Understanding and Managing Visitor Spatial Behaviour in Urban Forests Using Public Participation GIS.” *Journal of Environmental Management* 207:124–33. https://doi.org/10.1016/j.jenvman.2017.11.020.

Kuba, Kazuhisa, Christopher A Monz, Bård-Jørgen Bårdsen, and Vera Helene Hausner. 2018. “Role of Site Management in Influencing Visitor Use along Trails in Multiple Alpine Protected Areas in Norway.” *Journal of Outdoor Recreation and Tourism* 22:1–8. https://doi.org/https://doi.org/10.1016/j.jort.2018.02.002.

Levin, Noam, Alex Mark Lechner, and Greg Brown. 2017. “An Evaluation of Crowdsourced Information for Assessing the Visitation and Perceived Importance of Protected Areas.” *Applied Geography* 79. Elsevier Ltd:115–26. https://doi.org/10.1016/j.apgeog.2016.12.009.

Luna, Soledad, Margaret Gold, Alexandra Albert, Luigi Ceccaroni, Bernat Claramunt, Olha Danylo, Muki Haklay, et al. 2018. “Developing Mobile Applications for Environmental and Biodiversity Citizen Science: Considerations and Recommendations.” In *Multimedia Tools* *and Applications for Environmental & Biodiversity Informatics*, edited by Alexis Joly, Stefanos Vrochidis, Kostas Karatzas, Ari Karppinen, and Pierre Bonnet, 9–30. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-76445-0_2.

Mackay, Kelly J, and J Michael Campbell. 2004. “A Mixed Method Approach for Measuring Environmental Impacts in Nature-Based Tourism and Outdoor Recreation Settings.” *Tourism Analysis*. https://www.ingentaconnect.com/content/cog/ta/2004/00000009/00000003/art00001.

Manning, R E. 2011. *Studies in Outdoor Recreation: Search and Research for Satisfaction*. 3rd ed. Corvallis, Oregon.

Martínez-Pastur, Guillermo, Pablo L Peri, María V Lencinas, Marina García-Llorente, and Berta Martín-López. 2016. “Spatial Patterns of Cultural Ecosystem Services Provision in Southern Patagonia.” *Landscape Ecol* 31 (383). https://doi.org/https://doi.org/10.1007/s10980-015-0254-9.

Montini, Lara, Sebastian Prost, Johann Schrammel, Nadine Rieser-Schüssler, and Kay W. Axhausen. 2015. “Comparison of Travel Diaries Generated from Smartphone Data and Dedicated GPS Devices.” *Transportation Research Procedia* 11. Elsevier B.V.:227–41. https://doi.org/10.1016/j.trpro.2015.12.020.

Muñoz, Lorena, Vera Hausner, Greg Brown, Claire Runge, and Per Fauchald. 2018. “Identifying the Spatial Overlap in the Values of Locals, Domestic- and International Tourists in Protected Areas.”

Newsome, D, S A Moore, and R K Dowling. 2013. “Natural Area Tourism: Ecology, Impacts and Management., 2nd Edn.(Channel View Publications: Bristol, UK).”

Nitsche, Philippe, Peter Widhalm, Simon Breuss, Norbert Brändle, and Peter Maurer. 2014. “Supporting Large-Scale Travel Surveys with Smartphones – A Practical Approach.”

Transportation Research Part C: Emerging Technologies 43:212–21. https://doi.org/https://doi.org/10.1016/j.trc.2013.11.005.

Norman, Patrick, and Catherine Marina Pickering. 2017. “Using Volunteered Geographic Information to Assess Park Visitation: Comparing Three on-Line Platforms.” *Applied Geography* 89 (November). Elsevier Ltd:163–72. https://doi.org/10.1016/j.apgeog.2017.11.001.

Orellana, Daniel, Arnold K. Bregt, Arend Ligtenberg, and Monica Wachowicz. 2012. “Exploring Visitor Movement Patterns in Natural Recreational Areas.” *Tourism Management* 33 (3). Elsevier Ltd:672–82. https://doi.org/10.1016/j.tourman.2011.07.010.

Pickering, Catherine Marina, Sebastian Dario Rossi, Ana Hernando, and Agustina Barros. 2018. “Current Knowledge and Future Research Directions for the Monitoring and Management of Visitors in Recreational and Protected Areas.” *Journal of Outdoor Recreation and Tourism* 21 (June 2017). Elsevier Ltd:10–18. https://doi.org/10.1016/j.jort.2017.11.002.

Plieninger, Tobias, Sebastian Dijks, Elisa Oteros-rozas, and Claudia Bieling. 2013. “Assessing , Mapping , and Quantifying Cultural Ecosystem Services at Community Level.” *Land Use Policy* 33. Elsevier Ltd:118–29. https://doi.org/10.1016/j.landusepol.2012.12.013.

Pocewicz, Amy, Max Nielsen-Pincus, Greg Brown, and Russ Schnitzer. 2012. “An Evaluation of Internet Versus Paper-Based Methods for Public Participation Geographic Information Systems (PPGIS).” *Transactions in GIS* 16 (1):39–53. https://doi.org/10.1111/j.1467-9671.2011.01287.x.

Raun, Janika, Rein Ahas, and Margus Tiru. 2016. “Measuring Tourism Destinations Using Mobile Tracking Data.” *Tourism Management* 57. Elsevier Ltd:202–12. https://doi.org/10.1016/j.tourman.2016.06.006.

Ridding, Lucy E, John W Redhead, Tom H Oliver, Reto Schmucki, James McGinlay, Anil R Graves, Joe Morris, Richard B Bradbury, Helen King, and James M Bullock. 2018. "The Importance of Landscape Characteristics for the Delivery of Cultural Ecosystem Services." *Journal of Environmental Management* 206. Elsevier Ltd:1145–54. https://doi.org/10.1016/j.jenvman.2017.11.066.

Riper, Carena J van, Gerard T Kyle, Stephen G Sutton, Melinda Barnes, and Benson C Sherrouse. 2012. "Mapping Outdoor Recreationists' Perceived Social Values for Ecosystem Services at Hinchinbrook Island National Park, Australia." *Applied Geography* 35 (1–2). Elsevier Ltd:164–73. https://doi.org/10.1016/j.apgeog.2012.06.008.

Schägner, Jan Philipp, Joachim Maes, Luke Brander, Maria Luisa Paracchini, Volkmar Hartje, and Gregoire Dubois. 2017. "Monitoring Recreation across European Nature Areas: A Geo-Database of Visitor Counts, a Review of Literature and a Call for a Visitor Counting Reporting Standard." *Journal of Outdoor Recreation and Tourism* 18 (January 2016). Elsevier Ltd:44–55. https://doi.org/10.1016/j.jort.2017.02.004.

Shoval, Noam, and Rein Ahas. 2016. "The Use of Tracking Technologies in Tourism Research: The First Decade." *Tourism Geographies* 18 (5). Taylor & Francis:587–606. https://doi.org/10.1080/14616688.2016.1214977.

Shoval, Noam, M Isaacson, and P Chhetri. 2014. "GPS, Smartphones, and the Future of Tourism Research." In *The Wiley Blackwell Companion to Tourism*, edited by Alan A. Lew, C. Michael Hall, and Allan M. Williams, 251–61. John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118474648.ch20.

Stieglitz, Stefan, and Linh Dang-Xuan. 2013. "Emotions and Information Diffusion in Social Media—Sentiment of Microblogs and Sharing Behavior." *Journal of Management Information Systems* 29 (4). Routledge:217–48. https://doi.org/10.2753/MIS0742-

1222290408.

Stopher, Peter R., and Stephen P. Greaves. 2007. “Household Travel Surveys: Where Are We Going?” *Transportation Research Part A: Policy and Practice* 41 (5):367–81. https://doi.org/10.1016/j.tra.2006.09.005.

Sturm, U, M Gold, S Luna, S Schade, L Ceccaroni, C C M Kyba, B Claramunt, et al. 2018. “Defining Principles for Mobile Apps and Platforms Development in Citizen Science.” *Research Ideas and Outcomes* 4 (e23394). https://doi.org/https://doi.org/10.3897/rio.4.e23394.

Tolvanen, A, B Forbes, S Wall, and Y Norokorpi. 2005. “Recreation at Tree Line and Interactions with Other Land-Use Activities.” In *Plant Ecology, Herbivory, and Human Impact in Nordic Mountain Birch Forests*, edited by Frans E. Wielgolaski, 180:203–17. Berlin, Heidelberg: Springer.

Venturelli, Paul A, Hyder Kieran, and Skov Christian. 2016. “Angler Apps as a Source of Recreational Fisheries Data: Opportunities, Challenges and Proposed Standards.” *Fish and Fisheries* 18 (3). Wiley/Blackwell (10.1111):578–95. https://doi.org/10.1111/faf.12189.

Viswanath, Sanjana Kadaba, Chau Yuen, Xuefang Ku, and Xiang Liu. 2015. “Smart Tourist - Passive Mobility Tracking Through Mobile Application.” In *Internet of Things. IoT Infrastructures. IoT360 2014. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, edited by Voisard A. Giaffreda R., Cagáňová D., Li Y., Riggio R., 151:183–91. Springer, Cham. https://doi.org/10.1007/978-3-319-19743-2.

Walden-Schreiner, Chelsey, Yu-Fai Leung, and Laura Tateosian. 2018. “Digital Footprints: Incorporating Crowdsourced Geographic Information for Protected Area Management.”

Applied Geography 90 (December 2017). Elsevier Ltd:44–54. https://doi.org/10.1016/j.apgeog.2017.11.004.

Wang, Dan, Sangwon Park, and Daniel R Fesenmaier. 2011. “An Examination of Information Services and Smartphone Applications.” In *In 16th Graduate Students Research Conference*.

Wolf, Isabelle D., Teresa Wohlfart, Greg Brown, and Abraham Bartolomé Lasa. 2015. “The Use of Public Participation GIS (PPGIS) for Park Visitor Management: A Case Study of Mountain Biking.” *Tourism Management* 51:112–30. https://doi.org/10.1016/j.tourman.2015.05.003.

Wolf, Jean. 2000. “Using GPS Data Loggers To Replace Travel Diaries In the Collection of Travel Data By.” Georgia Institute of Technology.

Wood, Spencer A., Anne D. Guerry, Jessica M. Silver, and Martin Lacayo. 2013. “Using Social Media to Quantify Nature-Based Tourism and Recreation.” *Scientific Reports* 3. https://doi.org/10.1038/srep02976.

Zanten, Boris T van, Derek B Van Berkel, Ross K Meentemeyer, Jordan W Smith, Koen F Tieskens, and Peter H Verburg. 2016. “Continental-Scale Quantification of Landscape Values Using Social Media Data.” *Proceedings of the National Academy of Sciences* 113 (46):12974–79. https://doi.org/10.1073/pnas.1614158113.

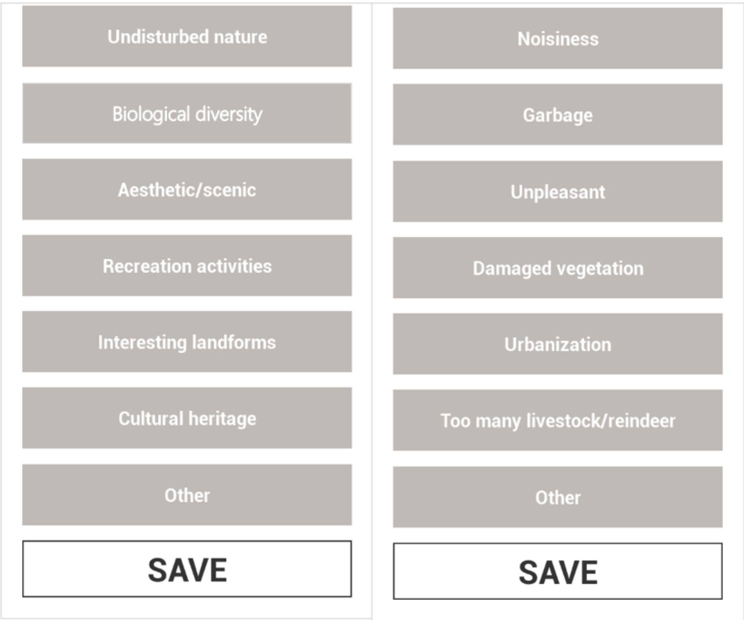
Table 1. Demographic variables included in the first questionnaire of the mobile app Jotunheimen Tracking.

Q1. What is your country of residence?	Norway (postal code)	Other (country)
Q2. What is your gender?	Male	Female
Q3. What is your age?		
Q4. What it the highest education level you have completed?		
Primary school	Secondary school	High education
Q5. What was the approximate total after-tax income of your household for year 2016? (optional question)		
Q6. How many times in the past have you visited this areas?		

Table 2. Final questions relating to the recreational experience for the whole trip inside the protected area.

Q9. The visit today has been important for… (from 1 strongly disagree to 5 strongly agree)
1. learning about the nature
2. being together with my family/friends
3. my physical/mental health
4. inspiring me to create crafts, stories or other artistic work
5. nurturing a deeper meaning of nature; emotionally or spiritually
Q10. My experience today was negatively impacted by… (choose)
1. crowdedness
2. lack of facilities
3. motorized vehicles
4. vehicle roads/tracks
5. trail condition
6. other:
Q11. How would you rate your overall experience today? (from 1 disappointing to 5 very good)

Figure 2. Buttons displaying reasons for liking/disliking a location (Values). The list on the left corresponds to the buttons that appear when "I like this area" is pressed. The list on the right corresponds to the buttons that appear when «I dislike this area is pressed.



Supplementary material (Data collection and results)

Through "Jotunheimen tracking" app we gathered data on demographic variables, real-time PPGIS on landscape values and disservices (i.e. tagging liked or dislike places *in situ* during a trip), trip information, non-spatial landscape values, impacts and overall satisfaction.

Our recruitment strategy was mainly targeting social media, newspapers, and leaflets and posters at accommodation venues and tourism offices. Every day from mid-July to mid-August we searched on Instagram photos geotagged inside the study area in the Instagram platform and we sent a message to inform about the study. We also distributed leaflets and posters in accommodation venues and tourism offices. The major tourist cabin network (The Norwegian Trekking Association) and hotels nearby were contacted in order to establish a collaboration to advertise the mobile app on their social media sites, but this strategy was less successful. We also published information in the local newspaper during the study period.

In our pilot study, the average age of respondents was 41.7 years, predominantly males with a ratio of 1:3, and 70.3 % had colleague or university education. Norwegians accounted for 42.3 % of all respondents, followed by Germans and Dutch (12.2 % each). The majority of the respondents (46.3 %) were first time visitors.

The initial survey was answered by 123 visitors to the study area. Only 25 respondents answered the last survey after completing the activity, which may indicate difficulties in understanding the functioning of the mapping survey, lack of time or interest to track an activity or past visitors completing the initial survey. The mapping phase of the app collected limited data due to few mapped values, lower number of responses than initial survey participants, and most of tracked trips being of less than 15 minutes duration, indicating a low understanding of the mapping survey. 311 landscape values and 8 disservices were mapped inside and around the study area, and 40 additional landscape values and 4 disservices were mapped outside. As in many PPGIS studies, the most frequently mapped values were "undisturbed nature" (62) and "aesthetic/scenic" (52) (van Riper et al. 2012; Brown, Montag, and Lyon 2012), but also "interesting landforms" with 51 markers. In the 36 trips recorded in the final survey, respondents reported 64 activities, as each trip could include more than one activity. The most frequently recorded activities were hiking and photography (24 and 10 respectively). The majority of the respondents completed their trip either with their partner (42.9 %) or with their family (39.3 %). Spending time with family and/or friends and contributing to physical and/or mental health were reported as the most important non-spatial values with mean values of 4.5 and 4.3 respectively, followed by nurturing a deeper meaning of nature (4), learning about nature (3.6) and inspiration (3). The overall experience of respondents were good (4.3), but 25% reported negative experiences.

We analyzed the mapping behavior of participants by calculating the distance between markers and between these and major roads. The median distance between the nearest neighbor points of start and end locations, and mapped values was 13.8 m, which indicates that respondents did not use the mobile app on long trips. We created a raster grid measuring the distance from roads to each of the quadrant on the study area, from which we extracted distance values for each marker. 90 % of all markers in the study area were located at a maximum distance of 1 km from roads.

We created a kernel density plot in order to identify areas with high density of markers indicating hotspots, areas highly valued by visitors, or mapping biases. The kernel density plot showed a high density of markers in three areas which correspond to accommodation venues located in Beitøstolen, cabins from the Norwegian Trekking Association in the western part of the study area, and a popular camping situated on the eastern side of the study area (*Figure 3*). These simple spatial statistics indicate that people map close to roads and accommodation and that our mobile app did not seem to work as intended, probably due to lack of understanding on the functioning of the app.

Figure 3. Kernel density map of landscape values. Dark areas show a lower density of markers than brighter areas.